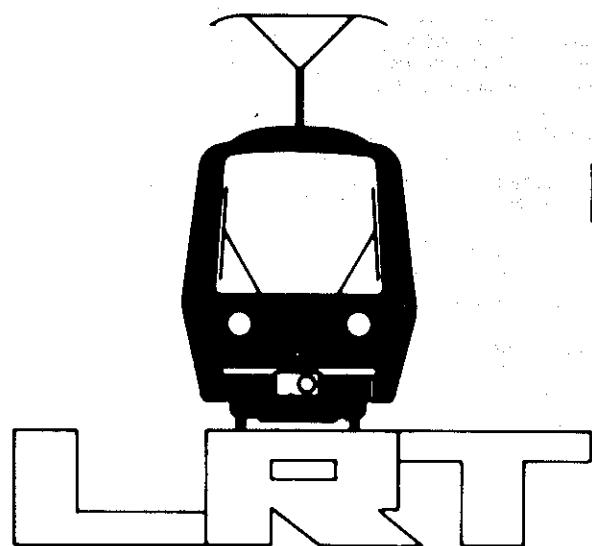


Special Report 195

Light Rail Transit:



Planning, Design, and Implementation

Papers Presented at the Conference on Light Rail Transit,
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Foreword

Light rail transit (LRT) was reintroduced to the U.S. transportation community at the First National Conference on Light Rail Transit, held in Philadelphia in July 1975. In the 7 years since, three U.S. cities have undertaken major programs to improve their systems, one new system was placed in service, another is under construction, and about a dozen large cities are seriously considering LRT. Across the border, two Canadian cities completed new LRT systems and other cities are adding to their existing network or planning new service.

To further the understanding of LRT, a second conference was held in August 1977 in Boston. By then the mode no longer needed introduction; instead, the focus was on planning and technology-specific aspects recognized as critical in the successful implementation of LRT.

The host city for the Third National Conference on Light Rail Transit, held in March 1982, was the home of the San Diego Trolley, the LRT system that has gained the most admiration of the transportation community and the attention of the general public. The conference was sponsored by the Urban Mass Transportation Administration (UMTA) and conducted by the Transportation Research Board (TRB). This Special Report contains the papers prepared for and delivered at the conference. The TRB Steering Committee for the Third National Con-

ference on Light Rail Transit served as the technical review body of these papers.

The papers focus on key technical and institutional issues that are unique to implementation of the LRT mode. They should help technical and policy professionals become better acquainted with the wide range of capabilities associated with the mode and its lower cost potential. Although LRT can be viewed as relatively simple in concept, experience shows that installation presents an intricate web of interrelated decisions requiring trade-offs and flexibility in design.

The papers fall into four groups. Those in Parts 1 and 2 of this document provide an overview of light rail transit and policy and planning considerations. These papers treat issues such as institutional arrangements, community and citizen participation, feasibility factors, development constraints, and energy considerations. The papers in Part 3 cover engineering design of LRT fixed facilities and railcar technology. Part 4 contains papers on operating issues, including such matters as surface operations, self-service fares, the interface with bus transportation, and general traffic considerations. This Special Report is an up-to-date review of LRT planning, design, and implementation and demonstrates the progress made since Philadelphia in 1975.

Part 1

Overview of Light Rail Transit

Overview of Recent Light Rail Transit Activity

C. KENNETH ORSKI, Corporation for Urban Mobility

It is indeed a pleasure for me to speak on behalf of the Transportation Research Board, for TRB has been intimately linked with the efforts to reawaken interest in light rail transit in postwar America. It was to TRB that UMTA turned, back in early 1975, with its request to organize a "consciousness-raising" national conference on light rail transit. The Philadelphia meeting, held in June 1975, attracted nearly 700 people and generated a level of interest that exceeded all expectations. The New York Times headlined the story, Trolley Staging a Comeback Over the Nation. Time Magazine, Newsweek, The Wall Street Journal, and a host of other news media treated the conference as a major news event. It has been almost 7 years since that landmark conference, but many of the participants at that meeting are still active in light rail transit and are with us today.

At the Philadelphia conference the keynote speaker was the UMTA Administrator and he expressed the federal government's position regarding light rail transit:

We feel that light rail transit is a viable alternative to other modes of transportation. . . . We do not favor light rail over other modes. We are merely saying that it should be considered as an alternative when a city is making the choice as to what kind of a transit system it should have.

This position was meant to signal to local governments and the planning profession that light rail transit was no longer to be treated as "the forgotten mode," and that UMTA, while remaining "modally neutral," intended to restore light rail technology to the position of legitimacy it once held in this country. We were happy to hear last night that this is still UMTA's position.

TRB's involvement with light rail transit did not end with the Philadelphia conference. Following that meeting, the Board created a full-fledged committee on light rail transit. That committee sparked a number of efforts to increase awareness and foster research about light rail transit. These efforts have included a special seminar, several LRT sessions at the annual meetings, and the publication of LRT News, the first issue of which appeared in October 1978 and which has been appearing occasionally ever since.

In the meantime, the federal government continued its active support of light rail transit. In December 1975, UMTA issued a formal policy statement in which it reaffirmed its belief in LRT as a "potentially attractive transit concept" and announced intention to "assist in the deployment of modern light rail transit in a city or cities where proper conditions for this type of service are found to exist." Eight months later, in August 1976, UMTA released a state-of-the-art report on light rail transit. This report quickly became the standard reference on light rail technology and has been something of a bestseller as government publications go.

By the end of 1977, it was becoming clear that the message was sinking in. Several cities with existing streetcar networks—Boston, San Francisco, Philadelphia, Cleveland, Pittsburgh, and Newark—were announcing plans for major system upgradings. Buffalo became the first beneficiary of a federal grant for a light rail line; Portland, Oregon, was the second. In the meantime, Edmonton was well on its way toward completing the first entirely new postwar light rail system in North America, and Calgary was announcing plans to follow in Edmonton's footsteps. By the time of the Second National Conference on Light Rail Transit, held in Boston in August 1977, TRB was able to report that no less than 29 cities in North America were contemplating light rail transit.

The trend toward LRT was being reinforced by esca-

lating costs of conventional rapid transit. In March 1978, the Department of Transportation was moved to take official notice of this fact in its Statement of Policy on Rail Transit. Said the Department:

Urban areas will have to demonstrate a compelling need for high-capacity, high-performance transit in order to obtain Federal assistance for rail transit. Light rail transit, operating partially or fully on surface rights-of-way, may offer a substantially less costly, less disruptive and more flexible option, and should be seriously considered by localities bent on improving their transit systems. (Federal Register, March 7, 1978)

The momentum of the late 1970s continued into the 1980s. Today, more than ever, light rail transit appears on local rail planning agendas. Virtually all North American cities contemplating rail transit today are thinking in terms of light rail technology. These cities include Los Angeles/Long Beach, Denver, Detroit, Portland, Sacramento, Santa Clara County, and Vancouver. Urban Rail in America, a recent study by the Regional Plan Association, estimates that, based on potential travel volumes, 10 other U.S. cities are candidates for light rail lines: Seattle, Honolulu, Houston, Dallas, St. Louis, Milwaukee, Minneapolis, Indianapolis, Louisville, and Cincinnati. Light rail also seems to dominate the thinking of vehicle suppliers. No fewer than eight manufacturers are competing for what promises to be a sizable market for new light rail cars over the next decade. According to Railway Age, a replacement market for more than 600 vehicles, together with the equipment needs for more than half a dozen new or expanded systems, could generate orders for more than a thousand new cars by the end of the decade.

Thus, this Third Light Rail Conference opens on a different note than the first two. In Philadelphia and Boston, we were still trying to determine what role, if any, LRT could play in the transportation future of American cities. We were still at the stage of finding out whether LRT made sense. Today, thanks to San Diego and our Canadian friends, we no longer have these doubts. We have proof that light rail transit works—indeed, that it not only makes eminent sense, but that, given current fiscal constraints, it may realistically be the only rail option available to our cities.

So the focus of this conference shifts from existential concerns to concrete issues of implementation. While there is always room to debate feasibility criteria and to discuss "when and where LRT works best," our emphasis in this conference will be on the pragmatic questions: how to design, build, and operate LRT systems most economically, and how to finance them in today's environment of limited federal assistance and tight state and local budgets. The last question is especially important, for the best conceived plans and designs will be of little use if adequate funds are not found.

It might be instructive to look at foreign experience. In Japan, private land development companies build rail links to connect new suburban developments with metropolitan transit systems, and they do so without government assistance. In other parts of the world, private companies operate profitable rail transit services in publicly built and owned facilities, under turn-key franchise agreements with municipalities. These examples show that we may have applied much less imagination and creativity to issues of financing and operation than we have to the planning and design of light rail systems. Innovative public and private partnership approaches may not be the best way to get rail systems built in the future—they may be the only way.

Potential for Light Rail Transit: Federal Perspective

CHARLES A. GARGANO, Urban Mass Transportation Administration

The fact that UMTA is sponsoring a conference on light rail transit in this new era of federal domestic budgetary restraint is indicative of our interest in and support for the light rail alternative. We believe now, just as we did in 1975 when we sponsored the first of these conferences, that a special effort is warranted and necessary to present the light rail transit option to government officials, planners, engineers, architects, private sector developers, the academic community, and transit operators.

At the same time, however, we must be realistic. Light rail transit is not a panacea, nor is it the ideal solution for meeting all of our urban mobility needs. There is no unimodal approach; no single transit system of any technology can effectively serve the broad range of travel patterns and service requirements in our nation's cities. But light rail transit is an increasingly attractive alternative, an alternative that will figure even more prominently in future consideration of the various transit options available to local communities.

We have enlisted the federal government's mass transportation assistance program in this administration's fight against inflation. Consistent with our electoral mandate and our determination to hold down federal spending, UMTA will not be funding new transit starts until the nation's economy improves. This decision to postpone new starts is in no way a judgment of the obvious merits of various projects now on the drawing boards. Rather, it is a pragmatic expression of a realistic attitude about what the federal government can and cannot afford. Those who argue to the contrary are deceiving themselves and perpetrating a cruel hoax by raising unwarranted expectations about the outlook for the future.

The domestic budgetary restraint that has thus far characterized the Reagan administration's approach to federal spending will transcend this administration. Clearly, there is transregional, bipartisan support for balanced federal budgets—not just in the Congress, but among the voters as well. This new political and economic fact of life will result in even greater demand for cost-effective, flexible approaches to meeting local transit needs; Uncle Sam simply will not be able to assume the enormous financial burdens inherent to the development of new multi-billion-dollar, state-of-the-art rapid rail transit systems.

That is why the light rail transit alternative is so important. It is a transit option that we believe local communities can pursue without a massive commitment of federal dollars. And it is a transit alternative that local communities must carefully consider as they review the approaches available to meet unique local transit needs.

Unfortunately, consideration and application of light rail transit has been limited by the unfounded perception that urban transit options are limited to bus or heavy rail. A concerted effort to educate policymakers and the public is therefore essential to the further development and deployment of this transit option. We need look no further than San Diego for a testament to what can be accomplished when imaginative leadership and community resources are applied to meet local transit needs.

The San Diego Trolley was built with virtually no

federal funds. It has no massive, marble monument to transit stations, no over-engineered, technologically mind-boggling designs, no astronomical cost overruns. Instead, it is an effective, no-frills approach to this area's unique transportation needs.

Obviously, what worked for San Diego may not necessarily be appropriate for other cities. However, the San Diego experience has demonstrated how attractive the light rail transit alternative can be, especially in light of the new federal domestic spending environment.

In those areas where public transportation needs are urgent, light rail transit is a good candidate for early development. The basic technology for light rail transit is in place—it has been in use for years. In fact, worldwide light rail transit is the most extensively used fixed guideway transit mode. As a result, the extensive, expensive, and time-consuming research, development, and demonstration process necessary for the introduction of new transit modes or technology is simply not needed for the practical application of light rail transit.

But this is only one of the features that makes this transit mode so attractive. Light rail transit also has incomparable flexibility. It can be adapted to a wide variety of geographic and topographic conditions, financial capabilities, rights-of-way, and existing transit infrastructures. Moreover, light rail transit can be developed incrementally; it can be expanded as demand and the ability to pay for it are increased. This incremental feature of light rail transit is especially important in view of the new public sector financial realities. Finally, light rail transit is simply much less costly than conventional rail transit. It does not have the overall high performance and capacity requirements of conventional rapid transit; consequently, construction and operating costs are lower. This lower cost makes light rail transit economically justifiable in urban areas where conventional rapid transit is not feasible because of cost or demand factors.

Light rail transit is the transit option of the future. The technology is in place, it is flexible, it can be developed incrementally, and it is less expensive than conventional rapid transit. The key to more extensive deployment is our willingness and ability to spread the message of its virtues.

In an address to the first light rail transit conference, UMTA's view of the light rail transit alternative was presented:

It is UMTA's policy to leave to local communities the widest possible discretion in deciding how they should meet their transportation needs and what should be the nature and mix of their transportation services. Thus, in the final analysis, the planners, engineers, transit operators, local elected officials, public interest groups, the press, and concerned citizens ultimately will decide whether LRT should become a major force in the transportation systems of American cities.

This is as relevant today as it was in 1975.

State and Local Roles in California's Light Rail Transit Program

ADRIANA GIANTURCO, California Department of Transportation

In California, as in most other states, we have a tradition of local ownership and operation of transit systems. However, in spite of this, it is fair to say that the major thrust and incentive for the construction of new rail transit systems in California has come from the state level and has used state law as its vehicle.

In the past decade, a number of statutes have been enacted that set in place various processes and mechanisms for work in the rail transit area, including a law that created San Diego's Metropolitan Transit Development Board (MTDB). In addition, a more basic law has been passed that provided a substantial state funding pool for rail transit. In 1972, by a vote of the people, the state constitution was amended to allow state gas tax revenues—which originally could be used only for highway purposes—to be used to fund fixed guideway construction. While the guideway amendment, known as Proposition 5, did not open our highway fund to guideway uses completely, it did make it legally possible for rail projects to start tapping into the approximately \$1.5 billion in annual state gas taxes, which otherwise would be restricted entirely to state highways and local streets and roads. Since Proposition 5 was enacted, we have allocated \$142 million of these state funds to the planning, design, and construction of various guideway systems in California—most to the San Diego Trolley. We are proposing that some \$439 million in Proposition 5 funds go to selected guideway projects over the next 5 years.

A second state law—SB 620, enacted in 1979—provided another major source of funding for guideway projects and other transit purposes, including local assistance. Under SB 620, specific appropriations of sales tax funds were made to various categories of transit uses, and urban guideways became eligible for a 3-year funding pool amounting to \$90 million. To date, \$80 million of SB 620 funds have been allocated, and we are proposing that an additional \$118 million from the sales tax be set aside for guideways in the next 5 years.

But projects do not get built just by having funds available, and we at Caltrans have been willing and eager to participate in the various stages of project development—initial planning, design, and construction—that lead to a service actually being operated. There are some very practical reasons why we have been interested in being more than just a funding agent for guideway projects. First of all, since we are generally talking about any given project representing a substantial financing investment on our part, we are very interested in the quality of the project, and being involved in its actual development is our best assurance that the project will be properly planned and designed. Second, since there are a number of rail projects in California, we think it is advantageous to have an accumulation and sharing of technical expertise; this is accomplished by having a single organization (Caltrans) involved in the different projects. Third, as a very down-to-earth matter, we think that the best way to assure a continued state interest in and backing for rail transit is to institutionalize it, giving the state a role and a stake in transit work.

Caltrans is currently working or has been working with local government on three light rail transit projects—the San Diego Trolley, the Sacramento light rail project, and the Guadalupe Corridor project in San Jose. Our involvement is somewhat different in each, which illustrates the fact that there are a number of different ways in which a state-local partnership can operate. To illustrate this, I

will describe the funding picture, as well as the policy-making and technical structure, of each.

The fact that the San Diego Trolley used no federal funds has been widely publicized. What has not been widely publicized is that most of the funds were state funds, the majority from Proposition 5 and some from SB 620. The project has a specific basis in state law, since it was a state law that created MTDB and gave it the responsibility for developing and operating a guideway project in the San Diego area. State representation on MTDB is not organizational but takes place by means of one appointment made by the Governor; Caltrans does not have a seat.

In San Diego, technical involvement by the state occurred in a rather indirect and piecemeal fashion. After the specific project was selected using the Arizona and Eastern Railroad for the basic system, MTDB asked for assistance, and we agreed to provide one of our employees to manage and supervise the overall engineering of the project. At MTDB's request, we also assigned other employees to perform other tasks during the project: right-of-way engineering and acquisition, geotechnical work, bridge design, and, finally, engineering inspection of construction.

As an organization, we learned two things from our technical participation during the initial leg of the San Diego project. First, we learned that our extensive skills in various phases of project development are fully transferable to the transit area and that our civil engineers, who in the past worked mainly on highways, are equally capable of working on rail. Second, we decided that the manner in which we had been involved in the project was not the way we wanted to proceed in the future. Because of the indirect and step-by-step fashion in which we got into various aspects of the project's development, our participation was not well known. Consequently, it did very little, if anything, to build up our legitimacy and credibility in the transit arena. Also, because of the unstructured and localized way in which we made our resources available to the project, our participation did little to help us build procedures and processes for application to other projects. While our relationship with MTDB has been an extremely positive one and we have been most impressed with the caliber of MTDB, I think we, as an organization, could have gained more technically from the experience than we did. With the light rail project in Sacramento, we are putting to use the lessons we learned in San Diego.

Although as in San Diego, there is very little local funding in the Sacramento project, both federal and state funds are going to be used. The federal funds are Interstate transfer monies. The rail project was developed as the final outcome of a cooperative state-local process to drop the Interstate highway project in question and to find an appropriate substitute. Caltrans took the lead in initiating the process.

Since the Sacramento project is not set forth in law, there is no formal organizational structure for its development and operation. The project is being developed by an agency brought into existence by means of a joint powers agreement between Caltrans, the City of Sacramento, the County of Sacramento, and the Sacramento Regional Transit District. All of these entities are members of the agency's board, which gives guidance to the agency's executive director.

Under the joint powers agreement, the design and construction is being carried out by Caltrans, the design-

nated project manager. It is intended that the facility be operated by RTD, an existing transit operator.

This arrangement appears to be working well. There has been little or no friction between the members of the board, an absolute minimum of red tape and bureaucracy has been built up as part of the joint powers agency, and the technical work is proceeding smoothly on an expedited schedule.

The Guadalupe project in San Jose is more complex than either the San Diego or Sacramento projects, both in terms of the project and the organizational structure to conduct it. Since the preliminary engineering and final EIS stages are just getting under way, it is too early to draw any conclusions about how successful the structure will be.

The project involves both a state highway and a light rail line in the same right-of-way, which is new right-of-way, not one currently in rail or highway use. The project is thus more complex and much more expensive than either the San Diego or the Sacramento project. The San Jose project is the only project of the three that is relying on UMTA Section 3 funding.

There is no MTDB-type legislation setting out an organizational framework for the development and operation of the project, but the development of the project is to be carried out within a framework established by a joint powers agreement between state and local government. The agreement sets up a policy board, a technical committee, a project manager, and a deputy project manager. It is intended that the staffs of all involved public entities, as well as consultants, will participate in the actual technical work.

The partnership between state and local government in the light rail area has not been financially equal in California. Local contributions have been minimal, and the state has agreed either to pick up almost the entire project cost or provide almost the entire match, if federal funds are involved. This situation will have to change in the future; it is unrealistic to expect that either federal or state funds will be available in the amounts being sought.

Thus, the question of local funding is the key element

in the overall funding issue. We should clearly be looking for more financial support from the local level. One very obvious way to generate more local funding in this state would be to take advantage of the provisions of Proposition 5 as they apply to gas tax revenues subvented to local jurisdictions. There is probably no better time than now. The state law increased the local and state gas tax bases just last year.

According to our estimates, if local governments in Proposition 5 counties were to give transit 25 percent of their increases in gas tax revenues over the next 5 years, they would be boosting guideway funding by \$120 million. However, the California Transportation Commission, which adopts a 5-year spending plan for state highway and some transit work, has before it a recommendation from their staff that our proposed level of Proposition 5 funding be reduced to free up more money for highway projects.

Simultaneous with this battle is the issue over a new bill—SB 1335—that would change the local share of SB 620 funds, our second source of funding for guideway projects. Under current law, after certain state overhead costs are deducted, SB 620 funds are split equally between local assistance and the remaining project categories—including guideways. Under SB 1335—which is in part a response to federal transit cuts—the local assistance share would be increased to 60 percent at the expense of the remaining transit categories, whose share would drop to 40 percent. This represents an attempt to solve a funding problem through the cannibalization of one element of transit by another. The transit community should take a page out of the book of the roadbuilding community and work on a united basis to ensure adequate overall funding.

We in California can be proud of what we have accomplished in the last few years with regard to light rail. This would not have been possible without state interest and state funding. But if we are going to sustain the level of effort we now have under way, we will need a local, as well as a state, funding commitment. With state and local government working together, there is no limit to what we can accomplish.

Potential for Light Rail Transit: Local Perspective

RON DIRIDON, Transit District Board of Supervisors, Santa Clara County

The advantages of light rail transit are needed now. The Santa Clara County transit experience dramatizes that point.

Santa Clara County is Silicon Valley: 1.3 million people—more than twice the population of 20 years ago. In 1975, there were 506 000 jobs in our valley; today there are more than 700 000 jobs, and 840 000 are conservatively projected for 1990. That is a 170 percent increase in our 1975 employment base, and we have had no significant highway expansion. You can imagine the massive commuter congestion.

Our transit agency began in 1974; it now has 650 buses carrying more than 130 000 trips per day. Our rate of increase continues to average over 13 percent compounded, making us the fastest growing major property in the country. But we have not scratched the surface of the transit need yet, and we cannot afford the operating cost to meet that need in buses only. So we began to solve the problem. In 1973, with UMTA's help, we conducted the first of four federally required studies.

Our Phase One Rapid Transit Development Project was a general concept study that cost \$200 000 and 2 years of time. The results indicated a need for 140 miles of

medium capacity transit—light rail—for our interurban link with a bus feeder and distribution system. That local system would feed into the Southern Pacific San Francisco Peninsula commute and BART heavy rail systems for regional trips. It sounded good; we wanted to build it then, in 1975.

Instead of going to the federally required Systems Level Alternative Evaluation Study, we tried to short cut, like San Diego, and lead into preliminary engineering. So we conducted, without UMTA's help, the Santa Clara County Light Rail Feasibility Study at a cost of \$200 000 and 2 more years. The results confirmed the concept study and recommended a 15- to 20-mile light rail starter segment in our main north/south Guadalupe Corridor to interconnect the densest neighborhoods with our city center and heaviest industrial concentrations. The study, which would have cost \$86 million in 1976, was rejected by UMTA because we had not conformed to their process. So we went on to the next federally required study.

In 1977, the Santa Clara County Joint Corridor Study, our Systems Level Alternative Analysis, was begun. The cost was more than \$2 million and 2.5 more years. After studying 13 alternatives in 5 corridors, the results con-

firmed our original study: light rail in the Guadalupe Corridor. But now the project cost was up to \$130 million.

Then we had the pleasure of beginning the Guadalupe Corridor Study, our Project Level Alternative Analysis, and Draft Environmental Impact Statement. The cost was another \$1.5 million and 2 more years. And we were not surprised to see light rail, with an adjacent expressway in some sectors, again recommended for our Guadalupe Corridor. But now the cost had increased to more than \$180 million for the rail portion of the project.

After 4 studies over 9 years, each confirming the prior findings, a cost of almost \$4 million, and construction costs that have more than doubled, we are ready to begin preliminary engineering and publication of a final EIS.

This is no marginal project:

- Less than \$10 million a mile total project cost.
- More than 42 000 riders per day expected to start.
- More than 5000 riders per hour in peak periods.
- More than 80 percent of the right-of-way in public ownership already.
- A two-directional payload paying 85 percent of the operating cost from the farebox.
- A virtually unanimous local consensus with an 85 percent popular vote in favor of the plan.

And we have just been advised by UMTA that we have been turned down on our request for a \$2 million preliminary engineering grant because we are a "new start." So, we are going ahead—with a promised federal letter of no prejudice—on our own, with state aid.

A joint powers agreement signed with the state on March 26 gives the state the expressway portion and our transit agency the light rail portion of the project. We are looking for added help from the California Transportation Commission and also considering various local financing options including assessment districts, revenue bonds, sale and lease-back of vehicles, and bank robbery if needed. Most important, we are going to build a light rail system in Santa Clara County—if we have to drive every spike ourselves.

As in many areas across the nation, we in Santa Clara County are ready to proceed with the interurban transit system of the 21st century—light rail. We have proved,

using the federal government's own criteria, that it is cost-effective and it will work. We have tremendous needs that, if left unmet, will jeopardize our economic and environmental viability in the near future. We have no choice. So what do we—what do you—need to do next?

- First, we must systematically and comprehensively spread the message of the virtues of light rail to the public. Let us reestablish the National Transit Advocacy Network that was effective in persuading the early Carter administration that adequate transit capital funding was essential to economic vitality. This group of transit representatives of the National Association of Counties, League of Cities, American Public Transit Association, AMTRAK, and others focused on subject areas of common agreement and was very effective in building the Section 3 capital funding to an acceptable level.
- Second, we must demand that transit, especially cost-effective light rail, be a major priority at the local, state, and especially the federal level.
- Third, we must insist that the federal red-tape studies be reduced to a single, combined alternative analysis, EIS, and preliminary engineering efforts that should lead to a speedy approval or disapproval by UMTA.
- Fourth, we must support the approval of transit capital grants based on cost-effectiveness and proven need, not on whether the system is a "new start."
- Fifth, we must take the risk to advocate for new transit funding sources while attempting to protect traditional allocations.

Most of all, we must retain a consensus and remain focused on the broad objective of promoting cost-effective light rail transit. We must not allow our efforts to be fractured into disastrous competition among transit agencies for inadequate and dwindling dollars. The American transit community must join together because the total system must have priority or our total economic system could fail.

Evolution of Light Rail in Europe Since 1977: Trends, Future Perspectives, and New Approaches

ANTOINE LOMBART, Transurb Consult Brussels

In the first half of this century trams had to carry the main burden of public passenger transport in most European cities and in many cities on other continents. The tram was an important part of urban transport, even in cities with over a million inhabitants where rapid transit systems (metropolitan and suburban railways) already existed.

The middle of the century saw the beginning of a structural transformation in transport characterized by a double shift: from public transport to private cars and within public transport from the tram to the motorbus. This trend first became apparent in the United States, where the number of tram passengers declined rapidly—e.g., from 7.3 to 0.6 billion passengers per year between 1935 and 1958. This process occurred about 20 years later in European cities.

The rapid increase in the number of cars greatly

impeded the operation of public transport and deprived the tramway of its most important basis: the provision of a punctual and regular service. The desire to own an automobile increased to the same extent that the attractiveness of the tram diminished. Although understandable at the time, the mood of euphoria that greeted the car, which was believed would solve the transport problem in towns and cities, often affected the decision to the disadvantage of the tram. More and more roads were built to give the car its due place. The old tramways interfered with the cars and were eliminated in many cities, where the infrastructure in the center or at the side of the road hindered parking and loading. The aim was to limit public transport to a few bus routes, and in the cities with over a million inhabitants to a metropolitan railway, for those of modest means.

In some European countries—e.g., England and France—trams were dispensed with almost entirely, whereas in others—e.g., Belgium, Germany, The Netherlands, Italy, Austria, Switzerland, Sweden, and the East European countries—they still remained the main form of public transport in many cities; less frequently patronized tram routes were converted to bus services.

In Europe, the following trends were already evident in the 1950s with regard to the form of public transport:

- Many smaller and medium-sized towns with up to about 200 000 inhabitants dismantled their tramways and switched to buses. In many cases they were old, sometimes historic towns, where trams could operate only on a single track or where the development of efficient sections was not possible for town planning reasons and was also often not financially justifiable.
- Large cities with populations between about 200 000 and 1 million retained the tram as the main form of public transport. However, the motorbus acted as a feeder to rail transport and supplemented it to an increasing extent.
- Cities with over a million inhabitants extended their rapid transit networks (metropolitan and suburban railways) and gradually eliminated their tramways at the same time. Here, too, buses performed feeder and supplementary functions on an increasing scale.

Exceptions to this trend were limited to only a few towns and cities. It is now clear that the trend initiated at that time proved to be correct. Basically, this also applies to comparable cities in other countries, in which the initial situation was similar to that in Germany. However, it was always necessary to continue to develop public transport—i.e., to make it more attractive in order not to fall further behind in the competition with the car. For the tram this meant that it had to extricate itself as far as possible from interference by private transport and provide punctual and fast public transport services with modern vehicles. The outcome of all measures based on this objective is a low-budget, high-quality public transport system—light rail transit.

This policy was pursued in Brussels (1 million inhabitants) from 1964 on. Sound studies and analyses led to the opening of the first light rail section in 1969, initially called semi-metro, later premetro. A comparison of the costs of investment and operation of this 10-year-old experiment with those of a "proper" metropolitan (heavy rail) system clearly indicates the numerous qualities of light rail and the soundness of the efforts undertaken to promote its realization.

This method was evoked by Vukan R. Vuchic in his paper, *Current Trends: Problems and Prospects of Light Rail Transit* (TRB Special Report 182, 1978).

BACKGROUND

Since 1978 the Commission of UITP has defined light rail as a railbound form of transport that can be developed in stages from a modern tramway to an underground or elevated transport system. Each development stage can be the final stage but should permit further development to the next higher stage.

Light rail systems can either be developed gradually as the main form of transport from an existing tramway or newly built as the only rail transport system in its catchment area or to supplement an existing rapid transit system.

Each of the three possibilities has been translated into practice, the development of light rail systems from existing tramway networks being encountered most frequently.

In 1978, 97 cities were planning, studying, modernizing, or constructing tramway or light rail networks. In 1982, there are 134—an increase of almost 40 percent (Table 1).

During construction of the light rail system, short sections of the network can be put into service immediately after completion and thus be used to improve city transport services without delay.

It is not always necessary to transfer large sections of the rail network to the second level. Construction of special rights-of-way at street level in conjunction with complementary measures, such as the control of signals for general traffic by the light rail vehicles, may also produce the desired effect.

In city centers, where traffic is concentrated in a confined area, it is often impossible to make sufficient space available on roads for separate tracks for light rail systems. In such cases the light rail sections involved are generally constructed underground, thus not only making rail transport totally independent of other traffic and able to operate without interference in its most important and busiest catchment area, the inner city, but also creating the possibility of replanning the city center and adapting it to public needs and requirements. Many cities utilize this opportunity to revitalize their centers. In particular, large continuous pedestrian precincts are created, where—shielded from street noise and away from exhaust fumes—people can again move freely and feel at ease. In addition, it is noticeable that the business communities have also invested large amounts in response to the investments by local authorities in the attractive redesign of their city centers. Revitalization of the city centers has an extraordinarily beneficial effect on urban public transport, whose passengers were already traveling mainly to destinations in the city centers, by increasing the numbers of passengers. Conversely, our city centers are also dependent on attractive public transport. Because they attract large volumes of traffic into an area where there is relatively little space for movement and parking, the city

Table 1. Cities planning, studying, or constructing tram or light rail networks.

Location	Before 1978	Situation in 1982	Increase
America	12	34	22
Africa	4	8	4
Eastern Europe and U.S.S.R.	25	25	-
Western Europe	51	60	9
Asia	3	5	2
Australia	2	2	-
Total	97	134	37

centers can continue to function properly only if they are served by space-saving, high-capacity public transport. Light rail is most suitable for this purpose in medium-sized cities.

The results of traffic surveys and investigations in several cities clearly illustrate the success of light rail. Although conditions in individual cities vary, it is still possible to make some basic statements.

Traveling times have been shortened (sometimes even halved), late running greatly reduced and often totally eliminated, and the number of available seats significantly increased (sometimes doubled) on the light rail lines. The improvements in the services offered have led to greater increases in the number of passengers. In several countries increases between 20 and 60 percent are recorded for light rail compared with the trams previously operating on the same routes. It is significant that car drivers have also been convinced of the improved service and induced to switch to public transport. Some results of a sample survey of households conducted in 1978 in the catchment area of light rail line A in Hanover are of interest in this context:

- 78 percent of all trips to the city center are made by public transport.
- 50 percent of all persons who continuously have a car at their disposal nevertheless use public transport for their journeys to the city center.
- The modal split of about 40:60 (public transport to travel by car) in the entire urban area is reversed in the immediate catchment area of the light rail system—i.e., about 60:40 in favor of public transport.
- Over 90 percent of the persons interviewed thought that light rail satisfied the most important criteria for successful public transport—namely, punctuality, regularity, comfort, and speed.
- 91 percent of the persons interviewed considered that the money spent on light rail was a good investment.

There is every reason to believe that light rail will continue to be successful. Conditions in the energy sector and the far greater public awareness of the environment will also have an effect. With an average number of passengers, modern light rail vehicles consume per passenger only about one quarter of the energy consumed by a car. If it is desired to save energy in the transport sector, this can be achieved most effectively by persuading motorists to make greater use of public transport. However, this is conditional on the provision of attractive services. All components of the urban public transport system must therefore reach the same high standard.

DEFINITION OF LIGHT RAIL

Light rail is a rail-borne form of transport that can be developed in stages from a modern tramway to a form of transport operating underground or on viaducts. Each stage of development can be the final stage but should permit further development to the next higher stage.

Unlike metropolitan railways, light rail is not a self-contained system. Light rail has many features of the tramway and also of the metropolitan railway that are more or less distinct according to the stage of development.

The stages of development differ from each other in the standards of construction of the track and of the stations—including the signal system—and also in the design of the vehicles.

The various stages of development are not necessarily in the order of the following discussion. On the contrary, the development of a light rail system is determined primarily by the objectives and by local conditions.

- Own right-of-way—In one of the first stages, the light rail lines should be separated from other traffic by construction of their own rights-of-way in the roadway. Intersections with car traffic are retained initially. However, intersections with pedestrian traffic should be avoided in city centers, particularly in pedestrian zones (separation, under- or overpasses). At road crossings the light rail system is initially incorporated with equal priority in the phase sequence of the signal system. The trains operate by sight.
- Tunnel sections in city centers—In many cities space is greatly restricted, particularly in the city center; separate tracks cannot be constructed. In this case the rail traffic must be put underground. The light rail tunnels are usually sited immediately below the roads. The tracks are designed to permit high speeds. Train protection in the tunnel sections can be developed in different ways, from operation by sight to a train protection system designed to metropolitan railway standards.
- Tunnels and underground branches in city centers—As tunnel sections advance in the city center, branches are also laid underground. As on a metropolitan railway, the branches are made without crossings. Light rail operation with short intervals between trains calls for train protection systems.
- Short tunnels on outer sections—Light rail tunnels are also constructed on outer sections that cannot be provided with their own right-of-way because of existing development or where a track suitable for light rail vehicles cannot be laid on the road. These tunnel sections should be kept short because of the high construction and operating costs.
- Extensive elimination of grade crossings on the outer sections—At intersections with car traffic, the light rail line passes under the intersection if there is heavy cross traffic. At other crossings, priority is given to the light rail system in the signaling system, the traffic lights being controlled to give priority to light rail movements. Pedestrian crossings are generally replaced by footbridges or underpasses. Extension of train protection equipment from the tunnel to the outer sections is advisable to increase the traveling speed and to shorten the intervals between trains.

This last stage completes the development of light rail systems; except for a few crossings, they operate completely independently of other traffic. In addition to this development, there are also various stages of development of the vehicles used on light rail lines. These stages have a significant effect on the design of the platforms in the tunnel and on the outer sections. In a light rail operation with trams, the modern trams used in the first stages run partly on tracks designed for light rail vehicles but also on conventional tram tracks. The platforms in the tunnel are divided into a tram area (low platforms) and a light rail area (high platforms) and thus permit mixed operation.

EUROPEAN TRENDS IN THE DEVELOPMENT OF LIGHT RAIL TRAFFIC

France

The case of France is typical. Before 1940 many French cities possessed a tramway network. After World War II, however, trams gave way to buses. Saint-Etienne, Marseille, and Roubaix-Tourcoing were the only cities that stayed with tramway operation; Saint-Etienne and Marseille have bought PCC vehicles that were also delivered to the United States. As in music halls, the present trend is retrograde. The most advanced light rail project is planned by the city of Nantes. It is part of the public

transport policy of the new government, and there is hope that its operation can start at the end of 1983 or the beginning of 1984. In Grenoble a basic decision was taken to construct a 10-km light rail line. In Toulouse studies were undertaken on the construction of a 3-km tunnel section in the city center, causing the cost of the light rail project to increase by 40 percent.

Among the various light rail projects, the Strasbourg plan deserves special attention because the last tram line there was only replaced by a bus line in 1960, but the city has the intention of turning back to rail traffic.

Belgium

In Belgium, the cities of Brussels, Antwerp, and Charleroi continue the development of the light rail projects; 6.8 km of light rail tunnel are under construction in Brussels. Moreover, a second tunnel section was opened in Antwerp in March 1980, while an extension of 1.1 km with two stations was put into operation in June of the same year.

At present Brussels has a conventional metropolitan railway, which links the city center with the eastern suburbs. The line is being extended westward. It is envisaged that it will traverse the city from east to west with a length of about 20 km by 1982. Various tunnel sections, each 2 to 3 km long, are currently being used by trams and form the so-called premetro. These tunnels form part of three lines: north-south axis, inner circle, and outer circle. They have metropolitan railway cross sections and are designed for conversion to metropolitan railway operation. These installations are part of the gradual implementation of a general plan to improve the transport network that was drawn up in 1965 and envisages completion of a metropolitan railway network with 5 lines and a total length of about 60 km by 1990. This plan provides for gradual completion and commissioning of the installations, which are to be operated initially as a premetro for a short or longer time—i.e., with trams operating on the surface outside the installations.

The ultimate aim of long-term planning is the metropolitan railway. All installations are designed so that they can be subsequently integrated in the final and relatively close-knit metropolitan railway network originally envisaged. In the short and medium term, however, it is planned to operate the installations with vehicles that are neither metropolitan railway rolling stock nor tramcars but form an intermediate solution—i.e., light rail vehicles that can operate on all roads and even on relatively narrow traffic routes in the city.

This policy of using vehicles that can operate anywhere and embody characteristics between those of conventional metropolitan railway rolling stock and tramcars allows all major effects to be concentrated at points where traffic conditions are particularly difficult. Without calling into question the extension of the conventional metropolitan railway, the policy proposed in Brussels envisages abandonment of the expensive extensions toward the suburbs in the medium term, because public transport vehicles can still operate relatively unhindered there. Hence the funds will be available for the inner city (within the outer circle).

It goes without saying that this policy must include measures that facilitate public transport on the surface in order to prevent the investments in the city center being nullified because the vehicles continue to be impeded on the surface.

Under a law already passed by Parliament, the government is in the process of issuing an order designed to empower the Minister of Transport to take the necessary measures to facilitate operation of public transport on the surface (own lanes, parking bans, one-way streets, remote control of traffic lights, etc.). It should be noted that this new policy in no way reduces the envisaged investments; on the contrary, it concentrates the available funds at the critical points of the network and can at most slightly reduce the kilometers of construction because the work in the city center is more difficult.

The Netherlands

The development in the Dutch cities of Amsterdam and Rotterdam is noteworthy. In Amsterdam it was originally planned to build a metropolitan railway network with a total length of 78 km. About 20 km is currently in service. It is planned to complete a further extension to Gein (about 2 km) by 1982. However, construction of the metropolitan railway will not be continued for cost reasons. Instead, it is intended to develop the existing tramway network into an efficient light rail system.

In Rotterdam a rail line on which mixed operation (metropolitan railway and light rail) is planned is currently under construction. Originally envisaged as a metropolitan railway line, this line was already under construction when a decision was made for cost reasons to develop parts of the line for light rail service with a few grade crossings. The vehicles are designed in such a way that the current can be collected via a contact rail (on the section constructed as an underground railway line) and also via an overhead line and pantograph (on the section constructed as a light rail system).

Germany

In the Federal Republic of Germany light rail systems have been built since the mid-1960s. In every instance they are being developed in stages from an existing tramway network to a light rail system. Individual sections of the network are constructed as reserved tracks on the surface or on the second level, usually underground.

Many cities—e.g., Bonn, Cologne, Frankfurt, Stuttgart, Essen, Düsseldorf, and Hanover—have already constructed large sections of the rail network as light rail systems and put them into service, while others anticipate that large sections of the light rail network will soon be operating. In virtually all cities where rail is the main form of public transport, development of the network is in full swing. Some of these cities (generally those with smaller populations) are restricting themselves to the construction of reserved rights-of-way, whereas others are also transferring long sections of their networks to the second level.

The evolution in Stuttgart is a good illustration. In the late 1950s Stuttgart also found that the old tramway no longer met the changed requirements for a local public transport system. The rapid increase in motor vehicle traffic, particularly in the city center, resulted in greater interference with the trams operating on the roads. There was a noticeable decline in the attractiveness of municipal public transport; abandonment of public transport by the passengers was the logical consequence. The first transport plans, designed to counteract the loss of passengers by improvements to the tramway system, envisaged the construction of an underground tramway. According to these considerations, the tramway with all its branches, intermediate turning loops, and various grade crossings was to be transferred underground in the city center. On the outer sections the tramway would have to operate partially on its own rights-of-way but still with numerous grade crossings and small radii.

Ten years later, however, it was realized that the expensive transfer of a small part of the tramway network to a second level in the city center would not be sufficient to make this form of transport so much more attractive that the drift away from trams by passengers could be prevented or even reversed. In 1969 the political bodies approved an initial light rail concept. It provides for a consolidation of the existing network and the elimination of all trouble spots such as grade crossings, junctions, and branches on the new light rail lines.

In 1973 the wave of enthusiasm for metropolitan railways reached such a high peak, as in other German cities, that Stuttgart also decided to construct a metropolitan railway with 2.90-m wide vehicles. But this enthusiasm quickly died down because the subsidies from public funds were not forthcoming in such large amounts as had been initially assumed.

The final aim of the plan now is to extend the Stuttgart tramway network as a light rail system. The existing tramway is to incorporate three important new features: conversion from meter gauge to standard gauge (1.435 m); replacement of the 2.20-m wide tramcars by 2.65-m wide modern light rail vehicles; and intensified construction of rights-of-way separated from other traffic.

Italy

In Turin, a new 11-km light rail line to Rivoli is planned. A first section will be put in operation with new vehicles in the spring of 1983.

In Milan, the reasons that the city decided to discontinue extension of the metropolitan railway begun only after the Second World War, in favor of light rail lines to supplement the metropolitan railway network, appear interesting. The metropolitan railway has improved transport services only in its immediate catchment area. An attempt was first made to extend the catchment area by fare policy measures. A flat fare for commuters and later (from November 1977) a 1-hour fare for all passengers, both of which are valid for surface transport and the metropolitan railway, were introduced. This, of course, necessitated good connections between the metropolitan railway and surface transport.

However, an effort had to be made to enable the passengers who did not live in the areas served by the metropolitan railway to enjoy its advantages on a wider scale. A way of providing a better and more extensive service in these areas was sought. This transport system had to have a metropolitan railway character and be capable of a similar performance, at least in the overloaded transport directions. This meant conversion of the tramway into a light rail system with its own right-of-way; functional stopping places; traffic control and structural measures for the sections used by trams and light rail; control of traffic lights; use of modern, spacious vehicles with a capacity of 250, including 70 seats; replacement of the pole-type current collectors by pantographs with corresponding conversion of the overhead line; and safe branching points ensured by an absence of crossings or automatic crossing control systems wherever possible.

Four light rail lines with a total length of 43 km resulted. They have their own right-of-way on between 57 and 79 percent of the lines, but achieve a commercial speed of only 11 km/hour and a maximum of 13 km/hour. This modest result is attributable to the fact that it has not yet been possible to introduce adequate traffic control measures in mixed operation.

In addition, the small mean distance of 282 to 322 m between stops does not allow full use of the dynamic running characteristics of the new large-capacity vehicles. However, more regular frequency of trains has been achieved with the larger vehicles by increasing the headway between trains. Labor costs have also been reduced by 30 to 35 percent by introducing the 8-axle vehicles in place of the 4-axle ones. All vehicles operate with one man and without issue of tickets in the vehicle.

Austria

Linz, the capital of Upper Austria, is cited as an example of the Austrian light rail projects. The current population of Linz is just over 200 000.

The 5.5-km new section is designed in accordance with the latest technology. The basic requirements during planning were high commercial speed, minimization of interference by other road users, and traffic installations compatible with the environment. The greater part of the line, 4.6 km, has its own right-of-way at the side or in the center of roads; in the case of sections running in the center of the carriageway, the parallel tracks are separated by continuous white lines. Insofar as road crossings between the stopping places were unavoidable, they are protected by the flashing warning lights used in railway

operation, which are operated by overhead line contacts. Whereas the current tramcars are 2.20 m wide, vehicles with a width of 2.40 m can also be used on the new section. This standard profile is now taken as a basis for all new sections.

Sweden

A few years ago, Gothenburg started the construction of a light rail network between the city and the neighboring municipality of Angered, which was incorporated into the city of Gothenburg. The incorporated districts are between 8 and 14 km from the center of Gothenburg. The construction of a fast light rail line played an important part in the first planning phases for Angered-Bergum. The planning department of the transport undertaking and the town planning authorities began to deal with planning questions in conjunction with the construction of public transport systems between Gothenburg and the new areas of the city.

For some time the city had been investigating the possibility of a metropolitan railway network. While the final decision on this question was awaited, several possible solutions for linking the new areas were discussed. The system should have a high capacity and also operate economically. During investigation of these alternatives, the national railway (SJ) announced that a narrow-gauge railway in the vicinity of the incorporated areas was to be closed. It was then proposed that the already existing track bed of this narrow-gauge railway be used to provide a good public transport system. However, it was necessary to modify the gauge for light rail operation.

Line 8 is 11.5 km long, of which 2 km run underground, with a station 24.5 m below the surface. The number of stations has intentionally been kept small to achieve the highest possible speed. This has also contributed to the profitability of the line. All stopping places were built in such a way that they can easily be converted to metropolitan railway standard. The platforms can easily be raised to floor level. Adequate space is available for ticket inspection barriers. With the present system the tickets are cancelled by automatic machines in the vehicles.

Switzerland

In four Swiss cities that operate tramways, great efforts are being made to facilitate tramway operation by construction of further sections with their own right-of-way and by tram-controlled signals at traffic junctions. At present the tramway networks in the four cities have a total line length of about 192 km, about 28 percent in their own right-of-way. Priority is given to the tramway at about one-third of the traffic signals. The aim of all improvement measures is to increase the commercial speed and thus make local public transport considerably more attractive.

In Zurich, a detailed survey of trouble spots (loss of time, accidents, etc.) and the causes of this trouble (parking, traffic control, etc.) revealed that 152 trouble spots and over 200 causes occurred on route 10 alone. About one-third of these trouble spots were eliminated by measures taken before 1975 (adaptation of traffic lights, prohibition of left turns, parking bans, and improved priority measures). Further measures are designed to eliminate another third of the troubles. It was not possible to find a remedy for the rest of the trouble spots. The results achieved on route 10 are very good; it was still possible to increase the commercial speed by 6.4 percent.

The networks of Basle, Berne, and Geneva pursue a policy that tends to give priority to tramcars. Various measures in the field of general traffic were taken and efforts made to ensure that the other users of the public road would respect them. The following measures should be mentioned: no thoroughfare for motor vehicles on certain roads; own lanes for rail transport (particularly

when buses also use the tram lines); continuous marking lines along the tram tracks; and stopping and parking bans in narrow streets.

Portugal

The investment plan for 1982-1986 of the Lisbon network includes the modernization of the group of tram lines running along the Tagus River, the acquisition of articulated tramcars for these lines, line extension, and the construction of new workshops.

Great Britain

The light rail concept is beginning to gain acceptance even in those European countries where surface rail transport was largely abandoned several decades ago. For example, a light rail line about 20 km long was opened in August 1980 in Newcastle, England, a city of about 270 000 inhabitants. Further extensions are currently under construction. It is intended to create a light rail network with a total route length of about 54 km by 1983. A large section of the network consists of lines previously operated by British Rail.

Soviet Union

In Eastern Europe there is a tendency to extend and improve the existing tramway networks and to construct light rail systems as well. In 1976 trams operated in 109 cities in the Soviet Union and carried 8.34 billion passengers with an increasing trend—15 percent of the total number of passengers carried by local public transport. The tramways are being continuously modernized in most cities. As far as is known, however, a new light rail line is under construction only in Kiev. This 9.3-km line links a new housing estate to the city center. The line runs only on its own right-of-way without crossings with other traffic. It achieves a traveling speed of 28.7 km/hour, with a maximum speed of 65 km/hour. The stations are built to metropolitan railway standards. A train safety system permits a train frequency of 110 seconds. The line will initially operate with existing tramcars. It is planned to use Tatra large-capacity vehicles later.

Poland

A metropolitan railway was originally planned in Warsaw. Here, too, a decision is apparently being made in favor of a light rail system for economic reasons. In northwest Warsaw a 3-km light rail line on its own right-of-way went into service in July 1977. A modern, efficient transfer station, at which 6 tram routes and 7 bus routes as well as the new line terminate, was built at its terminus (Huta Warszawa).

In Szczecin the first real light rail section is being planned in the form of a cross-city line. When completed the line will be 30 km long. It will operate on its own right-of-way and on viaducts in the area of the main railway crossings. The aim is a commercial speed of 35 km/hour. Existing tramcars will initially be used on the line. However, the clearances are such that wider light rail vehicles can operate on the line later.

Yugoslavia

In Yugoslavia tramways still operate in Belgrade, Osijek, Sarajevo, and Zagreb. The urban development plans of these cities provide for retention of the tramway or its conversion into a light rail system.

The Belgrade transport authority operates a tramway, trolleybus, and bus network. The tramway accounted for 63.8 million (16 percent) of the 387.5 million passengers carried in 1977. The urban development plan covering the period up to 1985 provides for improvement and modernization of the tramway. The main aims are the extension of

the transport network and the purchase of new vehicles and maintenance equipment. It is planned to extend the line network by 20.3 km of double track, so that a network length of 100 km will be available. The 130 tramcars of old design and different types are to be replaced at the same time by 170 modern articulated vehicles. Although a metropolitan railway is envisaged for Belgrade in the long term, it will not slow the modernization of the tramway into a light rail system and the general improvement of urban transport.

German Democratic Republic

Although some cities in the German Democratic Republic are converting certain routes from tramways to buses for economic reasons, some have also extended their tramway networks. Virtually all these new lines have their own right-of-way—i.e., they are built to light rail standards. The vehicle fleet is being renewed. Tatra 4-axle vehicles of type T3D from Czechoslovakia are generally used. In Karl-Marx-Stadt the narrow-gauge lines (925 mm) are being converted to standard gauge. In Magdeburg a new 1.7-km section went into service in 1976. Erfurt likewise opened a 1.7-km section to traffic in April 1978. In Leipzig, too, a tramway route was extended by about 1.6 km into a new residential area in April 1978, even though the tramway network had to be reduced because of the progressive construction of the rapid transit system.

NEW APPROACHES

The house where I spent my youth was part of a tramway depot, and after 27 years of professional life devoted to the management of a public transport company, I can look back on half a century of close contact with public transport.

At the beginning of this century most of the public transport systems were managed by private companies grouped in holdings, and the major goal of these groups was to realize the most favorable financial balance sheet possible. This was perfectly feasible until the years 1960-1965, when the use of private autos began to boom, endangering the financial equilibrium of the companies.

The "golden sixties" are over, and indirect proof is now available that the private car, although it is an outstanding complementary means of transport, was not the miracle-worker some people had believed it to be. The major task of public transport at the moment is to be at the service of the population and to reduce as much as possible operating losses without neglecting indispensable modernizations to make the product attractive. Tomorrow's public transport should more than ever be integrated in the planning and the everyday life of the city in all its aspects. Because private cars permit door-to-door transport most of the time, urban public transport should be able to do the same or offer a valid alternative.

Public transport managers should welcome the passenger at their doorstep—i.e., they should act as a kind of ombudsman and intervene with public authorities in order to place at the disposal of their customers well-maintained sidewalks leading to the stops; shelters protecting them from bad weather and illuminated at night; and reliable information posted at the stops that correctly informs the public.

The network structure must not be fixed forever; on the contrary, it should adapt to the urban activities. Public transport should be ahead of the urban transformations and even lead them in the right direction. The users, in this case the population, should be in continual dialogue with the various authorities, without forgetting the operating personnel who are dealing with the daily problems.

Awareness of the detailed analysis of the numerous aspects of urban transport can prompt the open-minded operator to adapt the operation to the real necessities of the moment.

In the non-OPEC countries, more and more thought is given to electric vehicles, which offer undeniable advantage in areas such as air pollution, noise, capacity, and economy.

Most of the networks in European cities with 1 to 3 million inhabitants that ventured upon a standard metropolitan railway operation can only conclude that the operating costs are very high (vehicles as well as stations); that some platforms at different levels are accessible only with great difficulty (elderly people sometimes panic at the mere sight of an escalator, and, moreover, the maintenance is extremely burdensome); and that insecurity grows with the volume of the stations, and this climate has a restraining influence on the use of public transport.

Once again, light rail traffic can offer a valid alternative, as it is possible to build the required facilities at ground level on very long sections. A tendency exists to construct high platforms at stops to permit easy access to the vehicles. This reduces the stopping times and increases the commercial speed, which contributes to the attractiveness of the system.

The wide range of rail vehicles, each with its own width, length, number of articulations, and couplings, offers the possibility to choose the type of vehicle that seems most appropriate for a particular operation.

I should like to conclude by emphasizing that public transport services can contribute strongly to a city's functioning. Each vehicle is constantly connected with the company's traffic control center, and the vehicles run through a vast network of roads at regular intervals. The drivers can therefore inform the control center about any anomaly met on the way.

On the S.T.I.B. Brussels Passenger Transport System network, for example, the drivers intervened, by transmitting information, on the following occasions: 166 accidents between third parties, 651 calls for an ambulance, 320 cases of traffic lights being out of order, 24 calls for the fire department, 23 cases of lost children, 40 acts of aggression, 44 brawls, 3 cases of leaking petrol and risk of fire, 22 cases of inundation, and 5 uprooted trees fallen on the road.

To strongly motivate the authorities responsible for the organization of all urban transport, it is absolutely necessary to draw their attention to the numerous complementary services public transport in general, and LRT in particular, can offer. With their support, an urban renovation can be brought about that gives the city back to the inhabitants and prepares the shape of the urban region for the coming decades.

LRT Fixed Facilities and Vehicles

THOMAS F. LARWIN, San Diego Metropolitan Transit Development Board

The existing and planned light rail installations in North America serve as testimony to the progress being made to move people more efficiently during this era of tight financial resources. An outstanding feature of LRT is its versatility and its corresponding ability to develop incrementally.

The San Diego project is but an initial increment of a larger LRT plan. We are already in the midst of a construction program to double-track a system that began as a single-track line in San Diego. Ten more vehicles are now on order, and we intend to expand the service to the eastern suburban areas within the next couple of years. Even then we will not be done—there are northward extensions being planned, grade separation projects being designed, and operating enhancements continually being made.

This flexibility and versatility can be translated into low-risk development and low cost. Light rail offers the flexibility and versatility to satisfy transportation needs at low capital and operating costs. Although we hear a lot about the capital cost features of light rail transit, low operating costs are equally important. There needs to be constant vigilance during the planning and the design process to achieve a low-cost operation. A proper balance will continue to pay financial dividends in the future.

VEHICLES

A wide variety of vehicle technology is currently operating. PCC cars are still operating in Cleveland, Pittsburgh, Toronto, San Francisco, Boston, and Newark. These cars average 40 years of age. Table 1 shows recent activities in procurement of newer vehicle technology. In Calgary and San Diego, 3-car train units are in peak-period service. In San Diego, 4-car train units will eventually be operated. While most of the areas are opting for double-ended vehicles, single-ended vehicles are also available if

the operations permit their use. These new vehicles have 3 or 4 doors on each side. Seating capacity ranges from 49 for the Tokyu car in Buffalo to 84 for the Breda car being used in Cleveland.

Platform boarding conditions vary. Subway sections of the San Francisco Muni use high-level boarding (platform aligned with the floor level of the car), but the San Francisco Boeing cars can use both high- and low-level off boarding. Low-level boarding is used outside of the subway sections. In San Diego, low-level boarding is used, although Edmonton and Calgary use high-level boarding on the same car.

Special needs of the elderly and handicapped are also a consideration in choice of boarding type. However, it is not necessary to provide handicapped assistance on the vehicle. The intended station design for the at-grade stations in downtown Buffalo has a platform that enables a person in a wheelchair to be lifted to the floor level of the train even though the car will have low-level boarding. Portland is also designing this type of off-vehicle lift. Special car lifts are provided on one end of each San Diego car.

RIGHT-OF-WAY VARIATIONS

LRT operating environments range from on-street, mixed traffic to grade-separated conditions. Mixed-traffic operations are still prevalent in most of the pre-1978 systems. Mixed traffic is the least desirable situation because of automobile traffic interference that causes delay, impaired reliability, and increased safety hazards. However, exclusive and separated rights-of-way are not always possible, especially in today's era of scarce resources.

On-street operations can be improved through various traffic engineering treatments. Such treatments include exclusive transit lanes as in Philadelphia and San Diego, paint striping to keep automobile traffic out, and special

Table 1. North American light rail vehicle procurement, 1977-1982.

City	No. Ordered	Manufacturer	Configuration	Type ^a	Loading Level	Seats/Unit
Toronto	190 ^b	Hawker-Siddeley w/UTDC	Single-unit four-axle	SE	Low	46
Edmonton	37	Siemens-DueWag	Articulated six-axle	DE	High	64
Calgary	37	Siemens-DueWag	Articulated six-axle	DE	High	64
Cleveland	48	Breda Construzione	Articulated six-axle	DE	Low	84
Philadelphia	112	Kawasaki	Single-unit four-axle	SE	Low	51
Philadelphia	29	Kawasaki	Single-unit four-axle	DE	Low	50
San Diego	24	Siemens-DueWag	Articulated six-axle	DE	Low	64
Buffalo	33	Tokyu Car Company	Single-unit four-axle	DE	High, Low	49
Portland	26	Bombardier	Articulated six-axle	DE	High, Low	76
Pittsburgh	55-60	Siemens-DueWag ^c	Articulated six-axle	DE	3 Doors High, 1 Door Low	58

^aDE = Double Ended; SE = Single Ended

^bSix prototypes (not included in above total) were built by SIG, a Swiss rail car manufacturer

^cApparent low bidder as of May 14, 1982

pavement texture and a small curb on each side of the transitway as in San Francisco. Hybrid methods can also be used. In Philadelphia, striping and overhead signing are used to allow left-turning auto traffic to enter the restricted transit area.

Various types of horizontal separation can further upgrade the LRT operating environment. In Toronto and San Francisco, LRT operates in arterial medians on a normal gravel-ballasted trackbed; a curb separates traffic from the trolley operation. Planned operation in Portland's downtown area contemplates a one-way operation along with one-way traffic, with the LRT in an exclusive transit lane. Calgary has a new twist in the downtown situation: a transitway that buses are allowed to use, which creates a joint light rail-bus path. In an area outside of downtown Pittsburgh, a joint trolley-bus transit facility can also be found. An at-grade transit-pedestrian mall will be developed in the downtown section of the Buffalo system now under construction.

San Diego's downtown operating environment is different from most; almost every block presents a different situation. Transit has an exclusive path, but it operates two-way, with one-way traffic on one side of the street. In another situation, the LRT operates in the center of the street on a path reserved for two-way trolley operation, with parallel automobile flow on each side of the light rail path. A combination of pavement markings and signing, plus a different pavement texture, is used to preserve the path for transit.

There are many examples of exclusive rights-of-way that range from simple grade separations to tunnel sections. San Francisco, Edmonton, San Diego, Pittsburgh, Philadelphia, Cleveland, and Calgary all have grade separations. Further, San Francisco, Edmonton, and Toronto have subway operations. The new line in Buffalo will also have a subway section, but it will be outside the downtown; the light rail rapid line will operate at-grade in the downtown area.

Various instances of shared rights-of-way with freight and heavy rail or commuter rail systems further illustrate the versatility of light rail transit. Edmonton and Calgary have rights-of-way that are also used by freights. In San Diego, track facilities are used by freights that operate at times when the light rail transit line is not open.

STATION FACILITIES

Light rail station facilities range from the very simple shelter to major subway platforms. The simple stations—as in Cleveland, San Francisco, Pittsburgh, and Toronto—are

basically a small raised platform, probably with some weather protection. These shelters are easy and inexpensive to maintain; in most cases, security is heightened because of the visibility. However, these facilities would not be suitable for high passenger-load locations. The platforms in San Diego have been designed for 4-car trains and are generally about 340-360-ft long, even though the shelter itself is only about 60 ft long. This station facility, while somewhat larger than the simple streetside shelter, represents less than a \$100 000 investment.

Light rail stations are more complex for systems having barriers with fare-collection facilities that require conductors aboard the cars, paying the train operator, or ticket agents and turnstiles at the stations, as with the San Francisco Muni.

Major facilities can also be developed to enhance transferring between bus and light rail. Toronto is particularly recognized for its devotion to mode transfer. The new lines at Edmonton, Calgary, and San Diego emphasize coordinated, timed transfers at the light rail stations. Facilities for transferring between light rail and regional rail (BART) are provided at the Muni Embarcadero station in the heart of downtown San Francisco.

TRACKWORK

There are numerous variations to trackwork construction; its design depends on the specifics of the area and the alignment. Climate, availability, cost of T-rail as opposed to girder rail, and traffic conditions are factors that will determine the best design. Type of tie (wood or concrete) and weight of rail are other variables on the nonstreet portions of the line. San Diego used normal ballasted track with wood ties covered with asphaltic concrete for street construction; portland cement concrete was used at intersections. Calgary placed the tracks on a portland cement concrete base spaced with tie rods and then brought them up to grade with portland cement concrete. No street traffic is allowed on San Diego's light rail path, while Calgary's path accommodates bus traffic throughout the day. In San Diego, 14 miles were on existing railroad property, where about 50 percent of the existing ties were judged to be usable and left in place.

ELECTRIFICATION FACILITIES

Electrification facilities, overhead wires, and substations can have a significant impact on the visual environment; however, this impact does not have to be negative. Design of the facilities will benefit from urban design assistance.

For example, organizing power poles in the center or even on the side of the roadway can lessen the visual impact. In sensitive environments, such as downtown areas, all wires other than the contact wire can be placed in underground

conduits. This method worked well in San Diego, and the vision of overhead wires cluttering the sky has not resulted.

Part 2

Policy and Planning Considerations

Why LRT Makes Sense in a Tight-Budget Economy

BRIAN E. SULLIVAN, Alberta Economic Development

This document considers the effects of changes in the economy on the role of light rail transit. Changes in the way the United States and Canada are likely to employ economic resources over the coming decade and ways in which societies will likely wish to see funds spent are examined. Expected changes in the nature of activities that generate wealth are reviewed, along with their implications about changes in transport demand. The characteristics of LRT are assessed against expected shifts in demand and investment priorities. Light rail seems an attractive investment in this decade, both because it fits the emerging criteria and because at this stage in its development its characteristics make it a low risk and indicate decreasing installation costs.

This paper is about strategy. It is also about synthesis. It examines the changing environment of transport investment and the changes in economic activity that underlie transport demand. It considers the attributes of a new—actually a "born again"—mode of transport and how these might be employed by sectors concerned with economic performance by drawing on knowledge of economic development, town planning, and public transport.

An examination of possible strategies can be a powerful aid to clear thinking about the opportunities and threats as well as the strengths and weaknesses of particular modes of transport and their relevance to future needs.

A broad, synthesizing approach permits consideration of a full set of influences on a particular sector or mode. Accurate information about a full range of variables—even if only within rather general orders of magnitude—is often more useful than complete, precise data on only one subsection of a problem. This is especially true when providing advice on matters of public policy.

Both approaches have their shortcomings, and before examining LRT and what it might accomplish now and in the future, it is best to define these. A strategy can provide a logical tale but is seldom the only possible assessment of information.

A synthesizing paper has as its principal drawback the fact that drawing together some common elements from disparate and complex fields requires substantial simplification. The exploration of caveats, side issues, and secondary interpretations must be left for another time. Furthermore, only enough supporting data can be shown to illustrate certain points. Otherwise, a presentation would result that would be too long and too complicated.

TRENDS IN THE ECONOMY

In North America the 1980s are proving to be a period when relatively more of our economic output is devoted to investment and less to personal consumption than in previous years. There are two important implications for public transportation: the emergence of major programs to rebuild public infrastructure and a fundamental shift in the economy away from traditional manufacturing.

This paper examines these changes and considers ways in which the low and decreasing cost of LRT and its high service and environmental quality can make investments in this mode of transport even more attractive than in the past.

The Shift From Consumption to Investment

As the economies of the United States and Canada grew during the 1960s and 1970s, there was also rapid growth in personal income and consumption. The outlook for the near- and medium-term future, however, is for a slower rate of growth in per capita income, in part because

economic resources are required to rebuild public infrastructure and to provide the necessary capital for a relative shift in income toward high-technology output.

A number of implications for public transport arise from a relative shift in emphasis in the economy. One is a swing in government funding programs toward greater use of available dollars for capital improvements rather than for operating expenses. Also, public expenditures to build up a nation's stock of capital goods and enable it to better generate income in the future are likely to be favored over those that relate solely to today's enjoyment. Finally, consumers will attempt to preserve current standards of living or increase them by having more than one household member work, by making do with currently held consumer durables, and by being more selective in overall expenditures.

Rebuilding Public Infrastructure

Just as corporations commonly provide direct capital goods for a particular enterprise, government generally provides underlying support for economic activity as a whole, be it sewers, roads, schools, or other services. Any given piece of this infrastructure will eventually require replacement, either because it becomes obsolete, is inadequate, or wears out.

In many parts of the United States and Canada there is a growing backlog of facilities that urgently need replacement and therefore jeopardize the ability of given communities to function properly. Broadly speaking, this situation might be the result of government priorities that lay elsewhere in recent years, or it might be the result of pricing policies that failed to charge users' fees high enough to provide a depreciation reserve and a return on capital.¹ Whatever the reason, the coming years will increasingly require investment in public infrastructure.

There is a tendency, when replacing worn-out or obsolete facilities, to assume that their underlying purpose remains unchanged and to concentrate on finding the best contemporary technical design. Whether new or changed demands have arisen since the facility under consideration was first put into use should be considered instead. In that way, the need to rejuvenate infrastructure not only benefits previous users but also opens up new possibilities.

Trends in Economic Development

Much research is being done in the western world in the area of economic futures. The purpose is to provide advice, for governments and others on the likely course of industrialized economies and the consequences of projected changes.^{2,3}

This section outlines expected changes in various economic sectors, since economic activity is a prime determinant of transport demand. Information about likely changes can indicate new opportunities and threats for public transportation. What follows is a fairly standard distillation of likely changes within selected, broad sectors. These are general trends only, drawn from "futures" work being done by Alberta Economic Development staff; all of the usual caveats about uncertainty, probable timing, etc., apply. This material, though tentative, does permit a better understanding of how demands for transport are likely to shift and which service characteristics are likely to command the greatest attention.

Traditional Manufacturing

Just as electro-mechanical technology replaced steam-mechanical and came to dominate factories in this century,

electronic devices and robots are now beginning to replace the electro-mechanical and are resulting in more robust industry. Two ramifications of this are worth noting: It permits much smaller scale manufacturing plants, and it results in an employment shift from the production line to design and maintenance of robots and similar equipment.

Resource-Based Industry

As their expectations and income rise, less developed countries seek higher prices for their raw materials. As a result, North America must search for indigenous resources through such means as enhanced recovery methods, the development of synthetic materials such as oil from tar sands, and the programming of substitutes such as coal for oil. Such activities involve a move to higher levels of technology and are incorporated in the material in following sections. The transport of resources is a major subject area and is beyond the scope of this paper.

Service Industry and High-Technology Goods

Developing countries require loans to buy the necessary infrastructure and other capital stock to bring themselves into the modern age. Servicing this debt requires a suitable cash flow and can be achieved only if the industrialized world buys goods from them. Their growing capability to produce manufactured items and their low labor costs combine to make the manufacture of traditional products (textiles, automobiles, etc.) increasingly attractive to the Third World.

The adoption of more advanced production methods in Canada and the United States will aid competitive performance, but we will likely see an intensification of the current shift to high-technology areas such as computers, communications, and life sciences.

Even more rapid growth can be expected in the associated software industry, i.e., research, design, application, marketing, and management activities. In this economy, information becomes the key, both as an input and an output element.

All of the above sectors show a shift toward high-technology production, goods, and/or services. Americans and Canadians increasingly will use products of high-technology plants, seek out goods of an advanced nature, and work in research, design, management, or some other service associated with these areas.⁴

DEMAND AND SITUATIONAL CONSEQUENCES FOR TRANSPORTATION

The consequences for transportation and the major locational factors for these new kinds of industry are discussed in the following sections.

Transport and Locational Elements

The term "high-technology goods and services" covers a wide field, as the preceding text indicates. Some important common elements are outlined below.

Freight Versus Passengers

The products of high-technology industries have a high-dollar value per pound, so the cost of freight is not the major determinant that it is in the resource sector. Therefore, from the standpoint of goods movement, such industries can locate virtually anywhere. Passenger transport, on the other hand, is at least as important to high-technology firms as other enterprises, and even more so for software organizations.

Contacts

The need for face-to-face contact with customers, firms, and people engaged in similar work, and with universities,

entrepreneurs, and suppliers of venture capital, is important to the operation of these industries.⁵ Although this need will decrease as communications improve, getting together with others is an essential part of the creative process on which this entire sector depends.

Setting

Although an attractive physical environment is desirable, the geographic location of raw materials and the need of traditional manufacturing plants to be close to final markets have posed constraints for many companies. Such limitations need not exist when freight costs are not a significant part of the final product price, and most high-technology groups are in attractive settings.

The small scale possible for such manufacturing plants means the firms need not service the entire continent to be efficient. Regional industries may once again become feasible. By the same token, the old multi-story facility of the compact cities of the eastern seaboard can efficiently house high-technology industry—the sprawling, single-level plant on a multi-acre site in suburbia is no longer a necessity but an option.

Another aspect of setting is significant. In a compact city, where workers can walk to their jobs or public transit can be used, the cost of commuting will be less than long commutes by automobile. Cities with rail transit have about 30 percent fewer workers who commute by auto than do other cities.⁶ Since the cost of labor is a major input factor for industry, one way to control expenses in the future is to protect the labor element from such external shifts as the rapidly growing cost of automobile commuting by workers that is passed to the firm in the form of higher wage demands.

Requirements and Constraints

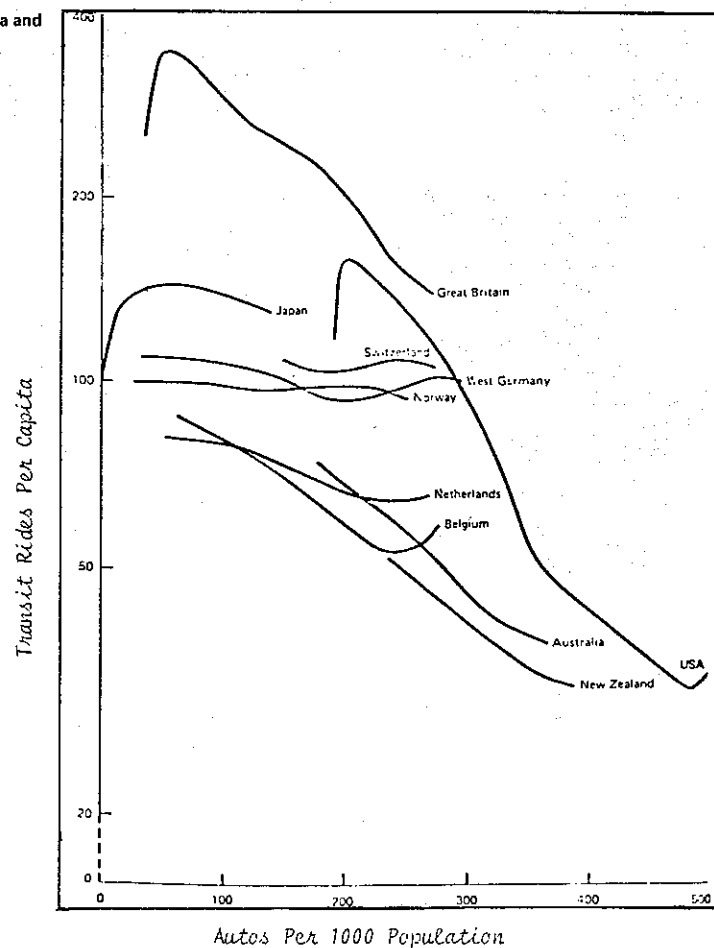
This paper set out to examine the infrastructure rebuilding question with emphasis on overall changes in the economy, to see if there were any changes that might indicate a different demand for transport infrastructure in the future. The points that reflect a likely future shift toward a high-technology and service-oriented economy and are closely related to transport issues are summarized below:

- Consumers will seek to protect their standard of living by seeking good substitutes for what they enjoy now. A good quality transit service will receive serious consideration by current car drivers.
- Government funding will likely emphasize capital spending more and operations less.
- Decisionmakers should seek joint uses in order to obtain more "bang for the buck" when rebuilding infrastructure.
- Intercity and urban passenger costs and quality will become more important due to a declining relative importance of freight costs.
- A greater need for face-to-face contact will appear.
- A quality environment will be important to cities seeking high-technology industry.

LRT AS AN INVESTMENT CANDIDATE

Important changes in the economy are developing that will affect the supply and demand factor of transport facilities and services. Before concluding that this indicates a major opportunity for the development of one form of public transport or another, the high level of auto ownership in the United States and Canada must be considered. A rational conclusion might suggest that people will choose competing goods or services according to price and perceived value, but the widespread possession of cars suggests that people will use them in preference to transit. This is not always the case. Figure 1 shows the relation-

Figure 1. Relationship between transit passenger rides per capita and level of auto ownership.



Source: The Demand for Public Transport. Report of the International Collaborative Study of the Factors Affecting Public Transport Patronage. United Kingdom Transport and Road Research Laboratory. Crawthorne, England. 1980.

ship between growth in car ownership and transit use in 10 countries. With the exception of the four English-speaking countries, transit riding in the western world held its own as automobile registrations climbed in countries usually associated with the aggressive development of high-quality public transport. The opposite has generally been the case with Britain, the United States, Australia, and New Zealand.⁷ This suggests that consumers do use public transport even in times of growing car ownership if the services offered are appropriate.

Attributes of LRT

LRT has been defined as "an urban transportation system that uses electrically powered rail cars operating singly or in short trains on fixed duorail guideways, may be grade separated, and loads passengers from low or medium height platforms."⁸ Not being a proprietary mode (like monorail systems), LRT exists in many forms and occupies a rather broad middle ground between bus and conventional rail transit. Its principal attributes as a mode are the following:

- It can bring a significant number of people together in a concentrated place.
- It can be built for much less cost than conventional rapid transit and still provide important operating savings compared to bus service.
- It can offer much of the service quality advantage

of conventional rapid transit, depending on the level of sophistication of infrastructure chosen (in-street trackage through to subway).

- It is environmentally "soft" (a busy place can be a nice place).
- It signals the permanence of service to the urban development industry by the permanence of its infrastructure (it can influence the shape of the community).

LRT can be built and used economically in low-density as well as high-density areas. Since its cost can be lower, it does not require the guaranteed high ridership needed by conventional rail transit in order to be justified. LRT excels in the following areas:

- It can link high- and low-density areas (whether homes with jobs or employers with market).
- It can provide circulation within either high- or low-density sectors.
- It can adjust the sophistication of the infrastructure as well as the extent of operations as the location, density, and ridership grow.

Matching LRT Attributes to Transport Requirements

Several cities have found the above attributes of LRT to be advantageous in their particular situation, and a number of new LRT systems have recently opened or are under

construction in North America. The demand characteristics of high-technology suggest an even greater potential for light rail in the future. Matching these demands to the salient product characteristics of LRT is considered in the following section.

Bringing People Together

Factory and retail employment has had a tendency to disperse since the end of World War II, but, unlike routine and humdrum work, creative work benefits from allowing people to meet face-to-face. Advances in communication will likely reduce such an advantage in the future, but, as does transportation, communication networks have hubs where people gather to digest and disseminate information.

Transit and downtown areas are complementary, and central business districts offer desirable locales for the software areas of high technology. Suburban sites are strong contenders for such industries, especially if adjacent to a major university. However, a suburban cluster can also be well served by LRT, especially since growing adoption of the Timed Transfer Focal Point approach to bus network layout (scheduled interconnection of several routes) can make such nodes attractive interfaces between rail and bus.⁹

Cost of Service and Transportation Productivity

Any form of public transport can bring people together at a given point, but LRT can do it for greater numbers and in greater comfort than a bus and without the high-capital cost of conventional heavy rail transit.¹⁰ LRT offers a balance that can be applied at moderate travel volumes and the kind of service quality that can attract motorists but does not require a major capital cost penalty. LRT is the only transit mode that shows a steadily declining real cost of installation, and light rail is midway between bus and heavy rail with respect to operating cost, meaning that investment can improve the productivity of transit labor.¹¹

Important economies can be achieved over a medium to long term by LRT if properly combined with urban development around stations. The productivity of light rail is not only evident in trade-offs between various transit options (bus, conventional rail) but also more fundamentally in the development of clusters of activity along a route that makes ridesharing among transit modes feasible by scheduled service and/or paratransit. The clusters also permit substitution of walking trips for vehicle trips. Corresponding economies apply to many services from mail delivery to repair services. The productivity advantage of LRT compared with buses is not as significant as the resource savings of polycentric cities (clusters) linked by a ridesharing system capable of handling high-peak loads.

Environment

The trolleybus is LRT's only equal in low levels of noise and fumes. Because LRT is built to be in scale with a streetscape, its physical presence need not be overwhelming, especially when a modest infrastructure has been selected.

But its environmental appeal goes beyond the relative absence of negative aspects: LRT is the only mode that the public regards as a positive addition to the landscape. Maclean's, Canada's national newsmagazine, described Calgary's recently opened downtown LRT transit mall this way: "Seventh Avenue has acquired a tidy, almost quaint continental ambience. Refurbished facades and the banning of car traffic have helped. But the sophistication is owed primarily to the city's silent new light rail vehicles built in Dusseldorf, West Germany".¹²

Seattle and Detroit also offer particularly striking examples of this sort. Both cities have recently installed, or are now installing, downtown streetcar lines—largely for the fun of it.

Developers know that a good urban building project is

greatly enhanced by a theme—by creating a certain atmosphere. LRT, quite apart from its transport element, can be used creatively to produce pleasing environments in which to live, shop, and work.

We are entering an era of greater emphasis on investment in capital goods, relative to personal consumption. Consumers want to preserve their present standard of living and seek good substitutes for expensive items. Governments want to shift funds from operating budgets into capital. LRT is attractive on all these counts.

Rebuilding and upgrading public infrastructure are key elements in improving a nation's productive capacity. Major transport investment presents important opportunities for light rail, since joint facilities can be more productive than single-purpose ones.

The nature of the North American economy is undergoing a basic change with a swing to high technology and service enterprises. This trend can be favorable for LRT if decisionmakers choose to accede to the demand implications inherent in such a trend.

LRT: The Declining Cost Curve

As attractive as light rail might be in light of the points presented above, any prospective use of public funds must be competed for aggressively in these tight budget times. LRT is a mode that was abandoned here for a generation and is now being relearned, partly from doing and partly from adapting practices from abroad for use in North America. We are, in effect, on the declining side of a learning curve, where successive applications can be more and more cost-effective. LRT thus stands out as the mode of transport with decreasing real costs of installation, and some of the reasons are discussed here.

Calgary, and shortly thereafter San Diego, broke a long-standing taboo in the North American traffic engineering world and opened LRT systems that use streetcar tracks for running through the downtown. Before this, new light rail systems were expected to use subways in central business districts—a far more expensive operation. The low-cost option of using existing tracks can also be considered for suburban territory, along with the use of abandoned or low-volume freight railway rights-of-way and the use of median strips of arterial roads.

Until recently all rail systems were expected to have fancy stations with tightly controlled "fare paid" areas and with ticketing handled by paid personnel or expensive, complicated machines. The adoption of self-service fares from Europe, first by Vancouver's Sea-Bus (waterborne rapid transit) and thereafter by Edmonton, Calgary, and San Diego LRT, permitted simple, unmanned stations without the cost of a driver on every car to collect fares.

Another important breakthrough came from Germany, where Linke-Hoffman-Busch (LHB) produced a diesel-electric LRT car, first for a suburban LRT line in Hamburg and more recently for an interurban service out of Graz, Austria. Similar to the cars operating in San Diego, Calgary, and Edmonton, the LHB units make it possible to build an LRT line without the expense of electrification. The cars are diesel-electric, which means that as traffic builds over time, overhead wires can be installed for all or part of a line without the need to acquire a new fleet.¹³

Some changes in traditional train control methods are opening up cost-saving opportunities. San Diego has developed an enhanced version of the normal railway block signal. Not a passive system, it includes a traffic control mechanism and makes red the normal aspect, not green. The British Columbia Railway, working with Glenayre Electronics and Transport Canada, is developing a new form of centralized traffic control—radio link control—that uses passive trackside transponders and a cab display as elements in a less costly form of train control.

These are measures that could be important to urban areas with moderate traffic volume and long travel distances, typical features of spread out, medium-sized U.S. and Canadian cities. Such low-cost measures are im-

portant not only in mature, established parts of these two countries but also in areas of rapid growth, where an expanding economy creates heavy demand for supporting public infrastructure and where several lines might have to be built at once.^{14,15}

LRT Investment and Risk Aversion

Any strategy has uncertainties. The timing and intensity of any aspect might prove different than anticipated; new elements might arise or circumstances may change; any one of a number of participants might rethink a decision. Prospects for LRT, by the assessment here or elsewhere, are no more immune from risk than are prospects for other possible transport programs. But light rail does have one advantage in this regard: the ability to be improved over time, while in service. LRT can be built now, using a minimum cost standard, and upgraded later if town development and traffic expectations are met.^{16,17}

If current passenger flow is too low or too uncertain to warrant immediate LRT construction, a right-of-way can be identified and protected against development, discontinuity through sale, and so forth. When roadways are rebuilt, structures and medians can be constructed to make future track installations possible without major expenditure.

When considering public investments, decisionmakers should be aware of the following light rail features that minimize risk:

- It can be built to the level of current need and upgraded only as and if needed.
- The system can be expanded incrementally; the initial start need not involve massive funds. Future dollars can be won by demonstration of its effectiveness.
- LRT is appropriate whether urban areas have relatively more dense and active cores or if a polynuclear form becomes increasingly dominant.^{18,19} Its design flexibility can accommodate a variety of growth patterns and can interlink a number of differing activity layouts.

SUMMARY

We are at an interesting threshold. There is a new emphasis on capital expenditure, a swing to a high-technology economy, and a consumer willingness to try substitutes. It is a time of rebuilding public infrastructure and cities and of building anew in fast-growth regions.

Light rail transit is coming of age at the right time. Its initial growing pangs are largely passed. It is on a decreasing cost curve. Its service characteristics match merging needs of Canadian and American economies.

Will it happen? Will the advantages seen in this paper for LRT be seized? They can, and will be, by decisionmakers who are encouraged to think in broad and strategic terms about urban and regional transport and who are presented with facts that demonstrate a useful range of modal choices for public investment.

REFERENCES

1. Brian E. Sullivan and Robert R. Piper. Transportation and Economic Development: The Growing Significance of the Transport Subsidy Issue. Paper prepared by the USDOT/OECD International Symposium on Surface Transportation System Performance, Washington, D.C., May 1981.
2. E.P. Neufeld. Who Will Finance Canada's Growth in the 1980's. *Econoscope*, Royal Bank of Canada, Toronto, November 1981.
3. The Reindustrialization of America. *Business Week* Special Issue, June 30, 1980, pp. 56-142.
4. Claire Starry. Growth Industries in the United States. SRI International Business Intelligence Program, Research Report 627. Menlo Park, California, 1979.
5. Facility Location Decisions. Belknap Data Solutions, Ltd., for *Fortune Magazine*. Time, Inc., New York, 1977.
6. Boris Pushkarev and Jeffrey Zupan. Urban Rail in America—an Exploration of Criteria for Fixed Guideway Transit, NTIS UMTA-NY-06-0061-80-1. Regional Plan Association for Urban Mass Transportation Administration, New York, 1980.
7. The Demand for Public Transport. Report of the International Collaborative Study of the Factors Affecting Public Transport Patronage. United Kingdom Transport and Road Research Laboratory, Crowthorne, England, 1980.
8. Transportation Research Board definition, contained in letter of 6 October 1978 from Wm. Campbell Graeb, TRB Engineer of Public Transportation.
9. Brian E. Sullivan. Route Layout Philosophy and Service Coordination Particularly for Light Rail Transit. TRB, Special Report 161. 1975, pp 26-36.
10. Peter Strauss. Light Rail Transit: Less Can Mean More. TRB, Special Report 182, 1978, pp. 44-48.
11. William H. Morris, Jr. Comparison of Busway and Light Rail Modes. TRB, Special Report 161, 1975, pp. 50-61.
12. Nationalists in the Boardrooms. *Maclean's Magazine*. Maclean-Hunter Publishing, December 7, 1981, pp. 54-56.
13. Diesel-Electric Twin-Unit Railcar. VT2E for the Railway Company. Altona-Kaltenkirchen - Neumunster, Linke-Hofmann-Busch, Salzgitter, Germany, 1980.
14. George Sternlieb and James W. Hughes. Back to the Central City: Myths and Realities. *Traffic Quarterly*, Volume 33, No. 4, October 1979, pp. 617-636.
15. L.S. Bourne and J.W. Simmons. Canadian Settlement Trends: An Examination of the Spatial Pattern of Growth, 1971-76. University of Toronto Centre for Urban and Community Studies for Canada Ministry of State of Urban Affairs, Ottawa, 1979.
16. Vukan R. Vuchic. Urban Public Transportation Systems and Technology. Prentice Hall, Englewood Cliffs, N.J., 1981, p. 308.
17. P. Appelmans, A. Lombart, et al. The Brussels Metro, *UITP Revue*, Vol. 25, No. 4, 1976, pp. 256-271.
18. John P. Kieth, Cities of the Future. In the Power to Govern. The Academy of Political Science, New York, N.Y. Reprinted 1981 by Regional Plan Association, New York, N.Y.
19. Harvey S. Perloff. Planning the Post-Industrial City. APA Planners Press, Chicago, Illinois, 1980.

Building Consensus for Light Rail: A Tale of Two Cities

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This paper summarizes the experiences of San Diego and Sacramento with light rail transit projects from inception to implementation. Differences and similarities in building a consensus for light rail in the communities and among official, decisionmaking bodies are described and contrasted. Public officials in San Diego became dissatisfied with the rail development approaches taken by planners and established a new agency and provided special funding for transit system development. The new agency accelerated the planning process and, at the same time, worked to build consensus for light rail among local officials and the public at large. Interest in light rail transit for Sacramento began with a group of citizens who wanted to improve transportation facilities and reduce the negative environmental impacts of automobile use and freeway construction. For 8 years they used a "grass roots" approach to arouse public interest and to build a pro-LRT consensus among the region's public decisionmaking bodies. No professional staff was committed to light rail during the first 5 years of this effort.

San Diego's 16-mile light rail line opened in July 1981 after an intensive 6-year effort by its proponents. This was an incredibly short development process for a fixed guideway transit system, made possible mainly by adherence to the following "principles":

- Reliance on proven, off-the-shelf technology;
- Development on an incremental basis that allowed early use of available resources and provided for upgrading when necessary; and
- Use of existing rights-of-way where possible.

Use of these principles and avoidance of federal construction grants allowed a development pace that helped to generate community consensus for the project. LRT quickly began to look like something that was actually going to happen; it created a bandwagon effect that galvanized community leadership to support LRT. With the formation of the Metropolitan Transit Development Board in 1976, a full-time professional staff was created to get the project built.

In Sacramento it took longer for elected officials to get interested in light rail. A pro-transit citizen's group—the Modern Transit Society (MTS)—was formed in February 1975, and the first elected official—a city councilman—was persuaded by them that LRT was advantageous later that year. LRT was included in formal alternatives studies over the next 4 years, but it was not until these were concluded, in 1981, that a majority of elected officials were convinced of LRT's feasibility. No professional staff was engaged in the LRT effort until 1979 and it was only one individual.

The example set by San Diego was of great assistance in Sacramento. Soon after professional staff was hired, policymakers approved essentially the same principles noted above, which helped focus debate in Sacramento and allowed clearly unworkable options (e.g., full rapid transit, monorails, and people movers) to be cast aside—a step fully supported by the MTS.

Essentially, the facilities now operating in San Diego and being engineered for Sacramento have much in common. The development of consensus for their construction, however, has been quite distinct in each case. Influential public officials provided the nucleus of support in San Diego; while in Sacramento, dedicated citizens worked for years to build consensus for LRT.

THE SAN DIEGO EXPERIENCE

In San Diego, interest in any alternative to the automobile was limited until the 1973-1974 gasoline shortage. However, the passage of Proposition 5 in June 1974 provided the real incentive to plan a fixed guideway system, since the San Diego legislation was unique in that it "banked" the diversion funds for a 5-year period.

The ensuing rush to fixed guideway planning in San Diego encompassed studies of a multi-billion-dollar, heavy rail proposal (local COG); an extensive, expensive street rail proposal (county); and an exotic, elevated people mover (city). None of these attained a high degree of community acceptance, but each of the studies identified common, high-capacity corridors and focused local attention on the need to begin to develop an alternative.

The creation of the San Diego Metropolitan Transit Development Board (MTDB) consolidated responsibility for transit development, transit planning, and allocation of all transit funds in the southern portion of San Diego County in a single agency. The agency was not required to assume day-to-day responsibility for operating existing transit providers. The policy board selected was composed of local elected officials and one member appointed by the Governor of California.

The MTDB policy board's early, well-known skepticism of any form of rail transit was probably an accurate reflection of the attitude of most elected officials in San Diego County. In retrospect, it helped MTDB's credibility in the community, since any proposed solution first had to overcome that attitude. It also led to the establishment of a small but highly motivated staff, supplemented when required by loan staff from the city, the county, Caltrans, and the California Public Utilities Commission. This loan staff, by ensuring continuous monitoring and input, helped eliminate interagency planning and construction conflicts.

Shortly after its formation, the MTDB policy board adopted the "principles" previously mentioned to help weed out, at an early stage, alternatives unsuitable for San Diego. These principles were understood so well by the community that they lent credibility to alternatives that survived their test. An unanticipated benefit of the principle process was the virtual elimination of additional, unnecessary criteria when an acceptable solution was within reach.

Another early policy decision—to avoid any attempt to seek federal funds—was initially regarded as an impossible hurdle but did much to ensure the success of the planning effort. The decision to "go it alone" was very popular in the community; it set an early and absolute budget ceiling that dictated planning for a simple solution—one that could be achieved within that absolute budget. Light rail transit was the only alternative able to meet this stringent criterion.

Generally, corridor selection was a relatively easy task, since it was really little more than a consolidation and verification of work previously performed to support earlier studies. To identify and adopt an initial segment was much more difficult, and conflicting recommendations were made to the policy board by the consulting engineer (Bechtel) and the MTDB staff. The staff recommendation prevailed and, while generally undesirable, the conflict and its resolution did much to establish the credibility of the MTDB staff with the public and concerned agencies.

The selection of LRT resulted from the Board's principles and the established budget ceiling. However, as those were being developed, the Board undertook two study tours that dramatically increased its understanding of what

transit could do in the community. The first was a 1-week tour of North American transit operations, and that was followed by a 1-week European tour. These tours resulted in the formal adoption of the LRT mode, and a series of formal, public Board workshops led to the adoption of most of the design elements. The Board's enthusiasm and their awareness that a project might be proven feasible also resulted. This was a radical and welcome departure from their earlier skepticism and was a turning point in the "sale" of the concept to elected officials.

Perhaps the factor that most influenced final acceptance and approval of the LRT system was an attempt by the Southern Pacific Company to abandon its 120-mile San Diego and Arizona Eastern (SD and AE) branch operation. This branch reached San Diego from the Southern Pacific main-line in El Centro through the mountains, dropped into Mexico to serve Tecate and Tijuana, then reentered the United States to connect with Santa Fe and serve cities in the eastern San Diego region. This line had been severely damaged by a storm and did not generate sufficient revenue to warrant reconstruction.

The MTDB decision to acquire and contract to operate the SD and AE in a joint mode (freight and light rail) received significant local support and provided an in-place right-of-way in the adopted first corridor. The shift to a joint use design concept was relatively simple, and although some expressed concern about the adoption of this dual use, the subsequent success of both the freight and transit operations has confirmed the wisdom of that decision.

Final adoption of the plan by the San Diego City Council followed development of its early, unanimous support by every organized group in the community. Before seeking council approval, most major businesses, the Navy, the Coastal Zoning Commission, all environmental groups, the Port District, service clubs, and the League of Women Voters had endorsed the proposal. Despite this overwhelming support, the initial hearing before the council ended with a decision deferred pending an actual contract to acquire the SD and AE at the stipulated price and the legislature's agreement to advance Proposition 5 funds.

The contract with Southern Pacific was achieved by the policy board's direct involvement in final negotiations; the necessary legislative changes were accomplished by Senator James R. Mills and Assemblyman Waddie Deddah after outstanding efforts; and the city council finally approved the project.

Within 90 days of final approval, fixed price contracts were let for purchase of the SD and AE, rails, cars, ties, special track work, and final engineering. While this was "after-the-fact," it indicates the absolute necessity to carry preliminary engineering to the point where contracts can be achieved quickly, given an absolute budget ceiling. It is why the San Diego project was completed within budget and on schedule.

THE SACRAMENTO EXPERIENCE

Sacramento's first interest in rail transit was expressed in 1973, when the long-term possibility of extending BART all the way from the Bay Area was mentioned briefly in the Transportation Element of the Sacramento County General Plan.

By 1974, growing concern over urban sprawl and its attendant problems led to protests against building more freeways. Sacramento had a basic freeway system in place by this time. The County Board of Supervisors bowed to citizen pressure in December and voted to drop several state freeway routes scheduled to be built in suburban northeast Sacramento County. This action followed two memorable hearings dominated by anti-freeway forces—the first attended by 400 people, the second by 600. The battle was waged by a coalition of community groups, including the ad hoc Carmichael Citizens' Advisory Committee, assisted by the Environmental Council of Sacramento (ECOS) and other groups who formed the ECOS Trans-

portation Committee. This nucleus grew into the Modern Transit Society (MTS).

A Sacramento branch of MTS was formed in February 1975. It worked to improve public transit—bus as well as rail. The various studies and other events they undertook are listed in Table 1.

Disposal of Northeast Freeway Rights-of-Way

In May 1975, the County Board of Supervisors appointed the North-East Transportation Task Force (NETTF), a group that included representatives of ECOS, regional and local chambers of commerce, the League of Women Voters, Regional Transit, the Central City Study Committee, labor unions, and others. The group's function was to advise the Supervisors on disposition of the abandoned route 143 and 244 rights-of-way. The Sacramento Regional Area Planning Commission (SRAPC) provided staff; the NETTF selected its own consultant. The Northeast Area Transportation Study, a major review of transportation needs in the northeast area, was the result. The area contains about half the entire metropolitan area population.

The NETTF's recommendation to the Board of Supervisors in 1976 contained several points: no major transportation use of the 143 and 244 rights-of-way; their sale to private interests; no American River bridge on the 143 right-of-way; regional priority to improve public transit and establish, with the City of Sacramento, a joint citizens' committee to determine the feasibility of developing light rail transit with Interstate Transfer dollars from the Interstate 80 Bypass. Throughout this effort, MTS members were active on the NETTF. The coalition of community groups that defeated the freeways continued to function and to work for better transit.

Historic Trolley

In 1975, two MTS members attended the first National Conference on Light Rail Transit, one as an "official" delegate of the NETTF. MTS used the knowledge acquired at the conference to develop the first MTS rail proposal for Sacramento—a "bare bones" historic trolley loop in the downtown area—that could be expanded and upgraded to modern LRT and extended, as needed, to serve suburban areas in the northeast and Folsom corridors. This idea was advocated in an MTS paper, "Downtown Historic Trolley Loop and Initial Light Rail Service in Sacramento."

In 1975, City Councilman Lloyd Connelly became the first elected official in the region to take active interest in what has become light rail. A year later a majority of council members voted to match SRAPC funds needed for a formal feasibility study of the historic trolley concept.

This effort, the "Historic Trolley—Sacramento; Feasibility Study," was completed by Wilbur Smith and Associates in 1977. It determined that the trolley would be feasible.

The Interstate 80 Bypass

One proposed freeway, the Interstate 80 (I-80) Bypass, remained on the planners' maps. This was planned in the mid-1960s to relieve congestion on the existing Route 80, Sacramento's original freeway, built shortly after World War II. Caltrans recommended the Bypass because it would be cheaper to build it than to reconstruct and widen Route 80. Development along the freeway made land acquisition costs prohibitive.

The I-80 Bypass was not completed by 1969 and was therefore subject to the National Environmental Policy Act. The required environmental impact statement was delayed during the 1970s; in 1976, the NETTF pushed for a restudy of the I-80 Bypass. This effort ran from 1977 to 1979 and evaluated 11 alternatives, including completion of the I-80 Bypass, reconstruction of Route 80, high-occupancy vehicle lanes, and light rail transit. Numerous public workshops were held in neighborhoods along the I-80 By-

Table 1. Key Dates Leading to Adoption of Transit.

Year	Event
1974	Deletion of Planned Northeast Sacramento freeways (Routes 65, 143, and 244) by Sacramento County Board of Supervisors
1975	Formation of Modern Transit Society (MTS) and publication of its proposal for historic trolley in downtown as basis for initial LRT system
1976	Northeast Area Transportation Study (NEATS), leading to call for sale of freeway 143 and 244 rights-of-way and development of LRT in the Interstate 80 corridor
1976	Passage of referendum in Sacramento County allowing up to 25 percent of county's state highway funds to be spent on fixed guideway transit projects (local implementation of Article XIX of California Constitution)
1977	Historic Trolley—Sacramento, Feasibility Study
1977	Passage of SB 885, amending the Regional Transit District Act to allow RT to seek a sales tax increase
1978	Start of Interstate 80 Multi-Modal Corridor Study reevaluating I-80 Bypass freeway
1978	Completion of Sacramento Multi-Destination Transit System report, setting transit development principles—artery and local access routes linked through timed transfers at transit centers
1978	Decision to undertake Folsom corridor light rail study, negotiated by Modern Transit Society (MTS) with public agency staffs
1979	Adoption of Regional Transit General Plan calling for restructuring of RT system around artery routes, timed transfer transit centers, and local access routes
1979	Completion of I-80 Multi-Modal Corridor Study and decision by Sacramento City Council to recommend withdrawal of the I-80 Bypass freeway from the Interstate system
1979	Defeat of Measure C by Sacramento County voters (44 percent in favor), which would have added ¼ percent to sales tax for transit
1980	Completion of Folsom Corridor Rail Feasibility Study determining feasibility of LRT and its desirability compared to other options
1980	Start of Northeast Sacramento Alternatives Analysis
1981	Completion of Northeast Sacramento Alternatives Analysis and selection of a 19-mile light rail transit line extending through both the I-80 and Folsom corridors as the locally preferred alternative

pass. MTS members attended every meeting, responded to antirail and antitransit statements, and kept a close watch on the project staff planners who were, at best, skeptical. The MTS and members of other community organizations (League of Women Voters, Lung Association, ECOS, etc.) also attended every meeting of the policy committee overseeing the study and effectively lobbied its members. The policy committee (city council members, county supervisors, RT board members, and a Caltrans official) voted in September 1979 to recommend (1) withdrawing the I-80 Bypass from the Interstate system and (2) making a more detailed evaluation of the HOV and LRT concepts in a Phase II alternatives analysis. The recommendations were adopted by the Sacramento City Council and approved by the Governor of California and the United States Secretary of Transportation.

Transit System Development and Funding

Expanded bus service from the City of Sacramento into Sacramento County began in 1973, when the Sacramento Regional Transit District (RT) was formed. The transit fleet increased from 120 to 225 buses and was funded by the Transit Development Act passed by the state in 1971. Rapid growth in the region continued, and a further doubling of the bus fleet was envisioned. To obtain funding for it, at the end of 1976 a Transit Financing Task Force recommended an increase within the county of the state sales tax. SB 885, authorizing RT to seek such a tax, was passed by the state legislature in 1977.

At the same time, RT and SRAPC began the work that led to adoption of a general plan for RT's further development. In February 1978, RT appointed a Citizens General Plan Advisory Committee, and this group introduced and advocated the timed transfer principle, first suggested by MTS in a 1976 newsletter. This idea was at first resisted by RT staff, but new members of RT's planning department embraced the concept.

The first transit center began operating at Florin Mall in 1979, featured revised bus routes, and included a limited stop express line to downtown Sacramento. The changes have proved successful; connection reliability is 98 percent. This success has established the credibility of the MTS.

Transit development plans in Sacramento received a setback in November 1979 with the defeat of local ballot Measure C, which sought approval of the 0.25 percent local sales tax authorized by SB 885 in 1977. Although 44 percent of the voters favored the tax, it lacked the two-thirds majority required by Proposition 13, passed in 1978. The measure's defeat has left Sacramento with limited transit operating dollars. Such a fast growing metropolitan area requires increased transit capacity and must therefore increase the productivity of its current resources. The RT solution is the restructuring of the current system as outlined in the general plan but without the planned expansion of neighborhood bus routes. The limited stop express routes upon which downtown traffic planning is being concentrated must operate with the aid of maximum transit technology.

The entitlement that resulted from withdrawal of the I-80 Bypass freeway gives the region the capability to make the major capital investment in transit that will put this more efficient technology in place on the Northeast Sacramento arterial routes. It was with this background that the Phase II alternatives analysis was begun in 1980, although it had a year 2000 planning horizon. It was assumed that, by then, transit service could be doubled.

Folsom Corridor Study

At the time the Phase II work in the I-80 corridor was starting, a state-supported study in the Folsom corridor was concluding. This work, the "Folsom Corridor Rail Transit Feasibility Study," found that LRT, with feeder

buses and park-and-ride, would be technically feasible and more workable in the area east of Sacramento than other options studied (HOV lanes and freeway widening). It also found that Folsom corridor facilities had been relieving congestion in the I-80 corridor; therefore, further studies should evaluate both corridors simultaneously.

MTS first suggested an LRT line to California State University, Sacramento, in its 1975 paper (above). In 1978, the Director of Caltrans, Adriana Gianturco, endorsed the idea in a letter to Sacramento Mayor Phil Isenberg. Gianturco agreed with Councilman Connelly and the MTS that the historic trolley idea, updated to modern light rail transit, should be considered and extended beyond the downtown area to California State University (about 4.5 miles) and beyond.

This study started in April 1979. A Policy Advisory Committee was appointed by RT to oversee the Folsom corridor work. It was chaired by Connelly and included representatives from the City Council, County Supervisors, RT Board, and Caltrans. An MTS member also was appointed to the study's Technical Advisory Committee.

Northeast Sacramento Phase II Alternatives Analysis

Early in 1980, RT's rail planner was selected to manage the Phase II alternatives analysis for Northeast Sacramento and loaned to SRAPC for that purpose. The start of the analysis overlapped the Folsom corridor study; because of the corridor's demonstrated value in relieving congestion in the I-80 area, it was decided to expand the Phase II study to include both the I-80 and Folsom corridors.

This expansion was a key topic in several neighborhood workshops held during project "scoping". MTS continued to monitor the study and, as it neared completion, began to plan a major campaign to build broad support for LRT.

This effort received a substantial boost from the new RT general manager, who had been in charge of the San

Diego LRT project. Faced with limited operating resources and growing transit needs in an era of inflation, he endorsed the need for higher transit productivity and convinced a new RT board to support development of efficient LRT trunks in Northeast Sacramento. Working with the MTS, a Community Task Force for LRT set out to build community consensus for the project, and by the time the Northeast Sacramento Draft Environmental Impact Statement was circulated (April-June 1981), their campaign was successful. The community was nearly unanimous that LRT should be selected and that it should be built in both the I-80 and Folsom corridors as a through route. The decision received 10 of 11 votes from the study's policy committee, 8 of 9 from the City Council, and unanimous votes from the RT Board and the Sacramento Area Council of Governments (SACOG, formerly SRAPC). Workshops and public hearings were attended by MTS members and representatives of other community organizations. A high point occurred when the Sacramento Board of Realtors president followed a Sierra Club representative and commented that it was probably the first time the two organizations had agreed on an issue. Another high point was the Central Labor Council speaker's self-introduction as representing "the 80,000 organized workers in greater Sacramento". Resolutions and letters of support for LRT were received from 46 community organizations, and 5,000 area residents signed a petition circulated by the MTS.

Since the spring 1981 decision, additional planning has been under way to set the final alignment in neighborhoods where community concerns needed to be addressed. Sacramento congressmen have worked to ensure funding for project engineering during 1982, and a joint powers authority, including the city, county, RT, and Caltrans, has been formed to design and build the project. The community was pulling together again to convince UMTA that authorization to begin LRT preliminary engineering should be granted.

LRT Development: State Perspective

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San Diego has received considerable attention for its imaginative deployment of light rail transit technology and for its decision to eschew federal funds and rely on state and local revenues to meet the capital and operating requirements of the LRT system. California's commitment to funding urban transportation encouraged the Metropolitan Transit Development Board (MTDB) to pursue a policy of fiscal independence. Equally important was the legislature's assignment of powers and responsibilities to MTDB. A product of state and local politics, MTDB represented a rejection of the nationalization of urban transportation policy of the past 20 years. Indeed, MTDB's success raised questions about the wisdom of a national policy that sought to bypass state governments in its efforts to achieve a national urban transportation policy and ignored the fiscal capability of state governments to support programs and moderate conflicts, and the state's authority to constitute local agencies. MTDB may serve as a model for a reformed national urban transportation policy that would give priority to state governments in urban transportation policy formulation and not seek to specify organizational arrangements for carrying out urban transportation planning. This paper describes the role of California's state government in the evolution of MTDB and its LRT system. It concludes with some remarks regarding federalism.

In 1971, California's Governor Reagan signed the Transportation Development Act (TDA) which established a transit funding program that has since produced \$2.1 billion for funding and operating public transit in the state. The program sets aside 0.25 percent of sales tax revenues and permits the funds in urban areas of the state to be used for public transit; in the nonurban areas funds may be used either for transit or for local streets and roads. Although the state legislature establishes guidelines, the revenues are identified as local and are returned to the county of origin for allocation. The program offers certainty of funds and opportunities to develop transit programs. The funds are allocated by regional transportation agencies (in federal parlance, MPOs).

Another funding decision was a constitutional amendment approved in June 1974 that permits gasoline tax revenues, previously constitutionally reserved for highway construction, to be used to construct rail transit systems but not to purchase rolling stock or subsidize operations. The amendment requires a local election be held to authorize a county to participate in the program. Nine counties, including San Diego, have made that decision. A state statute implements the amendment and allows the equivalent of up to 25 percent of the state highway revenues spent in a county to be allocated for guideway construction.

In 1974, regional transportation planning in San Diego was supervised by the Comprehensive Planning Organization (CPO). Because of San Diego's single-county urban-area status, the activities of CPO, by agreement of local agencies, were regulated by the San Diego County government; however, as development pressures mounted and because the county was viewed as an overly dominant force in local politics, the members of CPO, by means of a cooperative agreement, separated the agency from county government in 1973. In 1974, on the basis of several years' planning effort, CPO recommended a \$2 billion, high-capacity exclusive right-of-way, urban rail transit system for San Diego. The magnitude of this proposal created uncertainty in the community.

In response to the CPO proposal and to the funding opportunity presented by the constitutional amendment, legislation was introduced to create the San Diego Metropolitan Transit Development Board. The legislation

- Assigned to CPO long-term transportation system planning, including identification of travel corridors, definition of land use goals, and recommendation of priority corridors for guideway development;
- Assigned to MTDB near-term operational planning, including determination of funds available for transportation development, selection of transportation technology, and determination of routes, performance criteria, and station locations for guideway systems;
- Assigned to MTDB responsibility for allocating all state funds in its area of jurisdiction, including operating subsidies;
- Identified MTDB as the designated recipient;
- Assigned to MTDB responsibility for near-term, 5-year transportation planning and for development of the annual Transportation Improvement Program;
- Assigned to MTDB responsibility for building and operating transit guideways, provided off-the-shelf technology is used; and
- Designated 10 percent of the TDA revenues to offset the cost of MTDB's operations if San Diego County's allocation of guideway construction funds could be set aside for up to 5 years while MTDB explored the feasibility of developing a rail transit system.

Two extremely important decisions were made during the legislative process. The first concerned the San Diego region. It was clear to the legislature that in San Diego County there was no countywide or regional consensus regarding transportation development. The areas of the county outside metropolitan San Diego wanted out of the plan, and thus "metropolitan" was added to the title.

The second decision, linking multiagency planning, programming, and allocation of revenues with the authority to operate transit services, was made in order to ensure accountability. A perceived error in the development of San Francisco's BART system was superimposing it on the existing transportation system. To avoid this, the transit operators and city and county street and road personnel would need to join forces so that realistic decisions could be made about transportation investments, the assumption being that accountability is directly linked to the authority to operate a public service. To assign such important elements as planning and allocation of resources to non-operating agencies diminishes accountability of public agencies, although not the public's expectation of accountability. Therefore, MTDB was assigned the responsibility both to plan and to operate the transit facility.

In essence, MTDB was constituted to take advantage of funding arrangements in state law, to accommodate the political culture of San Diego, and to draw on the lessons learned from another transit development experience in California.

FEDERALISM AND MTDB

MTDB's enabling legislation did not escape notice. Agreement between CPO and MTDB was imperative, and the two agencies achieved agreement in a memorandum of understanding that continues to regulate their interaction. Both agencies sought UMTA's opinion of the arrangement and the administrator had no choice but to approve the memorandum of understanding. He concluded his letter of approval with a curious note, however:

The Federal Government does not regard this arrangement as a binding national precedent in any event. We will consider such arrangements on a case-by-case basis as they may be presented to us.¹

That remark implies that the federal government has the right to approve a state's decisions regarding the organization of substate jurisdictions. There is no constitutional foundation for such an assumption, although perhaps the federal government can establish national precedents for organizing urban transportation development processes. The administrator simply had no concept of American federalism. He viewed the system as an administrative hierarchy, not as a noncentralized political system with many independent centers of power.

State and local governments are not middle and lower layers of a national administrative hierarchy. Constitutionally, state governments establish local political systems within their jurisdiction. Perhaps, in the spirit of federalism, national transportation development policy-makers should consider states as creators of institutions, interpreters of political culture and norms, and financiers capable of raising revenues that serve to meet certain national transportation priorities. The issue and options paper on metropolitan transportation planning, issued in November 1981 by UMTA and FHWA, mentioned no alternate strategies for taking advantage of the unique role of state government. It simply reiterated what already exists and did not examine what might be done to encourage a greater state role.

For years the national government has sought a coherent transportation policy process in urban areas but has been frustrated by its inability to comprehend local arrangements. The political and administrative relationships among local jurisdictions result from state actions, and the necessary reforms can come only from state government. Perhaps this should be reflected in federal policy.

The Metropolitan Transit Development Board is a good example of the vitality of federalism. Federal policy should encourage state and local institutional and fiscal support and not worry if a "binding national precedent" is being created. In drafting the bill, the state legislature forged an innovative instrument on the basis of established funding, programmatic planning, and accommodation to local political factors. MTDB has responded with vigor and imagination.

REFERENCE

1. Letter from Robert E. Patricelli, UMTA Administrator, to the Chairman of the CPO Board of Directors and the Chairman of MTDB, dated May 24, 1976.

A Long Track: Hiawatha Avenue, Minneapolis

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Transportation corridors in many areas of the United States have been under study for many years. The Hiawatha Avenue corridor, linking downtown Minneapolis with the airport, has been studied since the late 1950s, and the current Environmental Impact Statement/Alternatives Analysis is the third major period of examination. The appointment of citizen members to a task force and agency members to a technical committee has produced unusual acceptance of the results. The roles of citizens, agencies, and the private sector are described and their impacts evaluated. This paper emphasizes the relationship of transportation design, development type, and public policies and discusses the role each played in arriving at an acceptable solution. It identifies the lessons learned and their possible adaptation to use by others.

Hiawatha Avenue (Minnesota Trunk Highway 55) is a substandard, at-grade, 40-ft-wide, arterial roadway running between downtown Minneapolis and the International Airport, a distance of 6 miles. The history of planning for the upgrading of Hiawatha Avenue extends over 20 years. Since 1963 there have been three major efforts to resolve the transportation issues, including the effort described here. The major events of this period are included in Table 1.

STUDY ORGANIZATION

The success of any project depends on its organization. Because improvements to Hiawatha Avenue could affect such a variety of areas—downtown, residential areas, neighborhood businesses, parkland, and the International Airport—careful consideration was given to the Hiawatha Avenue Study's organization and its determination process. The study's organization is shown in Figure 1.

The history of the corridor and the previous planning within the area suggested the structure of the study. The structure had to be clear to allow involvement and provide a means to receive early warning of possible misunderstandings and conflicts. There are four formal decision-making groups for the Hiawatha Avenue Location and Design Study: the City of Minneapolis Policy Board; the Study Management Team; the Hiawatha Avenue Task Force; and the Hiawatha Avenue Technical Committee. Each group is described below.

The Minnesota Department of Transportation appointed the City of Minneapolis the lead agency for the study. Final approval of the study's formal recommendations rests with the City Policy Board, comprised of the Mayor, the City Council President, and the Transportation and Property Services Committee Chairman.

The City Engineer, the City Planner, and the Project Manager manage the study, assisted by the consulting firm of BRW, Inc. Three subconsultants are also involved in the project. The Project Manager and the consultants represent the Study Management Team and work directly with the Hiawatha Avenue Task Force and the Technical Committee. The Project Manager also meets frequently with the City Engineer, the City Planner, and the Property Services Committee Chairman to inform them of the study's progress and receive their comments and recommendations. This provides a communication path for all levels of the study's participants.

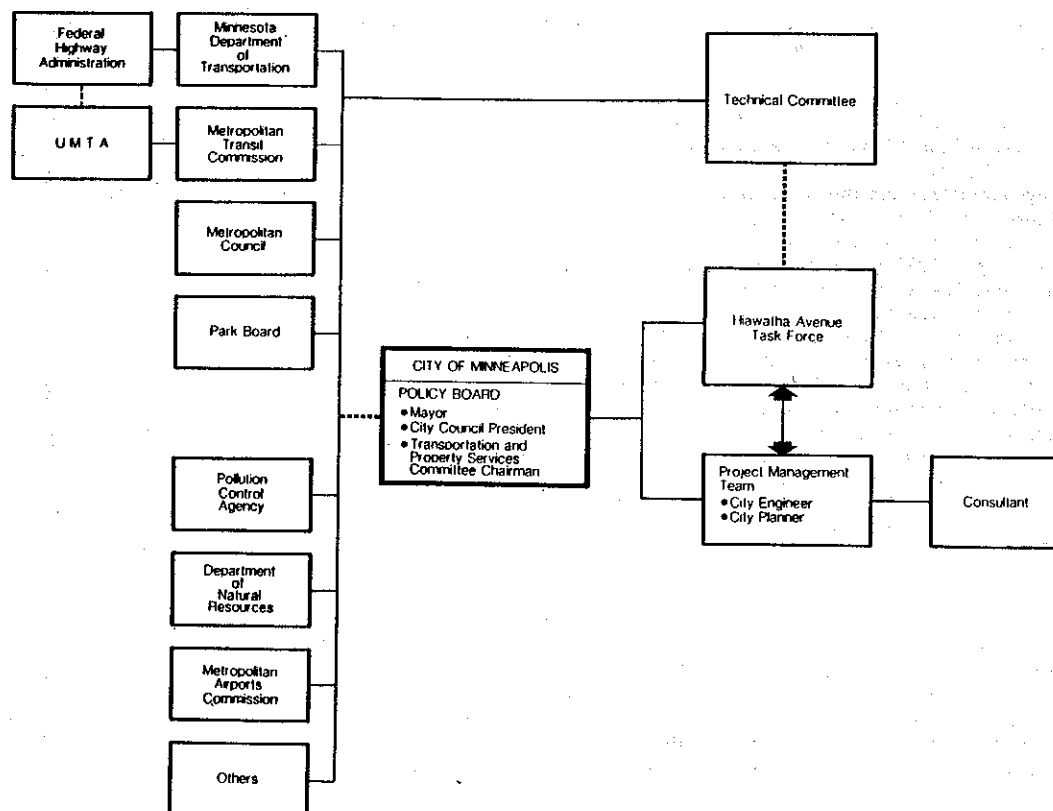
The Hiawatha Avenue Task Force (HATF) was established by a City Council resolution of September 29, 1978. HATF's purpose is to recommend to the city a transportation solution for the Hiawatha Avenue corridor. The 28 delegates, alternates, and the Chairperson all represent neighborhoods, businesses, and labor organizations in

Table 1. History of Hiawatha Avenue planning.

Year	Event
Prior to 1960	Eighteen studies performed on various locations and design alternatives for a major roadway in south Minneapolis.
1963	State legislation passed enabling city to issue bonds and advance \$10 million to the state to acquire right-of-way and for construction of TH 55 in Hiawatha corridor.
1967	State prepared Alternative Route Study Report that addressed three alternatives: route through Minnehaha Park, route west of the park, and route through the park with a tunnel between Crosby Place and 42nd Avenue. Minnesota Highway Commissioner's right of eminent domain over lands of the Park Board was upheld by the State Supreme Court.
1972	Environmental Impact Statement for TH 55 rejected by Federal Highway Administration (FHWA) because it did not satisfy federal requirements.
1974	Minneapolis City Council rescinded all previous plan approvals for the Hiawatha Avenue project. U.S. Public Law 93-643 authorized \$53 million in federal funds to be appropriated for the reconstruction of Highway 55 from Franklin Avenue to CSAH 62 (Crosstown Highway) as a demonstration project. The federal share of the total project cost was specified to be 90 percent.
1975	Minneapolis City Council appointed Hiawatha Design Advisory Committee. After numerous meetings and considerations, this committee recommended building an arterial roadway with land reserved for transit. Later minority reports filed with the City Council.
1978	A total of \$2.25 million was appropriated in the 1978 Federal Appropriations Act for preliminary engineering studies for reconstruction of TH 55 between Franklin Avenue and 59th Street. Minneapolis City Council disbanded Hiawatha Design Advisory Committee and established the Hiawatha Avenue Task Force to formulate recommendations and provide advice and assistance to the City of Minneapolis in its role as lead agency for the project.

the corridor area. Nine HATF members are women, 19 are men. Their ages range from 23 to 73; their occupations include engineer, homemaker, and laborer. Over half the delegates and alternates represent their neighborhood councils; nearly one-fifth represent area businesses; and

Figure 1. Study structure.



one-fifth represent labor; the others are at-large representatives. The HATF evaluates the information and alternatives provided by the study's staff, considers proposals offered by members of the community attending task force and public meetings, and then makes recommendations and decisions regarding possible transportation improvements to Hiawatha Avenue.

The Technical Committee members represent city, metropolitan area, state, and federal agencies. The committee reviews the recommendations and decisions made by HATF with respect to each agency's policies.

The recommendations and decisions of HATF and the Technical Committee are documented and presented to the Transportation and Property Services Committee of the City Council for approval. Throughout the study, participating agencies respond to recommendations of the decisionmaking groups. The involvement of the participating agencies—Policy Board, Study Management Team, Task Force, and Technical Committee—and the approval process for the decisions has led to an acceptable recommended transportation system for the Hiawatha Avenue corridor.

COMPONENTS OF AN IMPLEMENTATION STRATEGY

During the planning process, the HATF concluded that the recommendation of a transportation solution only for the corridor did not constitute a complete implementation strategy. The task force felt that developmental impacts and public policy recommendations were required as well. Thus, the implementation strategy includes a preferred roadway, a preferred transit solution, recommended public policies, and a developmental impact statement. Each of these is discussed below.

Roadway/Transit Alternatives

Early in the study the task force and staff listed perceived roadway and transit options for Hiawatha Avenue; permutations of these options produced 120 alternatives. To

identify the preferred solution from among these, a 4-step scoping of the alternatives was used. Each of the steps, or "screens," addressed specific alternatives that could be compared at a particular level. A set of 30 goals and objectives prepared by task force members provided the major criteria for evaluating the alternatives being addressed. From the results of the scoping process, the task force selected five roadway and transit alternatives to be studied in detail in the EIS/AA. There were four recommended transit service improvement alternatives and one recommended roadway improvement alternative; when combined, they make up four separate "build" alternatives. The fifth recommendation for detailed study was the "no-build" alternative.

Listed below are the alternatives considered in the EIS/AA. Subalternatives (not shown) deal with treatment of the build alternatives through Minnehaha Park, LRT distribution in the Minneapolis central business district (CBD), and the LRT south terminus location under Alternative 4.

Alternative No. 1	Roadway:	Four-lane at-grade arterial
	Transit:	High occupancy vehicle lanes—at-grade
Alternative No. 2	Roadway:	Four-lane at-grade arterial
	Transit:	High occupancy vehicle lanes—grade separated
Alternative No. 3	Roadway:	Four-lane at-grade arterial
	Transit:	Improved bus service and facilities
Alternative No. 4	Roadway:	Four-lane at-grade arterial
	Transit:	Light rail transit (LRT) system
Alternative No. 5	Roadway:	No improvement
	Transit:	No improvement

Figures 2 through 5 give a conceptual illustration of each of the build alternatives.

Public Policy Options

For analysis purposes, three public policy options are defined that would result in different land use scenarios and population/employment levels within the Hiawatha corridor:

1. **No Public Sector Involvement Scenario.** This option implies that there would be no measurable local government assistance to facilitate development beyond the comprehensive planning process. The land use impact of this existing policy would be similar to the impacts previously associated with highway construction, without significant governmental assistance to facilitate development around interchanges.
2. **Limited Public Sector Involvement Scenario.** This approach refers to modest government participation in the development process in the form of limited policies to facilitate transit-oriented new construction. In this policy option the local government acts as an expeditor to facilitate development but is not directly involved in the development process; little or no capital investment is required from the government entity. This option represents the low-cost public policy option for local governments. Policy changes commonly associated with this scenario include comprehensive planning, special district and planned unit development zoning, and station area design standards and criteria. All require minimum public sector investment but create a more positive atmosphere for attracting developer interest.
3. **Active Public Sector Participation Scenario.** Substantial public sector participation involves strong governmental policies to improve and coordinate development of transportation improvement areas. These policies include, but are not limited to,

Figure 2. Alternative 1 concepts: 4-lane roadway with HOV lane at grade.

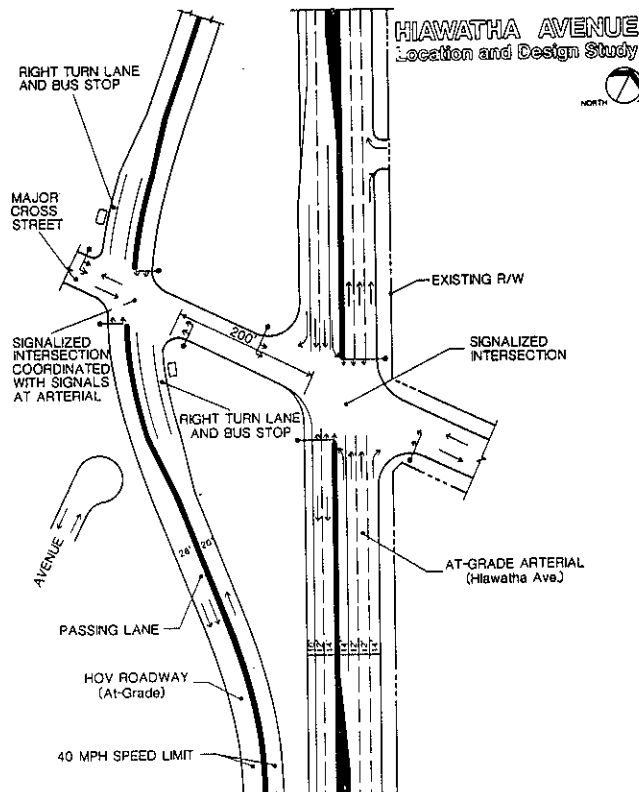


Figure 3. Alternative 2 concepts: 4-lane roadway with HOV grade-separated.

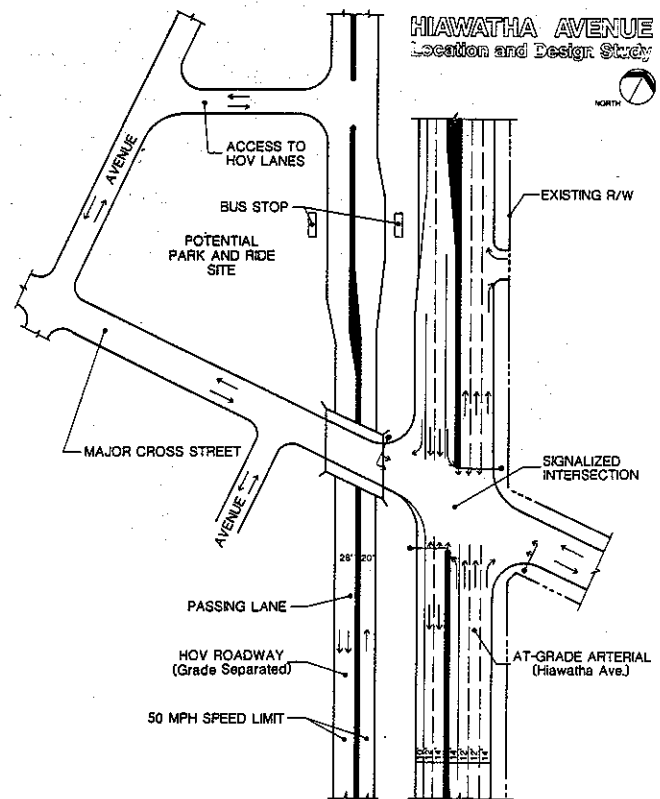
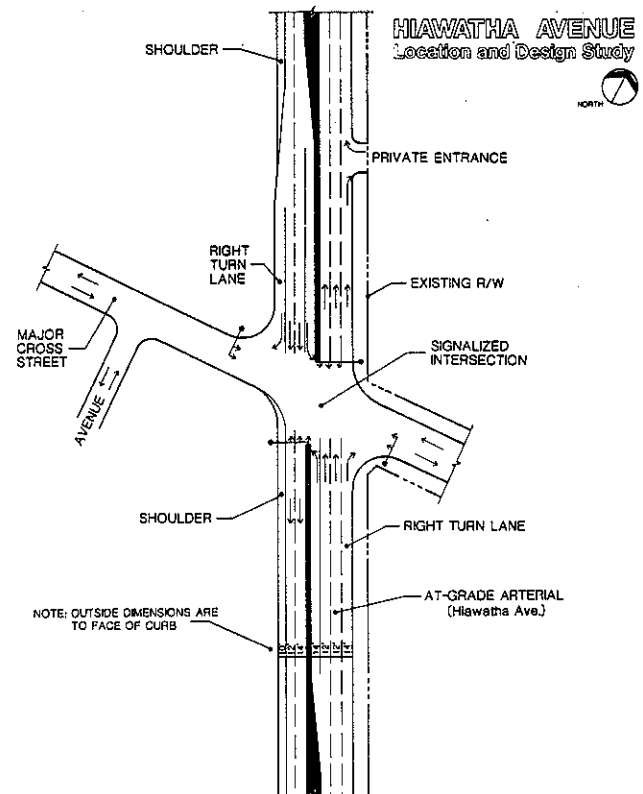


Figure 4. Alternative 3 concepts: 4-lane roadway.



- Supplementary purchase or condemnation of land;
- Tax increment financing;
- Equity participation;
- Institution of corridor development corporations;
- Property tax abatements; and
- Special assessment districts.

These policies require from the local jurisdictions financial and political commitments that provide significant incentive to potential private sector investors. Active involvement by the local government can help provide development impetus where minimal interest previously existed.

Figure 5. Alternative 4 concepts: 4-lane roadway with LRT partially at grade.

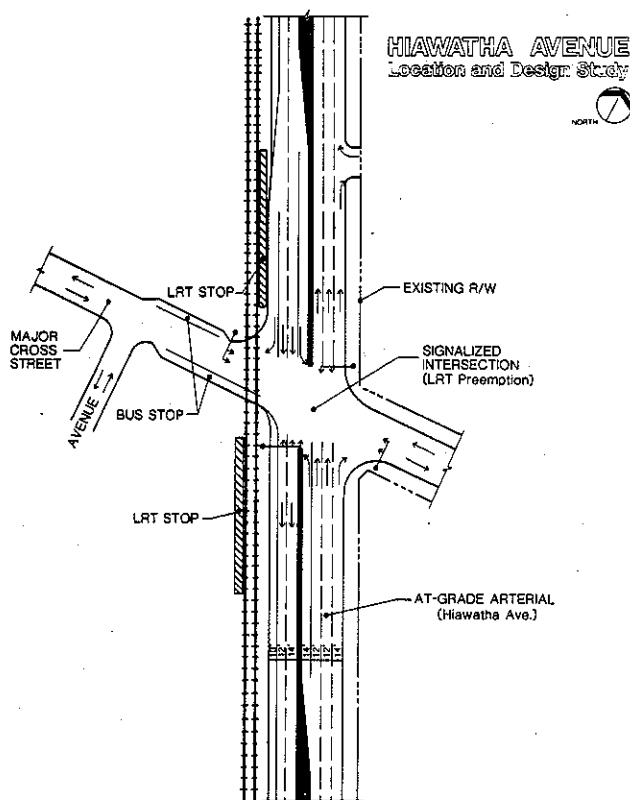


Table 2. Year 2000 employment estimates for Highway 55 walkshed corridor.

Option	Alternative 5 (No Build)	Alternative 3 (Arterial)	Alternatives 1 & 2 (Arterial/HOV Lanes)	Alternative 4 (Arterial/LRT)
No public sector involvement	33 496	33 833	33 833	35 833
Percent change over no build		1.0	1.0	7.0
Limited public sector involvement	33 496	33 833	33 833	36 833
Percent change over no build		1.0	1.0	10.0
Substantial public sector involvement	33 496	33 833	35 833	39 833
Percent change over no build		1.0	7.0	18.9

Developmental Impact

Tables 2 and 3 illustrate projected impacts of the various transportation improvement and public policy options on Hiawatha corridor population and employment. Projections are provided for the year 2000.

Comparison of alternative projects shows that large incremental changes result from inclusion of major improvements in the transportation system and active governmental participation in the development around the transportation facilities. Population and employment increases estimated to result from the inclusion of these transportation improvements are typical of increases experienced or recently estimated in similar corridors in St. Louis, San Diego, Baltimore, and Portland. The increases are relatively modest and are likely to be concentrated in areas near the transit station or interchange. There are corridor locations with sufficient vacant land to facilitate this projected growth; however, development will require the public and private sectors to work together to take advantage of these potentials.

ROLE OF PROJECT PARTICIPANTS IN PLANNING PROCESS

The role of each major project participant in the planning process is described in the following.

Hiawatha Avenue Task Force

The HATF has already been described. Its charge from the City Council is to develop a transportation recommendation for the corridor. It also serves as the direct link to the community.

The HATF has the highest public-interest rating of any group in the study. This is natural since the task force represents the people that live in the corridor. The attitude of the task force is that they are "tired of the lack of action for the past 20 years in the corridor, they want the roadway improved, and they want a long-range transit solution that will be a stimulant to help maintain a viable community."

Every decision of the task force has been unanimous; they have worked hard to resolve differences and to reach compromises. The chair and vice-chair have made presentations to the City Council, the Park Board, the Transportation Advisory Board, and numerous neighborhood groups. All general public meetings are run by the chairperson of the task force. The general attitude of the group is that they have worked hard, understood the issues, compro-

Table 3. Year 2000 population estimates for Highway 55 watershed corridor.

Option	Alternative 5 (No Build)	Alternative 3 (Arterial)	Alternatives 1 & 2 (Arterial/HOV Lanes)	Alternative 4 (Arterial/LRT)
No public sector involvement	71 991	72 991	72 991	77 491
Percent change over no build		1.4	1.4	7.6
Limited public sector involvement	71 991	72 991	73 891	78 491
Percent change over no build		1.4	2.6	9.0
Substantial public sector involvement	71 991	72 991	76 891	83 991
Percent change over no build		1.4	6.8	16.7

mised, and will present and lobby for the recommended transportation plan, land use plan, and public policies.

There would be no planning process without the task force; the process is designed around their needs. They have demonstrated the ability to make decisions; their remaining task is to present and "sell" their decision to the City Council and other approving bodies.

Hiawatha Avenue Technical Committee

The HATC is composed of representatives of the following public agencies: FHWA, UMTA, Minnesota Pollution Control Agency, Minnesota Department of Transportation, Metropolitan Council, Metropolitan Transit Commission, Metropolitan Airports Commission, Hennepin County, University of Minnesota, City of Bloomington, City of Minneapolis, and the Minneapolis Park Board.

The function of the HATC is to monitor the incremental decisions of the HTAF to ensure that they are consistent with the policies of the permitting and/or approving agencies. Thus, the focus has been to review the work of the task force and provide appropriate feedback. For example:

- Some members of the technical committee were reluctant to drop the freeway alternative but took no action, and results of the scoping process were accepted by all members of the technical committee.
- The original geometric design for the roadway portion of Hiawatha had an at-grade intersection between a county freeway (CR 62) at the southern end of the corridor and Hiawatha Avenue. The county wanted an interchange; after discussion, the design was changed to include an interchange.
- At the start of the study implementation of the LRT alternative was contrary to the policies of the Metro Council, and the staff obviously noted this condition. However, since the Council was studying LRT feasibility in the region, they did not object and, in fact, encouraged the study of LRT in the corridor.
- The UMTA representative expressed concern that no regional system plan had been completed and that funding might be a problem. This condition was recognized by the HATF.

To date the contribution of HATC members to the planning process has been positive. Suggested alterations to study results have all been incorporated. The real test of the contribution will come when the project is formally pre-

sented before each agency represented on the technical committee.

Mayor and Council of the City of Minneapolis

The majority of the elected officials of the City of Minneapolis did not participate in any of the events prior to the 1978 formation of the Hiawatha Avenue Task Force. The Mayor had limited involvement in activities before 1978.

City Council involvement was fairly low-key the past 3 years; the Mayor maintained a neutral position. Two aldermen who represent areas in the corridor showed some interest, mainly demonstrated by their monitoring of the study. The City Council viewed the study as important so that the corridor could be reconstructed and redeveloped. However, the council's discussion of LRT has not been enthusiastic. This feeling is primarily related to the cost of LRT and funding uncertainty and is reinforced by actions of the present national administration.

The involvement of the Mayor and City Council in the planning process has been controlled. They have listened, but played a limited role, predominantly reactive. They have not been specifically encouraging or discouraging.

Minneapolis Downtown Council/Greater Minneapolis Chamber of Commerce

The Downtown Council (DTC) is an organization representing businesses located in the Minneapolis Central Business District (CBD). The greater Minneapolis Chamber of Commerce (C/C) represents businesses throughout the entire Minneapolis area. Each group has a committee that deals with transportation issues. In the past 2 years the C/C has increased its interest in the CBD and in its emphasis on transportation.

The DTC's stance was positive until mid-1981, when members became uneasy about LRT penetration into the CBD, and this attitude makes the possible acceptance of LRT more difficult. The DTC has been helpful in attempts to modify the fixed-guideway prohibition planning policy.

The C/C has been very helpful since it began the study of the transportation issues in 1980. It has quietly but vigorously pursued the idea of building a single LRT line to demonstrate its operational and financial capability and encouraged the Hennepin County Railroad Authority to continue its effort toward the construction of an LRT mode of transportation. It has assumed a coordinative role that should help Hiawatha and the area as it looks toward LRT.

Metropolitan Transit Commission

The MTC members are appointed by the Metro Council, which also approves the MTC budget and ensures that it is consistent with adopted regional policies. There are eight commissioners and a voting chairman appointed by the governor.

The MTC primary focus is operating the existing bus system efficiently; involvement in implementing an LRT line is not a high priority.

Federal Elected Officials

The study area is in the 5th Congressional District of Minnesota, so most interaction has been with that office. The two U.S. Senators and the representative of the 3rd Congressional District, which has the southern terminus, have also shown interest in the study.

The 5th District Congressman has given close attention to the study. He has had reservations about the value of LRT as a transit concept and concern about the costs of construction and the availability of funding. The other elected officials have expressed appreciation for the information, but await the results of the study and the community's desire before committing themselves to any action, although they all want to resolve a transportation issue that has been around for 20 years.

Federal Agencies

Several federal agencies are involved, but only UMTA and FHWA have been involved continuously.

UMTA's position reflects the federal government policy of "no new rail starts." This makes it difficult to ensure that the EIS will be acceptable, particularly the alternative analysis. When the study started, UMTA was an active participant; since the change in federal policy, however, communication has decreased. The FHWA has actively participated in the study. The local office is staffed by professionals who have helped by interpreting rules quickly and clearly. They encouraged UMTA to take

part in the study effort and helped the Minnesota DOT change a bridge design at 34th Avenue and I-494 to incorporate LRT if it became the recommended transit alternative.

The present administration's lack of clarity in the areas of alternative analysis and funding makes planning a more difficult and prolonged process.

LESSONS LEARNED

The Hiawatha Location and Design Study has taught the following valuable lessons:

- Make LRT part of the total development program. Implementing the Hiawatha corridor plan must include a land use development plan and agreement on appropriate public policies to carry out the program as well as the transportation alternative. Without them, the proposal to build LRT would not have been acceptable.
- Build a broad constituent base. Community support is needed to resolve the transportation issues in the corridor. Residents of the concerned neighborhoods, local businesses, labor, the downtown business community, and elected officials must be convinced of the value of the alternative selected.
- Let neighborhood HATF representatives present the plan. Neighborhood representatives make effective advocates. They can illustrate community understanding of the issues and give reasons for their recommendations.
- Present the plan when the right external conditions exist. Five years ago the plan would not have been accepted because of conflict with regional policies. Conditions for action are favorable now: the problem has been around "too long"; part of Minneapolis is ready for significant redevelopment; and jobs and housing are important issues in the city.

Leverage--A Proposal for the Federal Role in Public Urban Transit

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The purpose of this paper is to outline the federal government's role in transit—i.e., leverage. Federal involvement in transit dating back to the early 1900s is examined to show how earlier policies contributed to the problems faced by transit operators today. The paper suggests that the federal government change its role from grantor to investor and thus leverage its funding so that the net economic benefit to the nation is greater than the federal investment and greater than if there were no federal involvement at all.

The current administration in Washington has made drastic changes in funding for urban mass transit. Its policies are based on two major philosophies: the superiority of the free market and the decentralization of power from Washington to state and local governments. Both philosophies contradicted the current system of federal spending on mass transit.

Government subsidy to industry is contrary to the free market philosophy: businesses should be run without government intervention; the nation's transit companies once were profitable enterprises and should remain so; transit should continue to operate only on routes where a profit can still be made. Although the fundamental idea—to reduce an unwieldy, inefficient central government—is sound, we believe that this philosophy to public transit is naive and ill advised.

This paper outlines a role in transit that clearly belongs to the federal government—i.e., leverage. It discusses problems faced by transit operators today caused by federal policies and programs that interfered with financing mechanisms, devastated the supply industry, and created inflation in the cost of labor, construction, and procurement. The federal government has been involved in the transit industry since the early days of the street-railroad industry, and before its involvement ends it has a

responsibility to undo the problems it created and to help put the industry back on its feet.

This paper discusses some policies and programs that could help achieve these goals. The government should stop acting as a "grantor" with giveaway programs and assume the role of "investor." Through leverage, a small outlay can produce large benefits or cost savings to the public transit industry.

CURRENT STATE OF TRANSIT

Financial Condition

The public transit industry in America faces a widening gap between revenues and operating costs. Recent budget cuts and the phase-out of federal operating subsidies will increase this gap. Although a recent phenomenon, subsidies have become an important revenue source for financially troubled transit agencies and for local governments that face revenue shortages of their own.

Over the past 10 years, government subsidies increased from 19 percent to 59 percent of total transit revenue.¹ This increase reflects policy decisions, made at all levels of government, that transit systems contribute to the public good and should not be abandoned. As fares were kept low and operating costs increased, in 1974 the federal government agreed to provide operating assistance. The federal share, 21 percent in 1975, quickly jumped to approximately 30 percent and held steady at that level.¹

Subsidies have plugged the growing gap between revenues and expenses, but that gap is now widening because fares have held steady or decreased when measured in uninflated dollars. Transit costs, particularly labor costs, have grown at so much faster a rate than the general rate of inflation that many commentators and legislators are beginning to reconsider the subsidy program. They claim that transit is not a public responsibility; that it is a poorly run private enterprise that does not compete with the automobile; and that if it cannot pay its own way, it deserves to fail.

Such claims ignore the fact that public transit in this country has never paid its own way, even when it had a virtual monopoly on intracity transportation. In its early period it relied on investor/owners who derived indirect benefits other than profit from ownership.

The first of these were land speculators, such as Henry Huntington of southern California. His Pacific Electric Railroad was financed by the sale of subdivisions at the end of its rail lines. Land buyers thus supplied construction capital and a sure source of ridership for the system when it was built.

This was true of many streetcar systems at the time when electric cars were on the rise. However, around the turn of the century, revenue from the regulated 5-cent fare was not sufficient to keep pace with the rising operating costs, similar to the situation today.

Between 1902 and 1917 the wage bill of American Transit companies increased by some 256 percent while revenues increased by only 179 percent. Many transit operators became bankrupt during this period, unable to meet operating costs and interest payments on their borrowed capital.²

The next group of investors to subsidize the street-railroad industry were the electric utilities.

Most electric utilities were, during the first quarter of this century, publicly regulated such that they could not show a return on their investments greater than some fixed percentage. With the markets for electric power expanding rapidly and producing growing income, they sought outlets for investment of their capital which would insure a steady demand for electric power while enabling the utilities to show only

limited short-term profits. Because public transit operations were in need of capital, and utilized electric power almost exclusively, the match seemed a perfect one.²

In 1935, this marriage of interests was dissolved by the Public Utility Holding Company Act, a law intended to break up utility trusts; allow more competition for electricity, gas, water, and transit; and reduce the utilities' influence over these industries. A side effect was to send the transit industry into a wave of bankruptcies and financial problems.

The transit industry became less and less profitable and was high on the list of targets for divestiture. Provisions of the Act allowed the utilities to sidestep the political issues inherent in abandoning an unprofitable industry and concentrate their resources in areas with a better return. Without such provisions, municipal governments and citizens dependent on streetcars and transit systems would have made it impossible for the utilities to give up their transit holdings. The Act may have had some short-term benefits for increased competition, but overall it was devastating to the transit industry.

Automobile use began to cut heavily into transit ridership during this period as well, with two results: it decreased revenue and the resultant automobile traffic hampered streetcar service. The electric railway operators recognized the problems and sought solutions. One was to develop a faster, more agile car; another was to scrap rail lines and replace them with buses. Consequently, suppliers in the bus industry became the next group to rescue transit operators from financial ruin through holding companies such as National City Lines:

By 1939, National had acquired some 29 transit systems, financed almost entirely by stock shares sold to General Motors, Firestone Tire & Rubber, and, through its subsidiaries, Pacific (later American) City Lines, to Phillips Petroleum, Standard Oil of California, and Mack Manufacturing Corp. By 1947 (the date of the anti-trust indictment) National controlled 46 transit companies, including major operations in Los Angeles, Miami, Philadelphia, Oakland, St. Louis, Baltimore, San Diego, Providence, and Rochester.³

For such companies, the attraction of transit investment was largely the tax advantages to be gained. They could purchase an obsolete, worn-out capital investment at a fraction of its book value and write it off at a higher amount. As with the electric utilities, they also gained a secure market for their products.

The arrangement did not last, however. Once the transit systems were modernized and converted to buses, the tax advantages were lost. And, in 1947, the federal government instituted antitrust action against National City Lines and GM. By the mid-1950s they had divested themselves of most of their transit operations:

With private investors to take over these ailing transit companies, and faced with the prospect of total abandonment of transit service, many municipalities reluctantly became the owners of public transit operations during the fifties and sixties.

Municipalities have, in recent years, continued to operate many uneconomic transit routes which had been successively handed down from land speculators to public utilities to automotive industry holding companies and finally to public ownership.²

Public ownership has not significantly changed the profit situation in the transit industry. The industry has always been in financial hot water and was at the brink of abandonment and bankruptcy three times, only to be saved

by investors whose interest was served by transit's survival. It has always needed such infusions of outside capital and a means to dilute its operating losses with income from a more profitable, associated industry. Those who call for the transit industry to pay its way with fare revenues have not taken into account those who have subsidized it from the start.

Physical Condition

Equipment maintenance is a serious problem in the transit industry. Only things critical to daily operations can be funded. Unfortunately, preventive maintenance is neglected, which has caused severe deterioration of vehicles and fixed facilities. The rail operators face the worst problems. They have more equipment to maintain and more complex vehicles to operate. For example, the maintenance problems in Philadelphia are becoming extreme:

On a fall day in 1979, of the 220 Broad St. subway cars, only 26 were available for service. For months, numerous trains were routinely cancelled, and express service had been ended. Ridership was declining.⁴

Other U.S. rail transit systems cite similar experiences. Maintenance costs in an inflationary economy can be expected to increase. However, rail transit maintenance costs have risen faster than inflation, primarily because of escalating labor costs. Federal regulations, discussed later in this paper, have contributed to the situation.

Both light rail and heavy rail vehicles are now more through modern technology, particularly electronics and automatic control. Some of these sophisticated additions aim at reducing operating costs by increasing fleet efficiency. However, more complex equipment demands a more skilled maintenance staff but, because funds are short, transit authorities are unable to hire or train the skilled staff needed to maintain the new equipment. Scheduled funding cuts can only exacerbate the problem.

Transit Equipment Market

Compared with other industrial and commercial markets in the United States, the market for transit equipment is neither rich nor healthy. For example, the Budd Company, which is German owned, is the only surviving American company that produces rail cars, and it produces no light rail cars. The market for light rail cars is small (Table 1), and long periods elapse between orders. The demand for heavy rail cars is larger but occurs in peaks. No manufacturing industry can survive a sporadic market, and both light rail and heavy rail car business is now going to foreign concerns that do not depend solely on the American market.

Figure 1 shows that rail car prices have escalated almost twice as fast as those for other rail equipment. Mora⁵ shows that this effect is constant with a number of different transit procurements, suggesting that the causes are not specific to local conditions.

These problems are national and the federal government contributed to their cause. For example, capital funding for new rail cars was made through grants. These were made with no indication that future grants would be forthcoming, so transit authorities tended to place large single orders—to get the vehicles while the getting was good.

The federal government could help stabilize the rail transit vehicle market through ongoing grants or guaranteed loans to transit operators, who could then guarantee to purchase a specific number of cars each year. This would provide a stable base for the supply industry and provide a basis for standardization of equipment. It would reduce, or at least slow, the escalation of car prices. The net cost to the federal government would be less than the overall reduction in costs that could be realized—significant savings leveraged.

OTHER FEDERAL INTRUSION

The federal government has always assumed a major role in the transit industry. Some of its actions in the industry's

Table 1. Light rail vehicle market, 1980-2014^a.

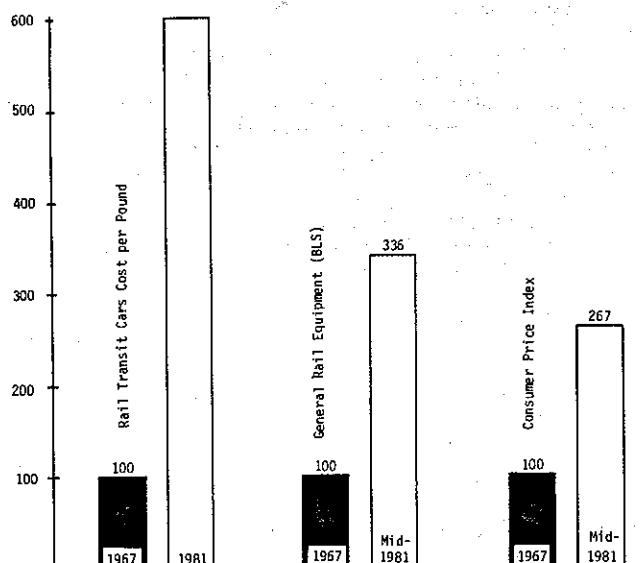
Transit Authority	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	Totals
Existing Systems:								
(Replacements)								
GCRTA	48					48		96
MBTA	75 ^b				135	75		205
MUNI	15			100		15		130
PAAC	55					55		110
SEPTA	148		148		141			437
NJT	15					15		30
Totals	356		148	100	276	208		1 008
New Systems or								
Expansions:								
NFTA	35					35		70
Tri-Met	26					26		52
SEMTA								
Totals	61					61		122

^a25 year lifetime for LRVs is computed from date of placement in service.

^bReflects 75 cars to be ordered during the period 1980-1981.

^cNot yet defined.

Figure 1. Comparison of cost growth, 1967-1981.



early years were intrusive and destructive. Although in the past 20 years, through UMTA, it has served as investor of last resort, there are still areas where federal encroachment has harmed the industry.

Antitrust Suits

The federal government instigated antitrust actions against utilities and automotive companies, which were the last private industries to invest in transit companies. These actions eliminated major capital sources for the transit industry and ultimately forced it into the public sector.

The divestiture also took away the management expertise the utilities provided and created a vacuum in the transit companies' upper management level.

Labor Regulations

Labor regulations imposed by the federal government as conditions to aid have increased transit costs. Section 13(c) of the Urban Mass Transportation Act protects the interests of transit employees affected by federal transit grants. Specific clauses require "protection of collective bargaining rights, the protection of individual employees against a worsening of their positions with respect to their employment; assurances of employment to employees of acquired mass transportation systems and priority of reemployment of employees terminated or laid off."⁶

This section of the Act has become very controversial, since it may have strengthened transit unions. Certainly transit salaries have increased much faster since public takeover. Some 48 percent of the increase in operating costs between 1967 and 1978 is due to cost-of-living increases for transit workers.⁷

Two other provisions of Section 13(c) have affected the industry. Some labor-saving innovations that might increase productivity have not been adopted because of the job protection provisions of the Act. Also, the industry must maintain such obsolete work practices and inefficient work rules as overstaffing rail cars and banning part-time bus drivers.

Another labor regulation, the Davis-Bacon Act, has directly influenced the cost of new rapid transit systems, busways, and other capital projects. It "requires that highest prevailing union wage rates be paid to workers on federally aided construction projects."⁸

UMTA Regulations

UMTA regulations have also contributed to the transit systems' operating deficits, most notably the requirement for access for the handicapped. Section 504 of the Rehabilitation Act of 1973 demands that all main-line, fixed transit facilities be accessible to wheelchairs. Compliance with this regulation was recently suspended, but while it was in effect its cost was high.

Another federal requirement that has affected operating revenues relates to the elderly. "In order to utilize federal operating assistance, transit operators must permit riders over 65 to ride at half-fare during off-peak hours."⁸ Off-peak hours have only light loads and are money-losers, and thus this requirement may have contributed to deficits.

CONCEPT OF LEVERAGE AS THE FEDERAL ROLE

The federal role in urban transit is sure to change. The policy of the current administration is to end operating assistance. Beyond that, the country's economic situation may not allow federal support in many areas where it has become common. Unfortunately, the transit industry does not have the political power to maintain its current funding level. If providing transit service is again regarded as a local responsibility, the federal role in transit will be to leverage its funding so that the net economic benefit to the nation is greater than the federal investment and is greater than if there were no federal involvement at all.

The concept of leverage—that the output, or final result, must be greater than the input, or investment—is a simple formula that determines all budgeting in the free market. There are certain areas to which the government can apply this formula and achieve results that would not be possible without its assistance. The following are examples:

- Research and development,
- Testing and demonstration,
- Standardization,
- Technical assistance, and
- Financial programs and incentives.

Research and Development

The benefits of research and development (R&D) programs conducted at the local and state levels are limited. With funding so critical, it is probable that few funds will be allocated for R&D at the local level.

Many problems are common to all local transit operations, and properly directed R&D can solve them—not only technical problems but also social and economic problems. For example, rail car costs have outstripped those of general rail equipment by 76 percent (Figure 1). Mora⁹ shows that the factors causing these cost increases might be controlled if better understood. The potential benefits of a detailed study and possible solution of the cost escalation problem are enormous. Rail car prices are approaching \$1 million per car. New York recently received bids for approximately \$800 000 per car. The 76 percent difference is about 43 percent of a rail car's cost. At \$800 000 each, this amounts to about \$348 000. If only one-fourth of this difference could be saved, it would amount to \$87 000 per car. The total possible savings on the 2640 light and heavy rail cars that will be purchased in the 1980s is \$230 million, \$36 million of this for light rail.

The rising cost of rolling stock is just one sphere where the potential savings are staggering. The cost of transit facilities construction and how it compares with similar, nontransit construction should also be examined.

Transit equipment often causes the greatest problems, and poor management, worn out equipment, and poor maintenance are blamed. Better management methods and better training and motivation of maintenance personnel are topics for research that have a high payoff potential.

No industry can afford technological stagnation. If

properly applied, technology has the potential not only to save money but to transform an entire industry. To ignore the need for technological R&D in transit would doom the industry's future. Electric-powered light rail transit does not depend on the petroleum supply. Research has developed power distribution systems to use the regenerative power produced when cars are decelerating. The Japanese have experimented with flywheels in stations that store braking energy and return it when the train accelerates to leave the station. Another, simpler application uses regenerative energy to heat water and sells the hot water to commercial or residential complexes along the transit route. Reduced energy consumption and energy independence are not just local issues.

The U.S. government has never helped finance private development of transit equipment. U.S. industries must compete for the domestic market with foreign companies backed by their governments. It is not unusual for foreign governments to subsidize private R&D efforts, but this practice is forbidden here. When an American company uses government funds for R&D it must agree to share the results, and no smart businessman is going to share any new idea that can give him an edge in the market.

A private and government joint R&D effort is a good example of leverage. To the U.S. transit operating industry, such a partnership could mean a domestic source of needed equipment; to the transit equipment industry, it could mean new jobs and a chance to compete in foreign markets.

Testing and Demonstration

The testing and demonstration phase is an area of product development where a partnership between government and industry would be both valuable and necessary. Many transit equipment improvements have been developed without federal funding. However, they must be tested and demonstrated in demanding, everyday transit operations. This is often too costly for transit authorities and their suppliers.

In the mid-1960s Westinghouse developed its Skybus automated people mover system. Only now, over 15 years later, is it finally being built to be demonstrated for transit service, and then only after competitive award. Based on this experience, no prudent management would budget private R&D money to develop light rail equipment in the United States. Any further reduction in government funding for product testing will discourage private investment in such development.

The need for an ongoing test and demonstration program is shown by problems that were encountered with recent procurements where new designs were specified. The trucks for the New York R-46 cars are one example; cracks in the suspension system of the Grumman bus are another. Many problems encountered with the SLRV at Boston were resolved and subsequently benefited San Francisco. (In effect, the early purchases in Boston served as a test program for San Francisco.) A proper test program for these new designs might have averted costly consequences.

Standardization

Since 1970, UMTA has led the rail transit industry in efforts to develop standards. It is important to understand that this cannot be done on a local level. Only with transit authorities and industry working as a team will standards be achieved. As with R&D and testing programs, the benefits are great, but the costs are too high for the operating and supply industry alone.

Some achievements to date in rail standardization that benefit the whole industry are the development of standard procurement terms and conditions, a model rail car guarantee/warranty,² and a light rail transit car specification guide. A Service Evaluated Products List was also developed—a "Consumers Report"—that relates the experi-

ence of transit authorities with certain rail car subsystem equipment. UMTA's Transit Reliability Information Program (TRIP) provides a unique reliability data base.

McGean¹⁰ shows that the potential benefits of standardization more than justify UMTA's involvement. For example, the standardization program will reduce the cost of new transit cars in the following ways:

- By simplifying the procurement process;
- By facilitating joint car buys by two or more transit authorities; and
- By reducing the costs of major car subsystems such as motors, compressors, and air-conditioning.

Analysis shows that joint car buys could save \$17 to 24 million per year,¹⁰ and subsystem standardization could save approximately \$6 million per year.

Standardization can reduce the need for large inventories of spare parts, the lead time for ordering new parts, and the cost of parts. This can effect a potential overall saving of about \$6 million per year.

Standardization can improve reliability. The savings from a reduced rate of failure can be from \$2.8 to 10.2 million per year,¹⁰ and the improvement to operating productivity can be even greater.

Rail car standardization can save \$30 to 50 million per year. The UMTA rail car standardization philosophy is based on industry self-regulation. Clearly this is an area where the concept of leverage will work.

Technical Assistance

As discussed earlier, the federal government helped create the current state of transit in the United States and, thus, now owes the industry the technical assistance it needs to overcome its difficulties.

Areas of technical assistance are as follows:

- Develop improved management, operations, and maintenance methods and procedures through grants.
- Develop and conduct training programs for transit management, operating, and maintenance personnel.
- Study specific cost escalation problems.
- Reduce and/or eliminate federal regulations that contribute to cost escalations.
- Develop federal regulations that favor cost reductions.
- Sponsor programs where transit authorities can meet to work toward a common goal (an example is the Authorities Conference Committee, the ad hoc group of light rail authorities that participated with Pittsburgh during its vehicle specification development and provided important review input to the Light Rail Transit Car Specification Guide).¹¹

Financial Programs and Incentives

Although the applications of leverage already discussed can be valuable, the transit industry's most urgent problem is financial. If the federal government withdraws operating funds, transit authorities must find help elsewhere. Local government revenues may be too low to maintain the same level of service. The federal government can provide incentives that will elicit other public and private local commitment. The local/federal matching capital grants program is one form, and there are others not yet tried.

The Department of Housing and Urban Development offers a grant program with leverage as its focus. The Urban Development Action Grant (UDAG), designed specifically to implement several urban policies with a minimum of federal funding, judges applicants partly by their success at leveraging. The less federal funding required (as a percentage of total investment), the better. HUD officials

look for a ratio of 3 to 1 or better in a successful application.

The UDAG program works because it is not concerned with normal budgeting and funding. It is a small pool of federal money available to anyone who wants to go out, do some leg work, get some commitments, and come back with a suitable application. No other program in the field of urban transportation is comparable to it.

Operating assistance parallels the block grant concept: a sum of money is given with no strings attached except to account for how it is spent. Capital grants are categorical; i.e., a host of conditions must be met, including alternatives analyses, Buy America, and E&H accessibility. To date, no grant is tied specifically to leverage.

Adding leverage to the capital grants program as another categorical condition is not proposed here. A grant with a small portion having leverage as its main criterion and available only to communities who could demonstrate its efficient application is a possible approach.

An earlier section of this paper proposed a federal loan program that might provide loans directly as well as loan guarantees. This, coupled with the Economic Recovery Tax Act of 1981, might create a strong incentive for local commitment of tax revenues. The biggest problem in lease-back sales is finance.

Because the government has been partly responsible for the rise in operating deficits, it could provide a financial incentive to reduce deficits. This might be matching actual cost savings by local transit authorities that reduce deficits and do not reduce services. The recipient authority would agree to use the federal incentive payments to improve productivity by providing more services and/or improving its capital plant.

These incentive finance programs have the potential to leverage local commitments. The loan program would provide the greatest amount of leverage, because the only costs to the government are administrative and the time cost of money. The incentive plan to reduce deficits could be applied only until a local commitment is made to fill the gap left by ending operating assistance.

CONCLUSION

The federal government is partly responsible for the current state of transit and consequently has the responsibility to help find solutions, especially if it plans to cancel its previous programs that worked toward these solutions.

A concept has been proposed in which the federal government acts as the lever to gain local funding commitment, to induce investments by industry to develop better products, and to encourage operating cost savings. Federal involvement is based on a simple qualification: The

benefits to the nation must be greater than the investment.

REFERENCES

1. American Public Transit Association. *Transit Fact Book 1981*. Washington, D.C., APTA, October 1981, pp. 46-47.
2. James Ortner and Martin Wachs. "The Cost-Revenue Squeeze in American Public Transit," *Journal of the American Planning Association*, Vol. 45, No. 1, January 1979.
3. Richard J. Solomon and Arthur Saltzman. *History of Transit and Innovative Systems*. Springfield, Virginia, National Technical Information Service, PB-199 408, March 1971.
4. Robert Roberts. "Transit Hardware: Shift to Renovation," *Modern Railroads*, October 1981, p. 44.
5. Jeffrey G. Mora. "Factors Affecting Railcar Costs." Paper for the Third National Conference on Light Rail Transit, San Diego, March 1982, p. 5.
6. Urban Mass Transportation Act of 1964 as amended through February 5, 1976. Washington, D.C., U.S. Department of Transportation, Urban Mass Transportation Administration, p. 21.
7. James E. Sale and Bryan Green. "Operating Costs and Performance of American Public Transit Systems," *Journal of the American Planning Association*, Vol. 45, No. 1, January 1979, p. 24.
8. Alan Altshuler et al. *The Urban Transportation System: Politics and Policy Innovation*. Cambridge, Massachusetts, The MIT Press, 1979, p. 45.
9. Jeffrey G. Mora. op. cit., p. 12.
10. Thomas J. McGean, Dwight B. Eldredge, and William H. Frost, N.D. Lea & Associates, Inc. *Benefits of Railcar Standardization UMTA-IT-06-0229-82-2*. Washington, D.C., U.S. Department of Transportation, Urban Mass Transportation Administration, 1982, pp. 2-5.
11. C.P. Elms et al., N.D. Lea & Associates, Inc. *Light Rail Transit Car Specification Guide, UMTA-MA-06-0025-81-4*. Washington, D.C., U.S. Department of Transportation, Urban Mass Transportation Administration, December 1981.

Feasibility Criteria for Light Rail Transit

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The evaluation of rail technology as a potential component of regional transit systems has been the subject of extensive studies throughout the country in the past decade. Particular interest has developed in the last few years with respect to light rail transit. In 1980, the Minnesota Legislature directed The Metropolitan Council, the regional planning agency, to conduct a feasibility study on the deployment of LRT in the Twin Cities. For the study,

feasibility was defined as "the ability of an LRT line to achieve regional transportation goals in comparison with other transportation alternatives." This paper describes the feasibility criteria developed in the Twin Cities to evaluate a proposed project. A dichotomy was established between qualifying and nonqualifying criteria. The minimum are those conditions that would have to be met to make a project feasible for further evaluation.

Light rail transit is being employed or proposed in several North American cities as a partial solution to urban transportation problems. It is regarded as a compromise between continued dependence on buses and larger investments in heavy rail. LRT also requires a greater capital investment than buses and an operational commitment for at least 20 to 30 years to justify the investment in right-of-way, infrastructure, and vehicles. This long-term commitment challenges the decision process and creates the need for a thorough evaluation, including the development of feasibility criteria.

Rail technology as a potential component of the Twin Cities regional transit system was the subject of extensive and controversial studies during the early 1970s. The result was the adoption in 1976 of an all-bus regional transit plan that explicitly excluded "fixed guideway for the exclusive use of transit" before 1990. Since 1976, however, several factors—rapidly rising bus operating costs, increasing use of public transit, and the possible future scarcity of petroleum products—have made high-capacity, less labor-intensive modes such as LRT increasingly attractive.

In 1980 the Minnesota Legislature directed the regional planning agency, the Metropolitan Council, to conduct a feasibility study on the use of light rail transit in the Twin Cities Metropolitan Area. This mandate required the Council to determine the conditions necessary for LRT to be feasible, and thus emerged the need to define feasibility and to develop feasibility criteria.

Generally, feasibility refers to whether an action under consideration is "desirable, achievable, suitable, advisable, appropriate, or political."¹ Based on this definition, feasibility could be determined only by considering alternatives other than the one under study, so a series of alternatives to LRT was developed. It was also clear that the feasibility of any proposed public investment should be measured against the goals and policies established by the community to be served. Therefore, the feasibility of installing an LRT line in the Twin Cities was defined for the study as "the ability of an LRT line to achieve regional transportation goals in comparison with other transportation alternatives."¹

The following regional transportation goals were considered:

- To provide metropolitan residents with good accessibility to regional and subregional opportunities;
- To provide residents of the Urban Service Area² with efficient, convenient, and attractive choices of transportation to both regional and subregional opportunities;
- To utilize transportation to strengthen the two downtowns or Metro Centers of Minneapolis and St. Paul;
- To coordinate metropolitan transportation services and investments with other metropolitan services and investments in order to determine priorities on the basis of overall metropolitan needs and the ability of the area to support these services and investments over time; and
- To provide transportation facilities and services that produce positive impacts on the social, economic, and physical environment and conserve the supply of metropolitan energy sources.

Feasibility criteria are needed to evaluate alternatives. The alternatives to LRT, such as bus improvements, trolley buses, and heavy rail, all entail trade-offs between capital costs, operating efficiency, environmental impacts, and land development effects. Criteria are required to compare these alternatives and determine which one has the best combination of characteristics. The criteria should either explicitly state the necessary result or define the values that are applied in the decision. Values that can be quantified—that provide a numerical

estimate for comparison or qualification—are easy to define when assessing feasibility; for instance: "LRT is feasible if its operating costs are less than those of the alternative" or "LRT is feasible if it can carry more passengers in the peak hour than another alternative." Those that do not lend themselves to quantification can also be used to determine feasibility, but they require the willingness to apply judgment.

Some criteria are critical to final decisions concerning actual implementation, and failure to meet them can eliminate an alternative from consideration. Excessive cost, unacceptable environmental impact, residential dislocation, or lack of citizen support are sufficient reasons for a negative determination. These vetoing criteria must be based on local goals and values.

QUALIFYING AND NONQUALIFYING CRITERIA

As feasibility criteria were developed for the Twin Cities, it became evident that a distinction must be made between two different types. While certain conditions had to be met to make an alternative feasible for further evaluation, other criteria would not be sufficient to render it infeasible. From this dichotomy, the concept of qualifying and nonqualifying criteria surfaced, and two sets of feasibility criteria for evaluation of the proposed LRT lines were developed.

Qualifying criteria are previously established regional goals that must be met. Failure to meet any of them would result in an LRT line that would not be eligible for further evaluation. Nonqualifying criteria, on the other hand, may not be met in their entirety; they serve for comparison, evaluation, and weighting purposes and as a means of identifying problems.

The disqualifying flaw in an alternative, as used here, is one inherent in the alternative that cannot be remedied. For example, an LRT line that disrupts a neighborhood and creates a barrier would not be judged infeasible if minor alignment shifts could alleviate the problem. But inadequate patronage or excessive cost to carry the line across a river could be reasons to determine infeasibility.

Nonqualifying criteria are intended primarily to rank proposed alternatives and identify potential problems associated with their implementation. In other words, these in time should establish a hierarchy among alternatives that make it possible to select one of them for implementation planning.

Both qualifying and nonqualifying criteria can be grouped into the following categories:

- Physical impact criteria,
- Transportation criteria, and
- Economic criteria.

Physical Impact Criteria

The first category relates to three physical impacts: land use, energy, and the environment. These impacts are based on an evaluation of the hypothetical construction and operation of a specific LRT line and its alternatives. Most of these impacts cannot be evaluated without decisions on specific alignment, operating characteristics, and patronage.

Land use is the most complex factor to evaluate because much of the development-related impact is projected and hypothetical. Some criteria, however, emerge as a basis for qualifying.

Neighborhood disruption is one major adverse impact of transportation improvements. Neighborhoods that consider minibuses traffic disruptive would find an LRT line, which is larger and more visible (wires, tracks, and shelters), totally unacceptable. Limiting LRT alignments to major streets and rail rights-of-way eliminates most problems, but there may be situations that require cutting through a neighborhood to circumvent major barriers (lakes, hills, etc.). In such cases (which did not exist in the

Twin Cities), criteria are needed to decide the issue. Such a criterion might be "the LRT line should not use, as right-of-way, local residential streets, as defined in the comprehensive plan for the community."

Similar criteria could be developed for such other adverse land use impacts as housing dislocation, disruptive use of park land, proximity to elementary schools, etc. In most such situations, the criteria will result in the proposed LRT line's realignment rather than its elimination, since these land uses usually can be avoided in laying out an LRT line.

There are, conversely, positive land use impacts that may become necessary conditions for building a line. For instance, in the Twin Cities, the major qualifying land use criterion was "the LRT line should serve at least one of the two Metro Centers."² This was based on the following considerations: The two centers are the primary foci of the entire transit system, LRT is the most accessible transit mode being considered, and regional goals require that such accessibility improvements focus on the two downtowns, not detract from them. On the other hand, to strengthen the two downtowns through transportation strategies is also a major regional goal, and because LRT is a relatively capital-intensive alternative, its cost-effectiveness can be achieved only along alignments with high ridership demands. It was believed that only service linked to a downtown area could generate these high levels.

Other positive land use impacts were not considered to be as critical and were evaluated using nonqualifying criteria, including service to secondary land uses. One such criterion states, "The LRT should link major activity centers and other large traffic generators to the Metro Center."² The purpose of LRT in these cases was to provide access between major population centers and the Metro Centers and use the other major centers as foci for local transit service that would both feed the LRT and serve the centers.

A criterion that caused considerable discussion was conformance of the LRT alignment to local and metropolitan development plans. The basis for concern was the circular, iterative nature of the planning process; neither LRT planning nor land development planning can be done in a vacuum. The resulting nonqualifying criterion states: "The LRT line and local metropolitan plans for development and redevelopment should be mutually supportive."²

In essence, this criterion indicates that a proposed LRT line should be viewed negatively if it conflicts with local or metropolitan planning. Conversely, changes in a community's land use planning and zoning should be made when necessary to obtain maximum benefits from the proposed LRT line.

Today, energy consumption is a major factor when developing evaluation criteria. In LRT analysis, however, energy considerations can be confused and controversial. LRT would not necessarily save energy, but it most likely would save petroleum, because it is powered by electrical energy, which is often generated by nonpetroleum fuel sources. Feasibility criteria for energy consumption, therefore, must consider the magnitude, source, and location of energy generation.

Analysis of various area corridors showed that LRT energy consumption, in total Btu or K-Cals, approached and sometimes exceeded the energy consumption of nonrail alternatives, particularly when all energy resources, including feeder buses, resource production, and resource transportation (coal from mine to generator, oil from well to refinery, etc.) were included.³ LRT's petroleum consumption, however, was less in every case than that of its alternative. One qualifying and one nonqualifying criterion emerged from energy analysis conducted in the Twin Cities. The qualifying criterion states: "The LRT line must conserve petroleum." In other words, the net result of constructing and operating an LRT line, adapting the bus service, and providing auto access to the line should be to reduce the consumption of petroleum fuel. The nonqualifying criterion considered all types of energy resources by

stating: "The LRT line should conserve energy."

The environmental image of LRT is generally positive, and developing feasibility criteria for this purpose was relatively simple. LRT is quiet, clean, and does not usually need large structures. It does, however, require wires, tracks, shelters, and occasional bridges or underpasses, and it generates a different kind of noise.

Air quality impact evaluation is more complex because of the location of the power generator. Non-LRT alternatives usually pollute the air in the transportation corridors they serve, but these corridors are usually located in high-density urban areas with other pollution sources. LRT causes pollution at the power generator, but it may be located far from the urban area. These distinctions, like that between petroleum and nonpetroleum energy sources, must be considered when developing criteria.

None of the environmental criteria were stipulated as qualifying, on the assumption that the nonenvironmental impact of LRT would render it infeasible. Nonqualifying criteria included the following:

- The noise impacts of the LRT line should meet applicable state and federal standards.
- The LRT's physical facilities should be visually integrated with the environment.

Transportation Criteria

Transportation-related criteria are primarily intended to address accessibility and ridership considerations and to coordinate and integrate transportation modes.

In terms of accessibility, a qualifying criterion developed in the Twin Cities study stated, "An LRT line must meet the transit accessibility criteria, as defined in the Metropolitan Development Guide, for the corridor it serves." This refers to the following travel time policies contained in the regional transportation plan: "The public and multi-passenger transit system should provide a travel time of no more than 45 minutes in either peak or off-peak periods from any part of the Urban Service Area to one or the other of the Metro Centers for 90 percent of the residents of the Urban Service Area. The Transportation system (both transit and highway) should provide a travel time of no more than 30 minutes in off-peak periods from any part of a subregion to any other part of the subregion for 90 percent of the residents in the subregion."

Another criterion also emphasizes the importance of improving accessibility to the Metro Centers, as previously discussed under physical impact criteria.

The potential ridership of a proposed LRT line is also considered, although only nonqualifying criteria were developed for this factor. One states: "The LRT line should meet peak ridership demands."

The proposed line must be able to accommodate predicted demands, which may be difficult in some situations. For example, an LRT train's length can be limited by block length and storage capacity of downtown streets and by stop space and design at major traffic generators. If several LRT lines use the same streets, the street capacity may not be adequate for peak loads. Since LRT vehicles usually cannot pass one another, this could cause severe congestion on the system.

A second nonqualifying criterion related to ridership states: "An LRT line should increase overall transit usage in the region over the existing system."

In order to justify the initial capital investment, an LRT line should be more attractive to the rider than an existing transit service; i.e., an LRT line must have a shorter travel time than the bus route it replaces in order to attract more riders.

The need to coordinate and integrate a proposed LRT line with other transportation modes was also included in several nonqualifying criteria developed in the Twin Cities study. One states: "The LRT line should be integrated with the existing transportation system without serious disruption or degradation."

The Metro Centers, in particular, already have numerous transportation activities—pedestrian, automobile, bus, taxi, goods movement, and emergency service—that occur simultaneously in a limited area. The LRT line should be planned and designed to be compatible with these activities. Also, many LRT lines operate in the center of streets, at curbside, or on exclusive rights-of-way with at-grade crossings. These locations can interfere with existing traffic flow or with parking, especially when the LRT right-of-way was formerly a vehicular right-of-way. These dislocations can be mitigated by providing off-street parking, creating turning lanes at intersections, and improving signals. It is important to design a safe facility that does not create severe disruptions to other traffic.

Metro Centers in both the Twin Cities are well served by skyway systems that would permit pedestrian movements to and from the LRT line in a climate-controlled environment. However, to provide access to the skyway system at only one point would create delays and cause pedestrian congestion at that stop. Therefore, multiple access points are an important design feature, as specified: "The LRT line should serve multiple boarding points within the Metro Center to distribute passenger movements."

Many existing bus routes to the metropolitan centers would be rerouted to feed the LRT line. This system reorientation should be accomplished to minimize the overall travel time and provide riders as much convenience as possible, as stated: "The LRT line should be efficiently integrated with the existing transit system."

Economic Criteria

LRT will likely cost more to build than most non-LRT alternatives except heavy rail and other fully grade-separated systems. An operating cost advantage that could make building one or more LRT lines worthwhile is the lower labor costs than for buses, because LRT can carry more people with fewer operators and complete more trips in less time. A proposed LRT line's cost-effectiveness should be determined by its capability to reach a break-even point in terms of total investment (capital, operating, and maintenance costs) compared to that of an alternative. Densities, peaking characteristics, and levels of service must be appropriate if a proposed LRT line is to be able to save enough to justify its larger capital expense.

Determining if LRT justifies its cost requires an economic analysis that includes a careful examination of all the assumptions used to calculate patronage and capital and operating costs, as well as interest rates, fares, subsidies, and cost allocation, including the following:

- Capital expenditures;
- Life of capital equipment;
- Prevailing interest rates;
- Sources of capital funds;
- Costs of operation (current and future) based on energy cost assumptions and labor cost assumptions;
- Fare structure and collection techniques; and
- Changes over time in patronage, equipment needs, and capital and/or operating costs.

To calculate cost-effectiveness, conservative assumptions should generally be made concerning interest rates, labor costs, etc., although the combined assumptions should remain within reason.

An important objective of the analysis is to determine how long it will take for the annualized capital costs and operating costs to break even. When this break-even point is earlier than the predicted life of the capital equipment, the investment is justified. This point can be calculated at various inflation rates to determine LRT's feasibility as a function of a specific rate. This is particularly important when inflationary trends are a major factor in the overall economic picture. In the Twin Cities LRT Feasibility Study, inflation rates of 6, 8, 10, and 12 percent were used.

The break-even year was calculated to range from 15 years after construction on the best corridor, assuming high inflation rates, to 51 years after construction on the least viable alternative at low inflation rates. This evaluation used only quantifiable dollar values and did not include intangible benefits, indirect costs and benefits, or secondary benefits. Such impacts might change the analysis, but the primary calculations provided enough data for a go or no-go decision on alternative corridors.

Criteria developed from this analysis reflect the concept that LRT should have operating benefits and that they should be related to its annualized capital costs. The qualifying criterion states: "The annual operating cost per passenger of an LRT line must be less than the annual operating cost per passenger of the existing bus service it replaces, when there is a clear service replacement. Otherwise, the annual operating cost per passenger must be less than the system average annual operating cost per passenger."

The complementary, nonqualifying criteria are as follows: "The total annual cost per passenger for the LRT line (including annualized capital costs and operating and maintenance costs) should be less than the annual cost per passenger of existing or proposed transit alternatives." "A proposed LRT line should be more cost-efficient than either the existing service it replaces or a non-LRT alternative." Specifically, then, costs and benefits should be calculated not only for the total system but also for its component markets.

Costs and benefits accruing to different institutions and equity can also be considered an issue. For example, transit users benefit from increased speed, comfort, and reliability; commercial real estate benefits from improved accessibility; corridor residents benefit from decreased air pollution. Adding these kinds of benefits and subtracting the costs to others will enhance the calculation's credibility and allow identification of sources of support or opposition.

Such funding sources as federal and state aid can also complicate the cost-effectiveness calculation. Two approaches are possible: to consider the total cost of the project as local expenditures or taxpayers' funds returned to the area; or to assume that either federal or state aid, or both, are gifts to the region. The second approach enhances the cost-effectiveness of high-capital-cost alternatives when capital grants are a significant factor, and affects the resulting decisions. The Twin Cities calculations assumed no outside aid and still found LRT cost-effective.

The Twin Cities tested the sensitivity of the cost-effectiveness to inflation assumptions by analyzing the impact of changing those assumptions. Other factors that can also be tested for sensitivity include premium fares, transfer costs, automobile use costs, parking availability, and local bus feeder systems. As these elements were held constant in comparing LRT with non-LRT alternatives in the Twin Cities, sensitivity tests were not done. These tests would be more appropriate to a more detailed analysis of a specific corridor.

Community Support

The success of major transportation investments depends on community support for the project. Local acceptance and commitment are critical to early implementation. In order to take this factor into consideration, the qualifying criterion developed in the Twin Cities study states: "Substantial commitment and support by the affected public and private sectors must be evident for the proposed LRT line."

This criterion requires that to be feasible the planning and implementation of an LRT line be supported by citizens, affected businesses, and public officials. This support must be demonstrated by actions and resolutions of city councils, county boards, chambers of commerce, community groups, and neighborhood organizations.

REFERENCES

1. The Feasibility of Light Rail Transit in the Twin Cities Metropolitan Area, Metropolitan Council of the Twin Cities Area, April 1981, p. 5.
2. Development Framework Chapter, Metropolitan Development Guide, Metropolitan Council of the Twin Cities Area, September 1975, pp. 16, 22, 25.
3. Light Rail Transit Feasibility Study, Metropolitan Council of the Twin Cities Area, Consultants Report, April 1981.

Energy Implications of Rail Transit

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Whether mass transit actually saves energy is not easy to answer; different studies show different results. This paper reviews the major studies, notably the Congressional Budget Office's 1977 report, "Urban Transportation and Energy: The Potential Savings of Different Modes," and several studies done in response that debate many of its findings. A possible petroleum conservation strategy that focuses on future urban and regional development is identified and discussed.

The U.S. energy crisis is essentially a transportation crisis. In recent years the transportation sector accounted for one-fourth of all the energy used nationally—some 19.8 quadrillion Btu in 1979—and half of the petroleum consumption. Ninety-seven percent of the transportation sector's energy needs were supplied by petroleum in 1979.¹ Highway vehicles used 80 percent of this petroleum and private autos 70 percent. Natural gas accounted for 2.6 percent, mostly in pipeline consumption, although interest is now being renewed in the use of compressed natural gas and propane for vehicles. The electricity used was less than 1 percent, and most of this was used by fixed rail transit systems, which in 1978 used 2223.0 million kWh of electricity—about 7.5 trillion Btu. Buses used diesel oil and a small amount of gasoline, equivalent to about 60 trillion Btu in 1978.²

Total and per capita consumption in the transportation sector rose steadily through 1978 and fell sharply in 1979 despite increases in other sectors (Table 1²). In the first 9 months of 1980, gasoline consumption was 7 percent

lower and imports of petroleum and products were nearly 20 percent lower than in the same period in 1979. This trend reflects a number of developments: sharply higher world oil prices, gradual deregulation of United States oil prices, and mandated automobile fuel efficiency standards of 20 mpg fuel average in 1980.

Additional factors will eventually affect energy use in the transportation sector, including development and use of alternative vehicles (e.g., the electric car), engines (e.g., the Stirling engine), and fuels (e.g., hydrogen, natural gas, ethanol, and methanol). Implementing existing and proposed energy efficiency standards for new automobiles (corporate average fleet efficiency), mandated to reach 27.5 mpg in 1985, will also reduce gasoline consumption. However, even if a fleet average of 24 mpg for all existing autos is achieved by 1990, the daily petroleum consumption is estimated to rise to 2.8 million bbl/day compared with 2.6 million bbl/day in 1975 when the fleet average was only 14 mpg.³

Another energy-saving transportation option is rail transit. Its energy-saving implications caused considerable controversy in the past few years, particularly as increased investment in mass transit has come under mounting criticism.

TRANSIT TRENDS

Only 16 of the 1003 transit systems in the United States in 1978 included heavy and/or light rail. Three systems consisted only of heavy rail and 948 only of motor buses.

Table 1. Sectoral primary energy consumption.

Year	Residential/Commercial		Transportation		Industrial
	Total 10 ¹² Btu	Per Capita 10 ⁶ Btu	Total 10 ¹² Btu	Per Capita 10 ⁶ Btu	Total 10 ¹² Btu
1970	24 574	120.0	16 077	78.47	26 170
1971	25 540	123.4	16 671	80.52	26 086
1972	26 807	128.4	17 675	84.63	27 145
1973	27 396	130.2	18 525	88.04	28 685
1974	26 699	126.0	18 057	85.20	27 998
1975	26 635	124.7	18 186	85.15	25 881
1976	27 831	129.3	19 071	88.62	27 603
1977	28 193	130.0	19 751	91.06	28 442
1978	28 807	131.8	20 626	94.35	28 716
1979	29 369	133.2	19 786	89.74	29 627

Notes: Excludes natural-gas transmission losses and unaccounted-for-natural gas. These data include distributed electricity end uses converted at rates corresponding to national average thermal power plant performance. Per capita values calculated by the author.

Heavy rail accounted for 27.5 percent of the 2.19 billion vehicle-miles covered and motor buses for 75 percent. Most heavy rail transit is located in 8 urban regions: New York, Chicago, Philadelphia, San Francisco, Boston, Cleveland, Atlanta, and Washington; 2 more cities, Baltimore and Miami, have systems under construction. The automobile still accounts for 97 percent of all passenger-miles traveled locally except in large cities where mass transit systems are available, but generally still ranges between 80 and 90 percent. An exception is New York City, where more than half the travel is on rapid rail transit or transit bus.⁸

Heavy rail use has dropped significantly over the past 4 decades, as has mass transit ridership in general (Table 27). Between 1940 and 1979, heavy rail vehicles in operation declined from 11 032 to 9567; light rail vehicles declined from 26 630 to 944; but motor buses increased from 35 000 to 52 866. The United States has lagged behind all other nations in urban rail construction. Between 1960 and 1980, rapid transit and light rail mileage doubled worldwide. Over two-fifths of the new construction was in developing countries, and over two-fifths was in Europe and Canada.⁵ A reversal of this trend may be in progress, however. The American Public Transit Association reports that transit ridership in July 1980 was 30 percent higher than in July 1972.⁷

The decline in mass transit in the postwar period was a result of federal home financing and road building policies that fostered urban sprawl and suburbanization in America. Between 1960 and 1970, populations in central cities rose by only 7 percent, while those of suburban areas rose 26 percent. Many transit systems suffered financial difficulties, and in 1964 the Federal Urban Mass Transit Authority was created to provide capital assistance to systems. In the 1970s, the OPEC embargo and subsequent rise in crude oil prices created a new interest in energy conservation and energy efficiency and a consequent re-examination of mass transit. The Project Independence Study of 1974 included a rather superficial section on transportation conservation that alleged that public trans-

it—identified exclusively with buses—was 2 to 4 times more energy-efficient than the automobile. The report called for legislation to double the size of the bus fleets and discourage the use of automobiles.

MODAL ENERGY EFFICIENCIES

Operating Efficiencies

A number of studies done in the 1970s dealt with the energy efficiency of various transportation modes, both passenger⁹⁻¹⁴ and freight.¹⁵ In 1977, the National Research Council's Transportation Research Board⁸ published a survey of these studies and a summary of their conclusions. All these studies evaluate energy efficiency in terms of operating efficiency only. The report measures energy efficiency in several ways: (a) Btu (or gallons) per vehicle-mile, the average fuel consumed by a vehicle in its daily duty cycle; (b) Btu or gallons per seat-mile, the efficiency of a given transit mode as it transports people; and (c) Btu or gallons per passenger-mile. (This assumes an average passenger occupancy that represents actual or expected use. Average occupancy is the sum of the total annual passenger-miles, divided by the total annual vehicle-miles.)

Table 3⁸ is an adaptation and summary of a table in the TRB report for passenger modes in urban areas. In all 3 estimates the automobile has a lower efficiency than rail, but the 2 rail estimates vary widely: 1646 and 4300 Btu per passenger-mile.

Congressional Budget Office Study

In September 1977, Senator Lloyd Bentsen, Chairman of the Senate Subcommittee on Transportation of the Committee on Environment and Public Works, asked the Congressional Budget Office to prepare a study on the potential of energy conservation in urban transportation. In contrast to most previous studies, this analysis considers not only the energy needed to actually propel vehicles, but

Table 2. Trend of passenger vehicle miles operated.

Calendar Year	Railway			Trolley Coach (Millions)	Motor Bus (Millions)	Total Vehicle Miles Operated (Millions)
	Light Rail (Millions)	Heavy Rail (Millions)	Total Rail (Millions)			
1940	844.7	470.8	1 315.5	86.0	1 194.5	2 596.0
1945	939.8	458.4	1 398.2	133.3	1 722.3	3 253.8
1950	463.1	443.4	906.5	205.7	1 895.4	3 007.6
1955	178.3	382.8	561.1	176.5	1 709.9	2 447.5
1960	74.8	390.9	465.7	100.7	1 576.4	2 142.8
1965	41.6	395.3	436.9	43.0	1 528.3	2 008.2
1966	42.9	378.9	421.8	40.1	1 521.7	1 983.6
1967	37.8	396.5	434.3	36.5	1 526.0	1 996.8
1968	37.5	406.8	444.3	36.2	1 508.2	1 988.7
1969	36.0	416.6	452.6	35.8	1 478.3	1 966.7
1970	33.7	407.1	440.8	33.0	1 409.3	1 883.1
1971	32.7	407.4	440.0	30.8	1 375.5	1 846.3
1972	31.6	386.2	417.8	29.8	1 308.0	1 755.6
1973	31.2	407.3	438.5	25.7	1 370.4	1 834.6
1974	26.9	431.9	458.8	17.6	1 431.0	1 907.4
1975	23.8	423.1	446.9 ^a	15.3	1 526.0	1 989.7
1976	21.1	407.0	428.1 ^a	15.3	1 581.4	2 026.3
1977	20.4	361.3	381.7 ^a	14.8	1 623.3	2 021.3
P1978	19.5	363.5	383.0 ^a	13.3	1 630.5	2 028.3

Notes: Table excludes automated guideway transit, commuter railroad, and urban ferry boat.

P = preliminary.

^aIncludes cable car and inclined plane.

Table 3. Energy efficiency for passenger transportation modes.

Mode	Passenger-Miles . Per Gallon	Seat-Miles Per Gallon	Btu Per Passenger-Mile	Load Factor Assumed	Source	Remarks
Auto	22	57	5 578	1.9	(10)	Urban (1972)
	15	54	8 100	1.4	(9)	Urban (1970)
Small						
Work and related business	21.67	70 ^a	5 768	1.6	(16)	
Shop and family business	41.39	63	3 020	2.3	(16)	
Social and recreation	74.93	94	1 668	2.8	(16)	
Subtotal	47.74	76	2 618	2.2		
Standard						
Work and related business	15.68	59	7 972	1.6	(16)	
Shop and family business	20.70	54	6 039	2.3	(16)	
Social and recreation	42.15	90	2 966	2.8	(16)	
Subtotal	24.51	67	4 209	2.2		
Total	29.70	69	4 209	2.2		
Bus						
	51		2 681		(10)	Urban transit (1972)
	48		2 891	24%	(17)	Urban (1972)
			3 700	<20%	(9)	
Rail						
	84		1 646		(10)	Transit (1972)
	32	128	4 300	25%	(18)	Urban (1970)
Misc.				PM/VM		
Bicycle			1 300		(19)	Total energy use
			97		(20)	10 mph
			200		(21)	5 mph
Walking			500		(20)	2.5 mph
			300		(22)	2.5 mph
Taxi ^b	8.0		15 600	0.7	(23)	
Dial-A-Bus	15.6			3.0	(24)	Peak hour
Van-Pool	81	108	1 540	9.0	(25)	Peak hour
BART	88			40	(26)	Peak hour

^aSmall cars are assumed to average 3.5 passenger-seats and other cars 6.0 passenger-seats.

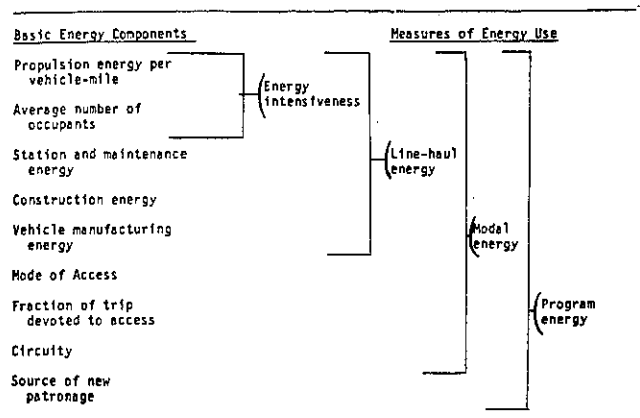
^bThe driver is assumed not to be a passenger.

also indirect uses of energy such as energy used to manufacture vehicles, build rights-of-way (roads, rail, etc.), maintain systems, heat and light stations, and drive to railroad stations. It also examines the energy implications of adaptations to new systems. For instance, if improvements to one service draw passengers from another, energy-efficient mode—if vanpooling draws passengers from buses instead of autos—the effect on energy consumption is negative. Another problem the CBO study examines is that of "circuitry." Many people who use public transit drive to stations, and combined automobile/transit trips are generally less direct than those made by auto alone, so a dual-mode trip may save little or no energy at all. The study does not analyze the long-term effect of changes in shopping, living, and working locations made because of changes in mode of transportation, and a serious deficiency of the report is that it does not recognize that such changes do occur. The various factors considered are shown in Figure 1.⁴

The CBO chose typical values for each component, based on what it called a comprehensive review of available literature, and then generated 3 sets of estimates—high, low, and middle—for each case. It examined auto-

mobiles, carpools, vanpools, dial-a-ride systems, old heavy

Figure 1. A framework for evaluating energy savings from urban transportation.



rail transit, new heavy rail transit, commuter rail, light rail transit, and buses. It emphasizes total energy consumption regardless of fuel used.

The conclusions based on the CBO study's middle estimates are shown in Table 4;⁴ Table 5⁴ shows some of the component estimates. The low and high estimates show little shift in the ranking of the modes: vanpools always appear to be the most energy-efficient and dial-a-ride the least. Other than dial-a-ride, new heavy rail transit is the only mode to show an energy loss. Although its operating energy requirements are relatively low on a per passenger basis, maintenance and station energy uses are high: 7300 to 10 000 Btu per vehicle-mile for old heavy rail and 13 990 to 14 700 Btu per vehicle-mile for new heavy rail compared to 1600 Btu per vehicle-mile for automobile maintenance. Guideway construction energy requirements for new heavy rail are high and have an

extremely wide range—2400 to 22 000 Btu per vehicle-mile, compared to 100 to 130 for autos. However, CBO notes that estimates of guideway construction energy use vary from 85 billion to 775 billion Btu per mile of track, a variation that suggests "the estimation process needs more refinement," says the report. Vehicle manufacturing energy use estimates also show a wide range: for heavy rail transit manufacture, energy use is 1350 to 8100 Btu per vehicle-mile, versus 720 to 1330 for automobile manufacture.

Rail transit rates low when the energy use ratio per passenger-mile traveled as a result of new programs is considered. Several studies are cited to show that new rail transit system passengers formerly used buses (36 percent on Philadelphia's Lindenwold line, 54 percent on San Francisco's BART line, and 72 percent on Chicago's Dan Ryan line) or were making a new trip because of the system

Table 4. Middle estimates for various measures of energy required by urban transportation modes: all measures expressed in Btus per passenger mile.

Mode	Operating Energy ^a	Modal Energy ^b	Program Energy ^c
Single-occupant automobile	11 000	14 220	N/A
Average automobile	7 860	10 160	N/A
Carpool	3 670	5 450	4 890
Vanpool	1 560	2 420	7 720
Dial-a-ride	9 690	17 230	(12 350)
Heavy rail transit (old)	2 540	3 990	N/A
Heavy rail transit (new)	3 570	6 580	(980)
Commuter rail	2 625	5 020	970
Light rail transit	3 750	5 060	30
Bus	2 610	3 070	3 590 ^d

Note: N/A = Not Applicable

^aPropulsion only.

^bAll forms of energy, computed on a door-to-door basis, adjusted for roundabout journeys.

^cEnergy saved (lost) per passenger mile of travel induced by new programs.

^dFor new express bus service. Regular urban bus service would show smaller savings.

Table 5. Middle estimates of basic components of operating energy intensiveness and line-haul energy by urban transportation modes: in Btus per vehicle mile.

Mode	Propulsion Energy	Average Number of Occupants	Station and Maintenance Energy	Construction Energy	Vehicle Manufacturing Energy
Single occupant automobile	11 000	1.0	2 000	125	1 100
Average automobile	11 000	1.4	2 000	125	1 100
Carpool	11 000	3	2 000	125	1 100
Vanpool	14 000	9	2 000	200	2 000
Dial-a-Ride	15 500	1.6	2 000	200	2 000
Heavy rail transit (old)	61 000	24	9 000	3 000	1 500
Heavy rail transit (new)	75 000	21	15 000	4 000	1 500
Commuter rail	105 000	40	7 000	1 200	2 500
Light rail transit	75 000	20	7 000	1 700	2 000
Bus	30 000	11.5	900	370	1 200

(13 percent, 11 percent, and 16 percent for the 3 systems). Vanpoolers, by contrast, formerly drove cars.

On the basis of its findings, the CBO study concluded that "rail transit offers little aid to the nation's efforts to save fuel."

Responses to the CBO Study

Not surprisingly, the CBO report was criticized by city planners and academic transportation specialists as biased toward the auto and paratransit. The following is a summary of some of the major arguments against the CBO's findings:^{5,27,28}

- It is misleading to base conclusions on average urban conditions and average mode efficiencies, when, as the CBO admits, no "average" city actually exists. Since conditions vary among cities, types of trips, etc., each mode is the most efficient for certain applications.
- The CBO focuses on energy use to the exclusion of other factors, especially performance; e.g., speed, reliability, passenger attraction. Any analysis that disregards these factors would conclude that bicycles and motorcycles are superior to all other modes.
- The modes considered do not serve the same travel demand: carpools and vanpools, for instance, are only for commuting to work, whereas regular transit serves all purposes at all hours and thus should not be compared directly. The report also includes empty miles of transit vehicles in its computations, but ignores them for automobile trips. Millions of auto trips are made each day for the purpose of dropping off or picking up a passenger (e.g., children at school). They should not be counted as if they had an average occupancy of 1.5 (2 persons in 1 direction, 1 in the other), but only 0.5, since the driver has no purpose in that trip. Doing this would lower the auto's estimated efficiency by 10 to 15 percent.
- While the energy consumed to build and maintain railway stations and related facilities is counted, corresponding items for other modes are ignored; e.g., the energy used to build and maintain private and commercial garages and parking lots, gasoline stations, body repair shops, street and highway maintenance, traffic controls, etc. The magnitude of this error is difficult to compute, but if corrected, it would result in a significant change in favor of rail.
- The report wrongly assumes that automobile energy efficiency will be greatly improved, while the energy efficiency of other transit modes will not change or will even deteriorate. Increased coasting (regenerative braking) alone could cut rail transit energy use by 16 to 30 percent. Energy-conscious station design can also effect significant savings for rail transit and is easier to implement than auto efficiency.
- The CBO report ignores the most important energy-related feature of rail transit: that it is driven by electricity, which can be produced from many energy sources, whereas automobile-based modes can, at present, be propelled only by liquid fuels. The use of nuclear and hydropower to generate electricity improves the gross efficiency of electricity production, while breeder reactors and, eventually, fusion reactors represent virtually renewable sources of energy.

An Alternative Model

Boris Pushkarev and Jeffrey Zupan of the Regional Plan Association analyzed the energy implications of rail transit as part of their comprehensive review of criteria to

support implementation of a fixed guideway system in an American city.⁵ They found that the average energy consumption for the 8 existing electric rapid transit systems cluster around the value 670 Btu/place mile (e.g., seat/mile), independent of speed. Buses are not necessarily more efficient than rail transit; at the speed at which most buses operate, 12 mph, gross energy use is about the same as for electric rail transit. It may be higher in downtown areas and lower at intercity free speeds. The energy efficiency of new advanced design buses is about 25 percent higher than in 1970. Pushkarev thus concludes that "both fixed guideway and free-wheeled mass transit vehicles have similar energy requirements for vehicle operation, regardless of diesel or electric propulsion. The greater efficiency of the electrical motor compared to the diesel engine is offset by greater losses in conversion from the primary energy source. Thus both bus and rail energy requirements are about one-third those of the traditional auto in local urban use."

If calculated per passenger-mile, the crucial factor is occupancy. Urban rail systems have a 23.3 percent occupancy rate compared to 19 percent for buses, equivalent to 1.4 persons in a 6-passenger auto. Yet, the auto uses 3 times as much energy as rail, so even if consumption was reduced by half, a car would still use 45 percent more energy than rail or bus. To compete with rail, the automobile would have to increase its occupancy to 2.0 or transit occupancy would have to decline to 16 percent.

The energy requirements for other transit operations are poorly documented and difficult to determine; Pushkarev and Zupan therefore developed their own estimates of the gross energy costs of autos, buses, and rail, including operation, maintenance, wayside and station requirements, vehicle manufacture, and guideway construction for different volumes of line miles.

An important factor is the phenomenon of nonownership of autos in the immediate vicinity of rail stations. This may be substantial and, according to one estimate, at service volumes in excess of 50 place miles/line miles, one-third or more of the energy cost of rail transit may be free, paid for by savings from reduced auto ownership.⁵ Indeed, several studies have shown that a community with transit has different energy use patterns than one without transit. Housing is denser, employment and shopping sites are better organized, and car use differs. One result is that total gasoline sales in such regions are less than if transit were not available, and, in cities with rail transit, gasoline consumption per capita is lower than in those without transit.

In addition, it is axiomatic that the construction of a new transit line, either highway or rail, attracts development because of increased accessibility, and, where it is a rail line, the resulting development is generally of high density. A July 1980 study by the Federal City Council of the District of Columbia showed that nearly \$1 billion worth of private development has taken place near Metro stations on the 43.5 miles then completed, with another \$5 billion of development contemplated if the entire 101-mile system is completed. Major new downtown office development has occurred in Philadelphia, Pittsburgh, Chicago, Detroit, Milwaukee, and other cities with transit improvements either proposed or underway.³⁰ High-density land use results in energy conservation in ways other than reducing petroleum use by autos: building heating is more efficient—it is estimated that a multi-dwelling facility uses 45 percent less energy per person than a single dwelling—and providing services in general requires less energy.

CONCLUSION

Pushkarev and Zupan conclude that an analysis of United States cities identifies 4 cities as serious candidates for new heavy rail transit systems: Los Angeles, Seattle, Honolulu, and Houston. A tentative candidate is Dallas-Fort Worth. Candidates for light rail transit include St.

Louis, Milwaukee, Minneapolis, Indianapolis, Louisville, Cincinnati, Denver, Kansas City, and Columbus.

The American people are becoming increasingly sensitive to the cost and availability of the petroleum energy supply. There is general agreement that new energy and land use strategies must be developed to alter energy use patterns everywhere. Currently, 85 percent of rail mass transit's energy supply is nonpetroleum derived. Rail mass transit clearly has made and can continue to make a contribution to reducing petroleum consumption and energy consumption in general through applying appropriate land use strategies. The magnitude of these conservation efforts is becoming more apparent as more disaggregated data are produced and analyzed.

REFERENCES

1. U.S. Department of Energy. Monthly Energy Review, Washington, D.C., U.S. Government Printing Office, October 1980, p. 22.
2. J.D. Parent. Revised U.S. Energy Production and Consumption Data for 1979, and Recent Consumption Trends. Energy Topics. Chicago Institute of Gas Technology, September 15, 1980.
3. L.J. Gambaccini. Statement, U.S. Congress, Senate Subcommittee on Transportation of the Committee on Environment and Public Works, The Congressional Budget Office Report: "Urban Transportation and Energy: The Potential Savings of Different Modes: Hearings." 95th Congress, 1 Sess., Washington, D.C., U.S. Government Printing Office, Serial 95-H39, October 5, 1977, pp. 35-36.
4. Congressional Budget Office Study. Urban Transportation and Energy: The Potential Savings of Different Modes. Washington, D.C., U.S. Government Printing Office, Serial 95-8, September 1977, pp. 7-12, 33-35, 47-51.
5. B.S. Pushkarev and J.M. Zupan. Urban Rail in America. Report No. UMTA-NY-06-0061-80-1, Urban Mass Transportation Administration, U.S. Department of Transportation, November 1980.
6. V.R. Vuchic, F.B. Day, and R.M. Stanger. Rail Transit: Characteristics, Innovations and Trends. Presented at 54th TRB Annual Meeting, Washington, D.C., January 15, 1975.
7. American Public Transit Association. 1978-79 Transit Fact Book. Washington, D.C.
8. Transportation Research Board. Energy Effects, Efficiencies and Prospects for Various Modes of Transportation. Transportation Research Board, Washington, D.C., 1977.
9. E. Hirst. Energy Intensiveness of Passenger and Freight Modes, 1950-72. Report No. ORNL, NSF-EP-44. Oak Ridge National Laboratory, April 1973.
10. J. Pollard, D. Hiatt and D. Rubin. A Summary of Opportunities to Conserve Transportation Energy. Report No. DOT-TSC-OST-75-22. Transportation Systems Center, U.S. Department of Transportation, August 1975.
11. W.E. Mooz. Energy Trends and Their Future Effects Upon Transportation. Paper P-5046. Rand Corporation, July 1973.
12. R.A. Rice. System Energy as a Factor in Considering Future Transportation. Paper 7-WA/Ener 8. American Society of Mechanical Engineers, December 1980.
13. W.E. Fraize, P. Dyson and S.W. Gouse. Energy and Environmental Aspects of U.S. Transportation. Report No. MTP-391. MITRE Corporation, February 1974. Transportation Vehicle Energy Intensities. Report No. DOT-TST-13-74-1/NASA TMS-64, 404. U.S. Department of Transportation and National Aeronautics and Space Administration, June 1974.
14. Jack Faucett Associates. Energy Consumption by Transportation Mode. Report to the Office of Secretary, U.S. Department of Transportation, May 1973.
15. Measuring Energy Efficiency in Freight Transportation. American Trucking Association, Washington, D.C., 1976.
16. Facts Bearing on the Problem. Unpublished Paper, Highway Statistical Division, Federal Highway Administration, Washington, D.C., April 1974.
17. Transportation Vehicle Energy Intensities. Report No. DOT-TST-13-74-1/NASA TMS-64, 404. U.S. Department of Transportation and National Aeronautics and Space Administration, June 1974.
18. W.D. Fraize, P. Dyson and S.W. Gouse. Energy and Environmental Aspects of U.S. Transportation. Report No. MTP-391, MITRE Corporation.
19. E. Hirst. Energy Use for Bicycling. Report No. ORNL-NSF-EP-65. Oak Ridge National Laboratory, February 1974.
20. N. Dougherty and W. Lawrence. Bicycle Transportation. Environmental Protection Agency, December 1974.
21. R.A. Rice. System Energy as a Factor in Considering Future Transportation. Paper 70-WA/Ener 8. American Society of Mechanical Engineers, December 1970.
22. R.A. Rice. System Energy and Future Transportation. Technology Review, Vol. 74, No. 3, January 1972, pp. 31-37.
23. A.L. Webster et al. The Role of Taxicabs in Urban Transportation. U.S. Department of Transportation, December 1974.
24. Demand-Responsive Transit Service. HRB Spec. Rept. 136, 1972.
25. R.D. Owens and H.J. Sever. The 3M Commute-A-Van Program-Status Report II. 3M Co., St. Paul, Minnesota, January 1977.
26. BART Interstation Fare Schedule Report. Bay Area Rapid Transit Authority, May 18, 1971.
27. V.R. Vuchic. Which Mode Can Save Most Energy? No Simple Answer Exists. Comments on the CBO's Report "Energy-Saving Potential of Urban Mass Transit," written testimony submitted for the Senate Committee on Environment and Public Works, October 5, 1977.
28. U.S. Congress, Senate Subcommittee on Transportation of the Committee on Environment and Public Works, the Congressional Budget Office Report entitled "Urban Transportation and Energy: The Potential Savings of Different Modes: Hearings." 95th Congress, 1 Sess., Washington, D.C., U.S. Government Printing Office, Serial 95-H39.
29. M. Pikarsky. Land Use and Transportation in an Energy Efficient Society. Conference on Transportation and Land Development, November 11, 1977.
30. D.B. Feaver. Passenger Transport. Reprint from Washington Post, Washington, D.C. American Public Transit Association, January 4, 1980, p. 1.

When and Where Does LRT Work?

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This paper determines that LRT can and does work in a variety of situations and analyzes the conditions necessary to support its successful implementation. To be effective, light rail service must meet the requirements of a substantial number of the tripmakers along its route. Travel time must be shortened to attract riders who have the option of traveling by private auto. Alternatively, travel volume must be so high that a low transit modal split will still yield high ridership in absolute numbers. Exclusive or preferential rights-of-way help minimize LRT's trip time and relieve highway congestion. Shared or converted railroad alignments, center boulevards, exclusive lanes, and short aerial or underground structures are the usual means of accelerating LRT to improve trip time. Simple, traditional street operation is effective only when travel volume is sufficient to justify LRT on its productive efficiency rather than its speed. For maximum efficiency, LRT must often closely integrate its service with that of a local bus network, but on long, fast radial lines serving a central business district, integration, although desirable, may not be a necessity. Conditions under which LRT works best range from long, fast, low-density suburban lines to short, slow, high-density inner-city lines. Some LRT installations are high-capital, high-efficiency operations; others require less capital to achieve superior results. LRT can only be used where it is the best transit mode for the specific application.

San Diego, San Francisco, Calgary, and Edmonton have recently and successfully implemented new or vastly improved light rail transit systems, and construction is under way in Buffalo, Pittsburgh, and Portland. Final plans for construction are being drawn in Baltimore, Denver, Detroit, and Sacramento. Studies have been done in Rochester and San Jose with favorable results. All this activity and interest in light rail transit (upgraded street railway) raises the question: Why and how?

HISTORY

Light rail operations over the past 25 years stand out in bold and happy contrast to the results experienced by surface transit generally, which lost 64 percent of its passengers during that period of metropolitan growth.¹ The shift from the 6-day work week of the World War II period to a 5-day week was completed in 1952 when banks inaugurated Saturday closings. The years from 1953 to the first energy crisis of 1973-74 provide a stable period for comparison of LRT trends to those of the surface transit industry generally. Major changes in light rail operations in many cities limit valid comparisons to the systems in Cleveland (Shaker Heights), Newark, and San Francisco, whose services were operated almost without change during the 20-year period.

Compared with the 64 percent decline in surface transit generally, these unchanged light rail systems lost only 10 percent of their riders; most of this loss was experienced when the Newark operation was shut down temporarily and when subway construction began to inhibit operation in San Francisco. Light rail in these three cities clearly had an attraction for riders superior to that of other surface transit systems. This attraction justifies light rail's existence, but there also must be economic justification such as that demonstrated by Boston's Transit Authority. In 1959, it opened a major new long line to Newton and Riverside, which immediately demonstrated a 900 percent increase in transit use. Previous service in the corridor was provided by a desultory commuter train and parallel feeder bus service to other, shorter LRT lines.

WHY?

Why does light rail transit service have such a superior attraction for riders?

First, the systems discussed had the following elements in common:

- High acceleration electric propulsion,
- Higher than average transit speed,
- Larger vehicles than motor buses,
- Exclusive transit lanes over part of the route,
- Protection from the weather,
- Train signals on exclusive right-of-way,
- Outlying parking for passengers (except San Francisco),
- Bus transfer privileges (except Cleveland),
- Overhead trolley power supply,
- Petroleum conservation and no on-line emissions, and
- Absence of air conditioning.

Second, these light rail systems were proved efficient. Passenger-mile data in Cleveland and Newark provide the following specifics: each light rail line needed only 2.1 or 2.2 employees per vehicle to support the total operation, including power systems and routine track maintenance; each passenger car produced 1900 passenger miles (3060 passenger kilometers) per weekday for a total employee productivity rate of 900 passenger miles (1450 passenger kilometers) per employee.

Comparable figures for a typical city bus is 550 passenger miles (887 passenger kilometers) for express service and 530 passenger miles (855 passenger kilometers) in general service.²

Express service usually has a low midday use rate, but it outperforms local service at peak hours. The light rail efficiency as demonstrated above affects either fares, or operating assistance required, or both.

A third, but less objective, reason for passenger preference for LRT is found in the following amenities:

- No on-board engine noise or smell,
- No air pollution along the route,
- No unexpected swerving or sudden stops,
- More interior space per passenger,
- Passengers can read while commuting,
- Fixed and self-proclaiming route,
- Smooth ride (assuming proper track maintenance),
- Double doors to speed loading and unloading,
- Multi-car operation possible to handle large volumes,
- Different from routine transit travel, and
- Urban development adjacent to fixed right-of-way.

A fourth, and crucial, reason is the avoidance of the higher capital costs of rail rapid transit and the higher operating costs per passenger of low-capital alternative modes.

There are also problems with light rail transit but, although real and sometimes vexing, their effect is small and more than outweighed by the advantages. One problem is that transit management often perceives light rail as a system that requires more attention than a bus operation. Some other problems include the following:

- Lack of flexibility;
- Dependence on a single power source;
- Nonstandard transit operation;

- Difficult spare parts supply; and
- Objections of motorists, police, and traffic engineers more interested in moving vehicles than people.

HOW?

There are five ways to implement light rail operation; these methods can be combined for use on different segments of the same line, thus giving light rail greater flexibility than other transit modes. The methods are:

- Using a long, exclusive right-of-way from suburbia to the central business district (CBD) (Riverside MBTA, Shaker Heights, San Diego);
- Creating a short, densely used exclusive right-of-way in the CBD or other major traffic center (Buffalo, Newark, Woodland Avenue in Philadelphia, Edmonton, Pittsburgh);
- Routing to avoid constricting traffic congestion (Calgary, New Orleans, Red Arrow SEPTA, Skokie Swift);
- Allowing priority street space for high-volume lines (Buffalo, Calgary, Canal Street in New Orleans, San Diego, Toronto); and
- Providing fast feeders to a heavier rail mode (Mattapan MBTA, Red Arrow SEPTA, Skokie Swift).

All these methods use the light rail technology of standard or trolley gauge street trackage, direct low voltage electric power supply from overhead wires (to permit street interface and pedestrian safety), 220 to 400 horsepower (165 to 300 kw) vehicles, manual control with block signal override when appropriate, and easy, direct passenger access from the right-of-way. The light rail vehicle is truly flexible; it is capable of aerial, underground, exclusive, or railroad right-of-way, as well as mixed street traffic operation, without design change or changeover delay. A single, one-way trip can include a subway operation in the central business district, a mixed traffic street operation enroute, and a private right-of-way operation at the outlying end of the route. This ability to use whatever right-of-way is available is the prime factor in making light rail a less capital-intensive rail transit alternative, although a light rail subway system may be no less expensive than a similar heavy rail rapid transit undertaking.

A VOLUME MARKET

Light rail transit cannot be economical to low-volume markets. The fixed cost of its unique infrastructure requires volume travel to amortize the investment over many trips, but there is no specific break-even point because of the wide investment range for different light rail applications. The longer and faster a line becomes, the lower the traffic volume needed to assure its economic viability. In San Diego, a peak volume of 1200 passengers, one way per maximum hour, is economical because of steady all day use and a low capital investment. Only 11 articulated rail units are required to operate the service schedule. The bus route that previously provided the service—#32 to San Ysidro—would have needed 23 buses to carry the same peak volume. The economy of light rail service is exceeded only by its attractiveness.

Even at midday, the San Diego-San Ysidro bus service required 10 articulated buses with standees, but 10 light rail vehicles will carry more passengers with plenty of seats, inducing still more ridership. The economics are clear: the same speed that attracts more riders and augments revenue will simultaneously cut costs significantly.

Shorter lines with less speed opportunity need more volume to justify investment in LRT. Toronto has the continent's most successful transit system; streetcars pre-

empt the center street lanes and speed movement nearly 10 percent faster than do curb-loading buses. In this case, the economy of light rail comes primarily from vehicle size and efficiency, with speed a secondary factor. With a 3-minute peak headway (for example) on a 90-minute round trip cycle, 30 rail cars (unarticulated) are required to meet the schedule and move 28 passengers per minute past the maximum load point. These 30 vehicles, with 15 percent spares, require 108 employees, including maintenance people and management.³

To serve the same route by bus, a 2.25-minute headway will be required to move 28 passengers per minute, and the round trip cycle will approach 99 minutes as buses are delayed detouring into the curb, then seeking street space to pull back into traffic. This will require 44 buses, plus 15 percent spares, and 128 employees, including maintenance and management, with an 18 percent higher cost level than for light rail operation for the same volume of travel.⁴ Labor costs are approximately 75 percent of all transit expense.

As travel volumes decline, it is not possible to reduce light rail infrastructure employees in proportion. At some point of lower volume, bus operation will become more economical than light rail, but superior passenger attraction will still give light rail some advantage at the break-even point. The economic advantage of light rail disappears when the peak headways fall below 6 minutes. However, if tracks are in good condition and relatively maintenance free, light rail will maintain its superiority until major repairs are required.

In such situations as in San Diego or Calgary, where street operation is combined with exclusive suburban right-of-way, no flat rule can be applied. Each specific situation must be analyzed on its own merit.

Light rail transit should not be specified for peak-hour volumes one way for more than 16 000 passengers per hour. Heavy rail rapid transit or commuter railroad service with larger vehicles and longer trains on exclusive rights-of-way are required. To move 16 000 passengers per hour with 1985 amenities would require 131 articulated light rail cars. Even with 3-car trains, a 1.3-minute headway would be required, and such speeds would fall to very low levels with trains on such close headways; congestion would negate any perceived light rail advantages. With 4-car trains on a 1.8-minute headway and no branch lines to skew loading near the maximum load point, LRT could handle 16 000 peak passengers per hour, but heavy rail would do it much better and more economically. (In 1957, Philadelphia operated a 27-second light rail headway in the subway by means of multiple berthing at stations with single cars, but speeds in the subway fell to 12 miles (19.5 km) per hour, further slowed by frequent delays.)

Where trade-offs become necessary, as with high volumes in center city but dispersed low volumes in the suburbs, it may be necessary to utilize heavy rail rapid transit on the trunk line with light rail on the branches (Red Arrow, Mattapan, Skokie Swift).

RIGHTS-OF-WAY

Light rail service can efficiently utilize six kinds of right-of-way, depending on cost, availability, and condition. Circumstances will dictate which type, or what combination, should be applied to a given corridor or route. The six kinds are the following:

- Center street operation, with as much transit priority as feasible;
- Park strip, median, or boulevard right-of-way (similar to above but exclusive and with crossing safety features);
- Joint use of light density railroad trackage;
- Power line or abandoned railroad rights-of-way;
- Aerial structures at highway crossings, with private right-of-way between crossings; and
- Subway, or below grade, right-of-way.

In general, the easier a right-of-way is to obtain, the less satisfactory it may be. Center street operation in central business districts brings speed down below 10 miles (16 km) per hour but should not be dismissed for this reason alone. In many central business districts, bus speeds fall to 5 or 6 miles (8 to 10 km) per hour or lower during peak periods. Light rail may be able to provide a 50 percent improvement in speed if conditions are favorable, even if that speed is only 8 or 9 miles (13 to 14 km) per hour. The only real advantages of street operation are that passengers are delivered conveniently and the right-of-way is available, but these can be major advantages, as they are in Toronto. New investment required for such rights-of-way may approach \$1 500 000 per double track mile (\$930 000 per km), including power supply and vehicles, assuming minimum utility relocations underground. San Diego and Calgary offer recent examples of this type of right-of-way.

Park strip, median, or boulevard operations, as in Shaker Heights, New Orleans, and elsewhere, are highly advantageous except for one major factor—crossing safety. Intersection hazards can be extreme. Low crossing volumes with adjacent rail stops for passengers, bans on left turns, or sophisticated signalling devices will be necessary to permit this type of operation where crossings are not grade separated. New Orleans copes with slow speed cars and frequent stops. Shaker Heights has a wide median, station locations at crossings, signals, and patience. Toronto's Queensway is a high type example of median operation with few crossings. New investment for this type of right-of-way will approach \$1 250 000 per mile, excluding rolling stock and power supply (\$775 000 per km).

Joint use of light-density railroad track will not cost less than new construction on a median strip, because signals and switch locks will be required. The track may need extensive rehabilitation. However, the results can be highly advantageous if the right-of-way is in a good location.

Joint operation should avoid mixing freight trains with LRT trains during such periods of frequent operation as 6 a.m. to 10 a.m., 2:30 p.m. to 6:30 p.m., or midday if frequent midday service is scheduled. Employees must be highly trained and skilled in switching operations and signaling functions not normally encountered on homogeneous transit operations. San Diego is an excellent example of joint use, and, in past years, the Chicago Transit Authority, the Illinois Terminal Railroad, the New York City Transit Authority, and Pennsylvania-Reading Seashore Lines successfully operated joint light rail and freight service on common trackage.

Power line and abandoned railroad rights-of-way can be economical locations for light rail alignments if they are in areas of potential passenger traffic. Power lines and electric rail lines share common rights-of-way successfully in many places. The primary consideration is available patronage rather than physical feasibility. Construction cost for light rail on these rights-of-way will average \$1 500 000 per double-track mile (\$930 000 per km), excluding rolling stock and substations. On ungraded power line rights-of-way, this cost may increase 33 percent or more if grading is necessary. If grade crossings are separated, the new investment will increase dramatically, depending upon the terrain.

Light rail aerial structures have aesthetic and cost disadvantages when compared to ground level rights-of-way, but aerial structures can potentially offer the best passenger service, without the grade crossings and underground stations disliked by some of the public. The cost should be less than half that for underground alignment, or roughly \$30 million per mile (\$18.5 million per km).⁵ Costs can be substantially reduced if short sections of single track for two-way operation are used, as in Pittsburgh and San Diego. Extreme care must be exercised to avoid service delays when single track is used. It is not feasible on close or irregular headways, although Pittsburgh has maintained a busy operation in spite of this handicap.

The aesthetic problem of overhead power wires on aerial structures can be relieved by locating the supporting poles between the two tracks with bracket arms, rather than at the sides of the structure with span wires. This reduces their visibility from the ground. Light rail operations can usually tolerate 6 percent grades with little difficulty, particularly when ascending to station stops and descending to accelerate. Such grades can bring the track down from an aerial structure to sight level (4 feet above the ground) in 300 feet, so city blocks over 600 feet long need not have the visual intrusion of aerial structures in midblock. Such grades are also energy savers. But if railroad freight is present, the heavier, less powered movements require gentler gradients.

Subways, or below-grade alignments, are ideal from a city planner's viewpoint but are otherwise undesirable. In addition to high cost, passenger dislike of underground passages mitigates against such construction unless it is unavoidable. Well-designed subways, integrated with adjacent commercial development, can transform a subway's disadvantage to a great advantage, as in Edmonton or San Francisco, but Edmonton kept the subway very short. In Pittsburgh, an existing railroad subway is to be converted to light rail use, retaining a single-track section to avoid costly new construction, but this single track can accommodate only one-third of the movements. A short, strategic new double-track subway is required for trips to another portion of the downtown area, where it will be closely integrated into new office buildings now under construction.

TRANSIT SYSTEM INTEGRATION

A high-density, urban area light rail system must have free or nominally priced interchange (transfers) with other rail and bus lines serving the local area. As many as two-thirds of all high-density riders transfer at points where highest ridership is obtained.⁶ Transfers are an essential element of high ridership, not because they are popular, but because individual bus routes cannot connect enough origin and destination points. With universal transfers, many economies can be effected in route structure on bus lines parallel to light rail transit where the LRT service is superior, i.e., faster and/or more economical. Such transfers would not be convenient between slow, long headway bus lines.

Long, fast, suburban light rail lines have less need for transfer privileges if they serve the central business district adequately, as in Cleveland and Pittsburgh. The Cleveland to Shaker Heights light rail line had its highest passenger volume (20 000 per weekday) 30 years ago when it had no transfer privileges. Feeder buses in low-density suburban areas often have only a few captive or necessity riders. Automobile owners usually prefer to drive or be driven to the car stop. This does not eliminate the desirability of transfers, but it does suggest the possibility of a successful suburban light rail operation if two independent operating agencies cannot agree on transfer arrangements.

OPERATIONAL ASPECTS

To be justified, light rail must be the fastest, or the most efficient, alternative for specific patrons. A speed of only 8 or 9 miles per hour can be justified in heavy central business district traffic if most other transit speeds are even slower. LRT schedule speeds of 15 miles (24 km) per hour are possible on exclusive rights-of-way with closely spaced stations and grade crossings, and increase to 20 miles (32 km) per hour as stations are spaced a third-of-a-mile or more apart. In Edmonton, Calgary, and San Diego light rail lines reach schedule speeds of 30 miles (48 km) per hour where stations are 1 mile apart but require formal stops; this is possible only in tolerant areas. An average speed of 40 miles (64 km) per hour is technically possible on very long lines with few stations aver-

aging 2 or more miles (3 km) apart. A 12-mile (19-km) suburban trip would be possible in 18 minutes with this type of operation, as light rail has been successfully operated in regular service at speeds up to and exceeding 70 miles (112 km) per hour.⁷ Certain recently abandoned railroad lines could provide the opportunity for such operation.

Speed may be less important, however, in terms of miles of line than it is in terms of minutes per passenger. It is good practice to delay a lightly loaded vehicle by stopping to pick up more passengers who are at points not convenient to widely spaced stops, as long as the majority of riders benefit.

Express and local light rail trains can enhance both speed and economy. Normally, cars or trains cannot pass each other unless costly, additional right-of-way and trackage is provided, but it is possible to alter a 4-minute headway to operate on staggered 6- and 2-minute headways. Only 4 minutes can be saved by the express, but, psychologically, it is worth 8 minutes and, economically, it permits segregation of loads; locals can be turned short of end of the line, with considerable savings and increased revenue.

COSTS

The construction cost of light rail line, including rolling stock and substations, can vary from \$6 million per mile in optimum circumstances, to \$90 million per mile (\$3.5 million to \$55 million per km) in the most difficult subway situations. There is no abstract economy for light rail in subways, where heavy rail will usually be more efficient and economical. The only justification for a light rail subway would be for completion of an otherwise less capital-intensive project with no feasible alternative for reaching the central business district. Edmonton is an excellent example of this situation.

Because of wide and varied investment requirements, each light rail project must be studied separately with emphasis given to avoiding subway construction wherever possible. In congested central business districts, however, there may be no satisfactory alternative.

The capital investment in light rail cannot be meaningfully compared with the cost of a fleet of buses or with an exclusive bus road that fails to penetrate the central business district. Total traffic capacity and speed of movement must be considered. For example, a light rail line that costs \$250 million and serves 40 000 weekday riders comfortably will provide peak-hour capacity equivalent to 32 lanes of arterial street or 8 lanes of freeway. Less statistically and more realistically, half of a new light rail line's patronage may be former local transit riders enjoying the improved service and half may be former automobile commuters; therefore, the light rail line will have abolished the need for 16 more arterial lanes or 4 more lanes of freeway in costly, congested areas. Nearly 8000 fewer costly downtown parking spaces will be required. In many cases, providing equivalent highway and parking facilities costs far more than the light rail system without providing its economy or civic benefits.

While costs vary widely in specific situations, a conservative assumption is that a new highway lane, in a high value area, cannot be built for less than \$10 million. Four such lanes, extending over 4 miles, would thus cost \$160 million; parking space needed to accommodate the highway users, another \$40 million; highway vehicles that can be replaced by light rail, \$40 million on short amortization schedules. Thus, light rail could easily be the low cost alternative for the needed capacity, even without considering such increases in community values as are now taking place in Pittsburgh in the light rail construction area.

Light rail operating costs are more consistent and amenable to analysis than construction costs. With reduced federal funding for urban transit, operating costs will become more important in decisionmaking. Single-unit light rail cars on high-volume lines require 3.1 employees

per vehicle to maintain, operate, power, and manage them if frequent midday service is maintained. As off-peak service becomes less a factor in an operation, the employee per vehicle ratio will drop toward the 2.1 ratio once achieved in Shaker Heights.

In 1982, each employee's compensation will average \$27 000 per year, including fringe benefits. Materials, supplies, rent, and insurance will add 50 percent to this employee cost, raising the total annual cost of light rail vehicle operation to \$125 500 per single-unit vehicle ($\$27\,000 \times 1.5 \times 3.1$), or \$42 per vehicle hour. Although it is 15 percent higher than the cost of bus service per unit, it is considerably lower in terms of cost per passenger mile. Because of its larger size and higher speed, the productivity of a light rail car, applied in its proper sphere of operation, should exceed bus productivity by 30 to 50 percent.

Each articulated car under similar circumstances will require 4.5 employees at a total cost per unit of \$182 250 per year ($\$27\,000 \times 150 \text{ percent} \times 4.5$). The saving in operators' platform wages is partially offset by the added maintenance required by the articulated unit, a slightly lower speed because of higher passenger loads, and fewer units over which to distribute the right-of-way costs. The 1982 per hour cost for articulated units will be approximately \$60.75, 3 percent less per passenger at peak hours than for single-unit cars, but bus costs increase during light traffic hours when too many empty seats prohibit reasonably frequent service. With appropriate volume, LRT operating costs per passenger mile will average 30 to 50 percent below those of articulated buses.

REVENUE-COST RATIOS

Single-unit LRT vehicles can produce 1900 passenger miles (3000 psgr km) per weekday at a 1982 cost of \$420 (\$42 per hour $\times$ 20 hours), which equals 22.2 cents per passenger mile (13 cents per km). With base fares of 50 cents for short rides, plus 12 cents per mile for longer rides through fare zones, fares will average 16 cents per passenger mile (10 cents per psgr km), resulting in 72 percent of cost covered by passenger revenue and another 1 percent by concession income. This is well above the current transit industry average of under 50 percent. Where there is relatively high midday ridership, as in Calgary or in San Diego, full coverage of costs from fares is possible. Tighter scheduling can also boost the revenue ratio and reduce the amount of taxpayer assistance needed. An LRT vehicle operating 10 hours per weekday can approximate 75 passengers per hour, 100 per peak hour (not all on-board simultaneously), and 50 base. The resulting 750 average weekday passengers per vehicle averaging 4 miles (6.5 km) each, as in Pittsburgh, will generate 3000 weekday passenger miles (4800 psgr km) per vehicle. At this optimum but achievable rate, costs will drop to 14 cents per passenger mile (8.5 cents per psgr km). The revenue-cost ratio will rise to 114 percent and abolish the need for any operating subsidy. Not all operations can achieve this goal, but in fairness to riders and taxpayers, all must try.

To cities considering light rail transit, where current transit operations cover only 35 to 45 percent of the cost from revenues, the economic possibilities of LRT should be attractive, even if the optimum cannot be obtained.

COMPARING LIGHT RAIL SYSTEMS

Light rail experiences in the United States and Canada include a variety of types and operations. They have been analyzed in order to provide relevant comparisons. Because accounting practices differ, the avoidable operating costs shown below are estimated from the data in this paper to improve comparability. Some operations may not keep records by vehicle type; some are too new to have compiled a full year's results; and some allocate system fixed costs in a manner unrelated to actual light rail costs. The data used here are believed to be sufficiently accurate

for comparison purposes. Capital costs for rehabilitation programs are excluded; only operating costs are included.

Light Rail Systems Data (Estimated)

The variation in light rail operations makes both analysis and comparison not only difficult but risky. Schedule speeds vary from 8 miles per hour (13 km) in Philadelphia to 38 mph (61 km) on Skokie Swift, yet both are successful in their own different ways. A typical new line averages 24 mph (38 km) per hour. Passenger mile per car mile (or km) productivity ranges from 45 in Chicago and San Diego to 15 in Philadelphia, but in all cases exceeds the urban motor bus average of 13.²

The passenger miles per car year productivity ranges from 2 250 000 (3 600 000 km) in San Diego with its articulated cars to 393 000 (628 800 km) in Philadelphia with its single cars on slow congested routes.

The revenue/cost ratio does not meaningfully measure efficiency because different communities have different fare policies, not subject to management or technical control. For example, the electorates in certain cities have voted funds to hold fares at noncompensatory levels as a public service. The cost per passenger mile (km) is the only meaningful unit of comparison, and it declines in inverse proportion to distance traveled. Long (intercity) trips cost approximately 10 cents per passenger mile (6 cents per km) but have an initial service and/or boarding cost of at least 15 cents for zero distance, bringing the cost of a 1-mile ride to 25 cents, or 35 cents for 2 miles (21 cents for 1 km and 27 cents for 2 km). Few transit systems achieve these optimum rates, partly because of traffic delays and peaking problems not frequently found in intercity travel.

Boston

The Massachusetts Bay Transportation Authority operates 4 radial LRT routes that disperse from the central subway (the nation's oldest) and an aerial viaduct that extends the subway a short distance in the opposite direction to a feeder bus interchange terminal (Lechemere). The 12-mile suburban Riverside line, converted from a commuter railroad line in 1958, has the best suburban penetration in the system. The Commonwealth Avenue line to Boston College has equally heavy use, is considerably shorter, and operates primarily on the median of the highway. The Beacon Street line lies between the Riverside and Commonwealth lines but is shorter than either, and performs more accessible, median area, local service to relieve the longer Riverside line of short-haul travel. It is a train type operation and uses both PCC cars and new LRT articulated vehicles. The Arborway line is primarily a street operation outside the subway, parallel to the Forest Hills elevated rapid transit line. A high-speed LRT shuttle is also operated from Mattapan to Ashmont—only 2 miles—where it connects with the red rapid transit line. It runs entirely on private right-of-way and attracts ridership requiring a 2-minute peak headway. A sixth LRT line, which runs over city streets to Watertown, is not currently in passenger operation because of rolling stock problems.

In Boston, LRT carries heavier loads than heavy rapid transit lines, but this practice is not recommended.

Calgary

The Calgary Transit System opened its first LRT route in May 1981 with extremely heavy patronage. As in San Diego and on Buffalo's proposed line, it travels on preferential street lanes downtown, then tunnels briefly to reach a reserved strip of Canadian Pacific Railway right-of-way in order to serve the southern portion of the city. It places heavy emphasis on feeder buses and wide station spacing. A 5- and 10-minute peak and base headway is operated with 2-car articulated trains.

Cleveland

Until the recent delivery of large new Breda articulated cars, the Shaker Heights Rapid Transit utilized a mixture of multiple- and single-unit PCC cars. Two 10-mile lines with 6 miles of common trackage radiate east from Cleveland's Terminal Tower. First they travel through abandoned railroad yards, then down the medians of suburban boulevards—one with residential character and one with high density development. Service is fast, and no street operation is in mixed traffic. Peak headways are frequent, with 15-minute base headways on the denser Van Aken line and 30 minutes on the residential Shaker Boulevard line. Sunday service is hourly. The Shaker Heights operation is perhaps the most aesthetically attractive anywhere. Before its amalgamation with Cleveland Transit in 1975, the Shaker Heights Rapid Transit had no transfer arrangements, but now, as part of the Greater Cleveland Regional Transit Authority, it has universal transfers.

Before 1930, the line entered downtown Cleveland over city streets and had good but slow distribution. With the move to faster, off-street service to the single Terminal station on Public Square, some patronage was lost because distribution was not as good. Following World War II, voters approved construction of a subway to improve the distribution, but the county highway engineer in charge of the project refused to build it.

For 5 miles, the Shaker Heights LRT shares its tracks with the heavy rail trains of the former Cleveland Transit System, reconfirming LRT's operating flexibility.

Chicago

The Skokie Swift of Chicago's Transit Authority is classified here as light rail because it uses vehicles upgraded from PCC streetcars, operates at grade-over-grade crossings, and obtains power from overhead trolley wires. It runs on the right-of-way of a former interurban electric railway and operates as a rapid transit feeder line shuttling passengers between Skokie and the Howard Street Rapid Transit Terminal. Some articulated cars are used. The service originated from a federal demonstration grant. Multi-car trains are not employed. No intermediate stops are made.

Edmonton

The Edmonton Transit System built a short downtown subway to provide central business district access for the light rail line, built along the Canadian National Railway right-of-way to serve the northeast corner of the rapidly growing oil city. Recently extended, only 3 years after its opening, the line depends largely on feeder buses for outlying access. Stations are a mile apart and have high-level platforms. Two-car articulated trains operate on 5-minute peak headways and 10-minute midday headways. Subway extensions to the west are under construction, and a more extensive system is planned. Grade crossing protection systems are synchronized with the rail block signal system to prevent trains from interrupting highway traffic.

Fort Worth

The Tandy Corporation operates the former M&O Subway as a public convenience for its commercial center and adjacent department store. It is totally a park-and-ride operation that uses extensively rebuilt PCC cars on a 1-mile line. It has attracted more riders than any other transit route in Fort Worth. The half-mile subway portion of the line was built with private funds for approximately \$1.5 million nearly 20 years ago.

Newark

Transport of New Jersey operates the city-owned subway

from the central business district to the northwest city limits, with 3 miles of parkside trackage and 1.5 miles of subway (5 km and 2.5 km). The right-of-way was obtained from an abandoned canal. The subway portion was overbuilt with an arterial highway. Bus transfers from competing, not feeder, routes supply much of the peak-hour traffic, for which a 2-minute headway is provided with large PCC cars. A reduced, reverse direction downtown fare is offered. Off-peak bus riders do not save enough time to induce them to transfer to the subway, but a 6-minute headway is offered walk-in riders. As transit riding declined generally, the Newark subway has become the most heavily traveled transit route in the state, measured at the maximum load point.

New Orleans

New Orleans Public Service operates the St. Charles streetcar line primarily on reserved median space, with grass between the rails. Grade crossings are frequent, and several blocks of street operation are used downtown. When a similar route was converted to bus 15 years ago, the peak-hour congestion caused by smaller vehicles, with fewer doors, on closer headways, slowed movement to 3 or 4 miles per hour (5 or 6.5 km) in the central business district, despite exclusive bus lanes. Residents and riders prefer keeping the grassy rail right-of-way to having the street widened for heavier vehicular traffic. The rail line has become a historic monument and still operates cars built in 1926.

Philadelphia

The Southeastern Pennsylvania Transportation Authority (SEPTA) operates three types of light rail service. The agency was created, in part, for this purpose. Five busy lines serve the central business district in a common 2.5-mile (4 km) subway, similar in principle to Boston's but without multiple-unit capability. With a 1-mile exception, street operation prevails outside the subway. At one time, a 27-second headway was operated with multiple berthing at stations, but population declines have lengthened these headway intervals.

Seven other lines operate throughout the city on longer but lower volume routes that run entirely on city streets. The longest route, 13 miles each way, traverses hills where residents object to the throbbing of buses' overworked diesel engines. Much of the trackage on this line was recently rebuilt. PCC cars are also being extensively overhauled. New cars have been purchased for the subway lines. One of the 7 surface lines is a rapid transit subway feeder, and all surface lines connect with the major subway. Exclusive lanes are provided where possible. In certain respects, these 7 lines resemble the Toronto light rail operation.

SEPTA's fastest light rail lines are in the suburbs where operations are similar to the Ashmont-Mattapan LRT service feeding rapid transit. One such line extends 6 miles to Sharon Hill and the other 8 miles to Media (9.5 and 13 km), with 2 miles (3 km) of common trackage. Combined headways reach 2.5 minutes at peak hours, with a 10-minute base midday. The largely exclusive right-of-way permits higher speed operation—faster than auto travel over certain segments. Several years ago, experiments were conducted with buses equipped with rail guide wheels, but the tests were unsuccessful. New cars have now been purchased from Kawasaki for 60-mph (96-km/hr) operation and double-end controls. Some two-way operation on single track is involved on the outer ends of the lines, as is some street trackage. Known as the Red Arrow Lines, its suburban ridership has continued over the years as automobiles and suburban shopping centers have decimated transit ridership in other areas.

Pittsburgh

The Port Authority of Allegheny County operates 4 light

rail lines from downtown Pittsburgh to Drake Road Route #36, Library Route #35, Mount Lebanon and Castle Shannon Route #42/38, and Arlington Avenue Route #49. Except #49, all routes operate through the Mount Washington transit tunnel with much exclusive right-of-way beyond the city. Route #49 is a short, partially single-track tunnel bypass, with a cliffside view of the rivers and the city. Like San Diego and Calgary, the Drake and Library lines (11 and 13 miles, or 17 and 21 km) operate exclusively on private rights-of-way outside the Golden Triangle (downtown). The heaviest trunk line, #35 and #36 together, operates on a 2-minute peak headway with single-unit PCC cars, but the operation is constrained by several sections of single track. This may be the busiest section of single track anywhere. Congestion and, occasionally, tieups occur at peak hours. The topography has deterred double tracking. Only intolerable highway congestion induces the 2-car families served by these lines to patronize them. Ironically, these lines have some of the few paid park-and-ride lots in the nation. Pittsburgh's light rail lines generate nearly half of all park-and-ride activity in the Pittsburgh metropolitan area, although they serve only 5 percent of the transit vehicle miles.⁸

Elected officials recognize these severe handicaps to efficient system operation. Construction has started on major improvements to remedy these intolerable conditions and modernize the system. A redundant railroad bridge over the Monongahela River and its connecting subway under the east edge of the Golden Triangle have been acquired for conversion to light rail use. A short, strategic subway will be constructed under Sixth Avenue to serve the department stores and Gateway Center, at the point of the triangle. This will convert Pittsburgh to an elongated, Edmonton-type operation. The bucolic Mount Lebanon to Castle Shannon extension of Route #42/38 will be upgraded and double tracked to connect with an extension from the Drake line to South Hills Village Regional Shopping Center, where a new car shop will be located. Reverse flow diversions will become possible to relieve some of the congestion on the single track used by Routes #35 and 36.

At present, 1-minute peak-hour headways are operated on the joint portion of the system across the Monongahela River into downtown Pittsburgh. Street congestion in the city, however, is a severe restraint.

In spite of its debilities, the Pittsburgh system has survived in the highway age because of passenger volume. Throughout Pittsburgh and the nation, transit ridership has dropped 64 percent or more since the end of World War II except on Pittsburgh's light rail routes. Ridership is still at 1945 gasoline-rationed levels during peak hours, but off-peak use has experienced some of the decline common to transit everywhere. After the war, the light rail lines attracted suburban development, which built peak-hour patronage, congested highways, and thus sustained patronage as midday travel to the city was diverted to suburban shopping centers.

Currently, with modernization of the LRT system, downtown Pittsburgh is undergoing its greatest building boom. Almost all open parking lots are being converted to office buildings, with total value exceeding \$1 billion. A new trade and convention center has recently been completed near the downtown terminal of the light rail system.

San Diego

The San Diego Trolley, Inc., operates a 16-mile line over a lightly used railroad bed from the edge of downtown San Diego to the Mexican border at San Ysidro. Downtown, 1.7 miles of new double track was constructed via Twelfth and C streets to deliver passengers to within 1 block of the length of Broadway. The railroad portion of the line serves the edges of National City, Chula Vista, and Imperial Beach; local feeder buses connect to the residential areas. Park-and-ride space is also provided. Service began in July 1981.

San Diego's busiest bus route, #32, which served this

same corridor, was cut back to serve as a feeder and for local, neighborhood travel. The bus route required a 2.5-hour cycle. The LRT will reduce this to 1.25 hours, a 50 percent saving in time, equal to 35 minutes each way. Many passengers must transfer, which reduces the time saved for some, but the net benefit is still great. Five trains with 5 operators can provide twice as much capacity as 10 bus drivers with articulated buses.

San Francisco

The San Francisco Municipal Railway operates 5 light rail lines under Market Street; this is similar to the pattern in Philadelphia, except that articulated cars are employed in train operation. Two old trolley tunnels under Twin Peaks are utilized to extend the exclusive right-of-way to heavily developed residential areas. End-to-end, 2 of the 5 lines duplicate BART (Bay Area Rapid Transit), but there is no competition. BART is much faster over a shorter route. Light rail serves the intermediate territory with frequent-stop service, and on a different alignment. The trunk subway is served by 2-minute headways with 2-car trains. The 5 branches have 1- and 2-car trains on less frequent headways. Ridership increased markedly as lines were diverted to the new subway. Additional LRT vehicles are being purchased to accommodate the patronage, which may reach 50 percent more than that of surface operation. Subway service was inaugurated in 1980 on a partial basis; full service was inaugurated in 1981.

Toronto

Unlike any other light rail operation, Toronto Transit Commission depends for its success on street operation, using fast, well-maintained PCC cars. New Canadian light rail vehicles (CLRV) are now replacing 200 of the older PCC cars. Others were replaced several years ago by the new subway on Bloor and Danforth. Toronto is unique for having built patronage over the years while most other systems were losing it. Light rail has been a part of Toronto's success, preempting the best part of the street for transit. There is no legislated preemption. The presence of the rail cars on frequent headways discourages other vehicles from using the same space.

The subways, however, have become the mainstay of transit in Toronto. Efforts to phase out light rail a decade ago were met with such strong public opposition that new vehicles were ordered instead, and track was upgraded. It appears that where transit service is good, the public will support it. Toronto recovers over 60 percent of its operating cost from the fare box—one of the best ratios on the continent.

CONCLUSION

The energy supply is dwindling. The cost of petroleum is certain to rise further. Transportation is energy-dependent; it is also costly. It has resulted in severe and undesirable congestion and air pollution. It has decimated large areas of our cities. Better solutions to urban transportation problems are needed. New technology is, by definition, not the answer, although it may be of limited assistance where applicable.

There is no ideal solution, but for urban public transport, light rail transit, in its proper place, has emerged as a superior performer—holding on to former, higher ridership levels, developing new ridership, sustaining revenue, and cutting the cost per passenger, if not the cost per vehicle. Light rail cannot be used indiscriminately; it has unique advantages for unique situations. Many cities are using it, and many more can use it to improve urban conditions. For relatively fast, efficient, overall service, a subway operation downtown and a suburban, exclusive right-of-way with controlled grade crossings are the best choices, as in Edmonton, Newark, Shaker Heights, or on Boston's Highland Branch. Light rail is not recommended for very high-

volume operation. Rapid transit trains on totally separate rights-of-way are required for capacity and efficiency. Light rail cannot be expected to carry over 16 000 passengers at peak hours. Light rail services's value is below rapid transit levels, where buses have inadequate capacity, speed, attraction, or efficiency.

The sheer cost of downtown subways often precludes the ideal light rail configuration. A good, practical, alternative is the Calgary or San Diego pattern, where a downtown street is preempted for transit and exclusive right-of-way provided for transit outside downtown. New Orleans' pattern is similar but has too many grade crossings. Low volumes of movement, relative to subways, can be served economically and effectively by use of this pattern.

A third pattern of light rail operation involves a downtown subway, as in the first pattern described above, and surface street operation in outlying areas, where exclusive rights-of-way are not obtainable. Five Philadelphia lines, San Francisco lines, and certain Boston lines employ this pattern. It is obviously successful, but less desirable than exclusive right-of-way where available.

A fourth pattern of light rail operation is that demonstrated by Skokie Swift, the Ashmont-Mattapan line in Boston, and the Red Arrow lines west of Philadelphia, where light rail has exclusive right-of-way for use in shuttling passengers to a high-capacity, full-scale rapid transit line. The public may not appreciate the advantage, as this pattern requires a transfer. But the speed of service compared to buses, and the economy of operation compared to heavy rail for light volume, are such major advantages that it is the only feasible way to provide good service. It is extremely wasteful of both money and energy to operate long, heavy rail rapid transit lines deep into the suburbs because of the dwindling occupancy as the trains move further from the city. With express tracks and very high volumes, this disadvantage can be overcome, but for most applications, the light rail feeder is best.

The fifth and last common light rail pattern is the street railway, as employed in Toronto and on several Philadelphia lines. Although traffic engineers seldom see advantages in on-street operations, there are several, and speed is not one of them. Direct access to traffic generators is a prime advantage; preemption of the traffic stream by transit is another. Vehicles are not dependent upon petroleum; total street capacity is increased. However, the prime advantage is the efficient and economical handling of volume. For 2000 passengers per peak hour one-way, 30 buses would be required to serve the maximum load point during the hour; a better job can be done on a trunk line with just 23 light rail cars, reducing costly platform time by 23 percent. Such an operation 10 miles long (5 miles each side of downtown) would cost \$7 million per year to operate with buses, with 50-cent fares covering 86 percent of the cost. Using light rail, the cost would be only \$6 million, with no subsidy needed. (This is an ideal condition, assuming no half fares for senior citizens and no transfers at reduced revenue, but the point is still valid.)

As energy supplies dwindle and prices escalate; as federal aid is reduced; as cities redevelop; and as inflation pressures on transit management, taxpayers, and riders increase, it is mandatory to find better and more effective ways to move people in centers. Light rail cannot do all or even most of the work, but it does offer such great value for specific situations that its intrinsic merit should force a wide application to urban transit in the years ahead.

REFERENCES

1. American Public Transit Association. Trend of Originating Transit Passenger Trips. Table 9. APTA Fact Book, December 1979, p. 27.
2. American Public Transit Association. Motor Bus Statistics. APTA Fact Book, December 1979, p. 66.

3. Urban Mass Transportation Administration. Section 15 Report. Form No. 404. For Cleveland, Philadelphia, and Pittsburgh. June 30, 1980.
4. American Public Transit Association. Trend of Transit Employment, Compensation and Labor Costs. Table 13. APTA Fact Book, December 1979, p. 34.
5. De Leuw, Cather & Co. Light Rail Transit—A State of The Art Review. Table 33. U.S. DOT-UMTA, spring 1976, p. 224.
6. Toronto Transit Commission. Annual Statistical Report, 1979.
7. Westinghouse Electric & Manufacturing Co. Cars & Car Equipment, Vol. VI, 1930.
8. Southwestern Pennsylvania Regional Planning Commission. A Study of Park-N-Ride Lots. Table 7. September 1975, p. 41.

Factors Influencing Light Rail Transit Feasibility

MART KASK, Executive Director, Puget Sound Council of Governments, Seattle

As part of its regional transportation plan update for the post-1990 period, the Puget Sound Council of Governments (PSCOG) commissioned a study to assess the feasibility of a light rail transit system. The study found there would be sufficient demand to warrant some form of light rail for the Central Puget Sound Region of Washington by the year 2000. The feasibility study weighed the advantages and abilities of LRT and an all-bus transit system to meet future demand and found the cost of LRT, in the highest demand corridors, would be comparable to that of an all-bus system of the same capacity. LRT operating costs might be lower, and it would use less energy. LRT is a particularly attractive solution to Seattle central business district transit problems and has a potential for cost savings that could offset higher construction costs on other segments. The study identified two high-capacity regional corridors connecting with the CBD as the most feasible and cost-effective for LRT. PSCOG is working with the City of Seattle, Metro Transit, and the Downtown Seattle Development Association (private sector) to develop the scope and process and to obtain funding for further study.

The Puget Sound Council of Governments has recently completed an update of its regional transportation plan to the year 2000. A key recommendation is to consider light rail transit as an alternative transit mode in selected regional corridors in the post-1990 period. This recommendation was based on the results of a study conducted in fiscal year 1981 to determine the feasibility and justification of including fixed-guideway transit as a component of the long-range regional transportation plan.

The decision to consider fixed-guideway transit was made within the context of the following factors:

- Expanding areawide economy,
- Increased public acceptance and use of transit,
- Lack of support for major new highway projects,
- Need for energy conservation, and
- Regional development policies.

Forecasts of employment growth have been adjusted upward substantially in recent years. The ratio of transit ridership per capita in the Seattle urban area is one of the highest in the nation for urban areas of comparable size. The unique topography of the region has limited the mileage and capacity of the freeway system and compressed travel demand into a few well-defined corridors.

THE REGION

The Puget Sound Council of Governments is the Metro-

politan Planning Organization (MPO) for the Central Puget Sound Region of Washington, consisting of the 4 counties of King, Kitsap, Pierce, and Snohomish. The population of the region is 2.2 million; 80 percent live in the urbanized areas of the 3 largest counties. The major population center is King County with a population of 1.3 million, including its central city, Seattle.

Like most urban regions, its transportation system was developed under diverse circumstances over many decades by numerous jurisdictional entities. In addition, the region has unique attributes and problems that offered opportunities and imposed constraints on past development of the region's transportation system and will influence determination of its future transit needs.

The region is both the victim and the beneficiary of its geographic location and topography. While the Puget Sound waterway, large inland lakes, and glacially formed topography that characterize the region provide unusual scenic beauty and numerous economic attributes, they also create an unusual setting for an urban transportation system. Generally, urban development has been a series of linear corridors, mostly north-south. Topography is a moderate to severe obstacle to most east-west corridors and, overall, has added significantly to the cost of providing the transportation facilities necessary to serve the area.

The north-south corridor runs for about 60 miles between the cities of Tacoma and Everett, with the Seattle CBD located midway. It is served by Interstate Route 5. New growth in King County has tended to locate in a 5- to 8-mile band due east of Seattle across Lake Washington. Transit service in the cross-lake corridor will be concentrated on Interstate Route 90, yet to be completed. These geographic features and the resulting pattern of urban development are particularly relevant to assessing the feasibility of light rail transit.

The Central Puget Sound Region has a dynamic economy because of its role as the preeminent business and financial center for the Pacific Northwest and Alaska. Population has increased commensurate with employment opportunities stemming from this economic growth. From 1950 to 1980, the region's population grew at an average annual rate of 2.1 percent compounded while the overall U.S. population increased at an annual average rate of 1.36 percent. The growth has consisted of about 55 percent net in-migration, a ratio expected to continue. There are many indications that the long-term growth of the region will continue at a rate greater than that of the nation as a whole by a margin at least as great as in the past. Growth forecasts figure prominently in the assessment of light rail feasibility.

The transportation plan update followed extensive efforts to define the area's urban development objectives. A regional framework for future growth was followed by the adoption of subregional development plans in each of the 4 counties. Individual local governments pursued policies, planning, and urban development strategies to better rationalize growth, especially in relation to transportation. The designation of activity centers encourages employment growth in nucleated areas where it can better be served by transit. These policies and strategies affect the subarea growth forecasts and the feasibility of fixed-guideway transit to serve the major activity centers.

CHANGING POLICIES AND PLANS

Regional comprehensive land use and transportation planning was initiated in 1961 by the Puget Sound Regional Transportation Study (PSRTS); work concluded in 1966 with development of alternative land use and transportation plans for 1990. The study produced a Recommended System of Freeways and Expressways that was adopted by the sponsors of the project—the Puget Sound Governmental Conference and the Washington State Highway Commission—in November 1966.

The proposed system was extensive and was based on projected growth and the facilities needed to meet that growth, as determined by the values of that time. Many of the facilities have since been deleted. Figures 1 and 2 show the substantial reduction made in the number of freeway miles proposed.

At the same time, however, growth was occurring at about the projected rate. The growth was partly accommodated through greater emphasis on transit; transit system management strategies were significant for achieving more efficient use of the existing system. Management was also helped by different travel patterns than were anticipated. But a large portion of the projected and realized growth has not been accommodated, and it has resulted in increased highway congestion. The region has had to accept a lower level of service because it cannot build all of the capacity needed to eliminate the congestion.

YEAR 2000 PLAN

The year 2000 plan calls for a very limited expansion of the freeway/expressway system. The area will rely heavily on increased auto occupancy and transit ridership.

Because of the peak-period transit volumes projected in the major regional corridors, especially those directly connecting with and serving the Seattle CBD, a high-capacity line-haul transit system will be required. Preliminary assessment indicates that light rail transit should be fully considered as an alternative transit mode in addition to an all-bus system.

How to accommodate transit demand in the Seattle CBD is perhaps the most serious problem. Current bus passenger volume has reached a level that is objectionable to many who work and do business in the CBD. Expected increases are unacceptable under current operating conditions. Two alternate solutions have been proposed: transit terminals with electric trolley service interconnection along a transit mall, and a grade-separated (subway) facility. The subway alternative would involve a major investment and require a detailed analysis. Before such an analysis can be done, a decision must be made regarding the justification and need for a fixed-guideway transit component because of its implications for the regional transportation system.

LIGHT RAIL FEASIBILITY STUDY

Elected officials who form the Puget Sound Council of Governments decided to devote a substantial portion of the region's UMTA planning grant to a study of the feasibility of light rail transit in the Central Puget Sound Region

Figure 1. Adopted regional plan of freeways and expressways, 1966.

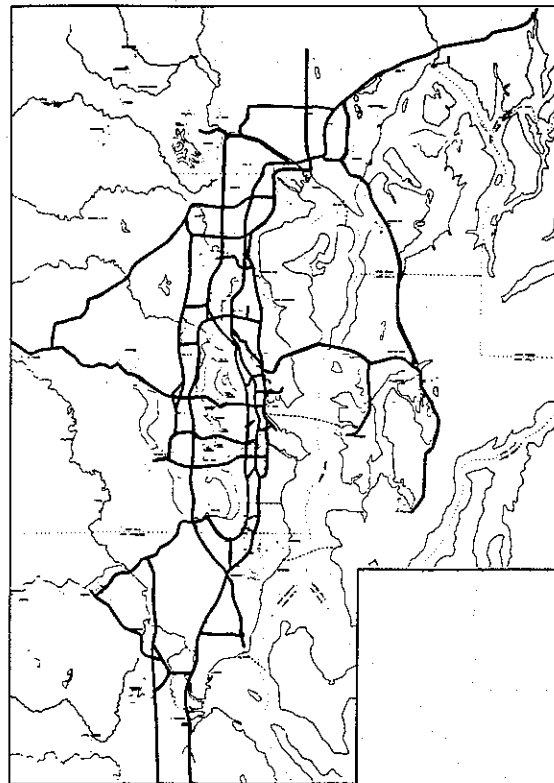
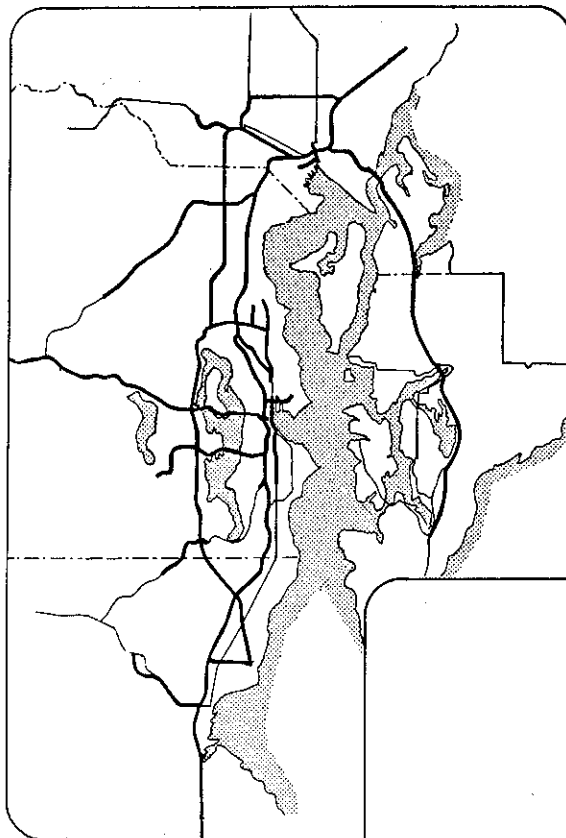


Figure 2. Year 2000 plan: freeway-expressway system, 1981.



after 1990. The objective of the study, as stated in the request for proposals, was to determine, at the systems level, whether growth trends, transportation factors, and the area's urban development objectives, projected beyond 1990, would justify a role for fixed-guideway transit in the regional transportation system.

The study was expected to provide the information necessary for a decision on whether to proceed with a detailed system level and corridor analysis of alternatives outlined in UMTA's procedure for major urban mass transportation investments.

Sponsors raised the following questions for the study to answer at a level of definition appropriate to an initial policy decision:

- Assuming incremental development of fixed-guideway segments in the transit system, what is the ridership potential compared to an all-bus system? What are the ridership thresholds in corridors and within activity centers that justify the detailed consideration of fixed-guideway technology as an alternative?
- Considering the current and forecast land use in the region, what are the potential impacts of fixed-guideway transit segments on urban and suburban development? Conversely, to what extent is justification of fixed-guideway technology dependent on changes in land use (increased densities)?
- What types of technology have a practical application in the region, and to what extent do alternative technologies have a bearing on the initial policy decision regarding fixed-guideway feasibility?
- To what extent does feasibility depend on the availability of rights-of-way and their locations for use by fixed-guideway facilities?
- Assuming incremental development of fixed-guideway transit facilities, how can an approximate estimate of capital costs be developed to provide a "benchmark" for comparison with other alternatives?
- How important are energy costs and the relative differences among energy sources in the question of fixed-guideway transit feasibility?

In October 1980, the consulting firm of Daniel, Mann, Johnson and Mendenhall (DMJM) was selected to conduct the light rail feasibility study. The draft report was presented in March 1981. Policy direction was provided by the PSCOG Standing Committee on Transportation, which includes local elected officials, State Department of Transportation officials, and transit operators. A technical advisory committee for the study was formed with representatives of the transit agencies and the State DOT.

Data Base

The feasibility study relied completely on existing data produced by the Council of Governments in the course of the transportation plan update. PSCOG had operational a battery of transportation models using the UTPS package. These models, including a mode-split model, had been validated with fairly recent data (1975 and 1977) and had been proved technically sound for estimating transit patronage. The consultant was provided with the network simulation and UTPS output information on two alternatives: a bus system substantially as it now exists, and a system with high-capacity and performance characteristics in major corridors. Existing (1977) and forecast data (1990 and 2000) for population, employment, and household groups by traffic analysis zone were already available. As part of the feasibility study, the consultant assessed the potential effect of a fixed-guideway transit component on future population and employment location. The consultant reviewed the projected transit patronage levels and

found them to be "reasonable" for use in assessing a fixed-guideway system.

Apparent Decision Thresholds

To establish a threshold transit volume level for assessing the feasibility of fixed-guideway transit, the consultant examined various studies of theoretical capacities, the actual volumes of existing systems with high-volume bus and rail corridors, and the projected volumes of new systems just being implemented. Based on the data, an apparent decision threshold in the 4000 to 7000 passengers per hour range was thought reasonable. In the Puget Sound Region, maximum peak-hour volumes as projected for the year 2000 are more than 14 000 in the I-5 corridor (north-south) and over 7500 in the I-90 corridor (east-west)—well above that apparent threshold.

Criteria and Methodology

The consultant identified criteria by which to compare the all-bus and fixed-guideway alternatives. The criteria covered 4 major transit areas: performance and operating factors, cost factors, urban factors, and environmental factors. Within each area, from 2 to 5 sub-items were identified (Table 1) together with the basic analysis methodology used in the preliminary assessment.

Corridor Analysis

The first task was to identify the candidate corridors and to define, in concept form, alternative all-bus and combination rail and feeder bus systems to serve each corridor. The consultant used the projected year 2000 transit patronage and assignments and selected the following corridors:

- I-5 North (to Everett),
- I-5 South (to Tacoma), and
- I-90 East (to Bellevue and Kirkland).

Each is a radial corridor connecting with the Seattle CBD. The corridors were selected on the basis of projected transit volume and auto congestion levels.

With the definition of the study corridors and their respective demand volumes, concept level transit systems were developed for all-bus and light rail service.

Findings

Capacity

Either system has the capacity, under the assumed operating concepts, to satisfy the projected peak-hour demand volumes in the year 2000, as well as the ability to expand capacity, within limitations, if necessary. For the bus system, the stations and terminals are the limiting factor since the volume of buses per hour that can be handled in these facilities is a function of the size of the station/terminal. In the case of the rail system, the capacity is a function of the train length and headway.

CBD Issues

Capacity limitation is a particularly critical issue in the Seattle CBD. Among the options proposed as potential solutions, the one preferred is based on a twin terminal concept; regional buses would be intercepted at the north and south ends of the CBD, and CBD circulation then provided by electric trolleys operating in a mall or tunnel. This option was accepted for the LRT study and examined in the context of the impacts of a regional rail element. The evaluation found that the most dramatic impact of the regional light rail system is a major reduction in terminal sizes required. If a tunnel solution is adopted, additional savings would be realized because a smaller tunnel and stations would be required. Thus, a regional rail system

Table 1. Preliminary criteria list.

Factor	Analysis	
	Quantitative	Subjective
1. Performance		
Capacity	X	
Trip time (or vehicle speed)	X	
Energy efficiency	X	
Compatibility with demand distribution		X
Expansion and growth potential		X
2. Cost		
Capital cost	X	
Operating and maintenance cost	X	
3. Urban		
Transit-induced development opportunities	X	X
Accessibility		X
Community disruption		X
Interface with other modes		X
Consistency with adopted subregional areawide plans		X
4. Environmental		
Aesthetics		X
Noise		X
Air pollution		X

will not only work with the various CBD concepts but also reduce the net cost significantly.

Travel Time

Corridor travel times were found to be comparable under either option.

Energy Efficiency

The consultant compared the energy efficiency of the two options only with regard to the unit consumption of each mode. Total annual operating miles were not developed, so neither the total operating energy requirement nor the construction energy requirement could be developed. The comparisons were made on the basis of energy per vehicle-mile, per passenger-mile at various load factors, and per passenger-mile based on average system productivity in actual system operations. The LRT vehicle was found to be the most energy efficient in each comparison.

Comparing the difference in cost (current prices) between diesel fuel and electricity to operating efficiencies, the energy cost per passenger-mile for the bus system is, on the average, about double the cost for LRT. The region's relatively low electricity cost is an important factor in keeping down the energy cost of rail modes.

Capital and Operating Costs

The level of detail in the feasibility assessment severely limited the development of cost data. However, the consultants were able to estimate a capital cost of \$417 million to \$582 million for the bus system, depending on the CBD solution used, and a capital cost of \$825 million to \$990 million for the entire rail system. The cost estimates assumed use of existing right-of-way for both systems, except for minor transition points. The rights-of-way include Interstate highway lanes and parts of the old interurban system that connected Seattle, Everett, and Tacoma. Thus, no major new structures would be needed.

Comparison at the total system level indicates that the total 80+ miles of rail probably cannot be justified. However, when assessed on a segment basis, the comparisons better indicate the relative value of the modal op-

tions. For example, bus system costs at the outer ends of the corridors are minimal; almost all its cost except for maintenance facilities and bus fleet is in the central, high-volume corridors. The capital cost of the rail system, however, is virtually the same throughout the corridor regardless of volume, except for vehicles and maintenance facilities. Nearly 40 percent of the rail segment is in lower volume segments; reducing the system by even 20 miles will bring the two systems' total capital costs closer together.

Operating cost estimates were based only on peak-hour service and were \$14 450 for the rail system and \$16 320 for the bus option.

Transit-Induced Development

The last criterion for which quantitative analysis was conducted related to the potential for transit-induced development under each option. This analysis, conducted by a subcontractor, reached the following conclusions:

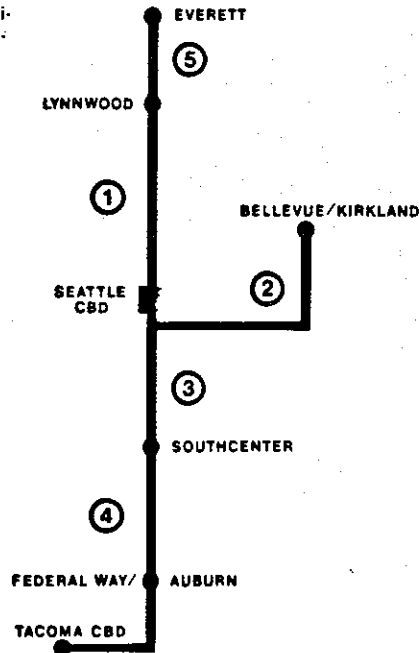
- Major improvements would be needed to produce significant transit-induced development in the freeway corridors; development would be similar under either option.
- High-capacity transit located in nonfreeway corridors would be more likely to generate significant transit-induced development; rail impacts would be the most significant.
- The most likely development would be intensified residential development in the outer reaches of the corridors through in-filling or single-family and new multi-family residences near station stops.
- The most likely core area impacts would be to reinforce office/commercial development.
- The overall impacts would generally support current growth management policy.

Conclusions

The consultant study produced the following findings:

- A regional light rail element has the potential for

Figure 3. Ranking of corridors, light rail transit feasibility.



major cost savings and reduced transfer volume in terminals when compared to various bus-related options for solving the Seattle CBD issues.

- Light rail costs may be comparable to those of an all-bus system, considering the level of investment expected in the high-volume segments of the corridors with the all-bus option. Life cycle costs may also be comparable and potentially more favorable because of differences in operating costs and vehicle life. A more detailed analysis is necessary to determine these relationships accurately.
- LRT system operating costs may be lower at the demand levels projected by recent PSCOG studies.

- An LRT system has a significant potential for reduced energy consumption, particularly petroleum fuels.

These findings indicate that a feasible LRT project exists and warrants inclusion in a detailed alternatives evaluation. However, the findings also indicate that the project must be on a lesser scale than the full 80+-mile system described in this assessment. In that context, the probability of a feasible and cost-effective project within a corridor or combination of corridors may be ranked as follows (Figure 3):

1. The north corridor, including the Seattle CBD, between the CBD and the general Lynnwood area;
2. The east corridor from the Seattle CBD to some point north or northeast of Bellevue;
3. The south corridor to some point south of South Center (preferably in a nonfreeway corridor);
4. The south corridor to Tacoma; and
5. The north corridor to Everett.

FUTURE STEPS

The first step after completion of the feasibility study was to put light rail transit in the regional transportation plan update as a long-term recommendation.

The next step will be detailing the system and evaluating light rail compared to buses in individual corridors. This will involve looking at alignment, station location, system operation, and connections with a feeder bus system. The consultant has done a fairly detailed scope of work for this phase, and the PSCOG plans to request an UMTA Section 8 alternatives analysis grant when the FY 1982 appropriations bill becomes effective.

In the meantime, PSCOG is working with the City of Seattle and Metro on the environmental impact statement for the midrange transit alternatives for the Seattle CBD to ensure that light rail transit could be accommodated if it later became the chosen mode. The CBD project also has tasks, not yet begun, that deal with such long-term solutions as dual-mode vehicles operating in a tunnel, LRT in a tunnel, and LRT on the surface with terminals and a mall. The objective is to preserve the option for a future regional light rail transit serving the Seattle CBD.

Suburban and Interurban Applications of Light Rail Transit

RICHARD F. TOLMACH, California Department of Transportation

While most analysis of light rail transit has been focused on urban premetro and semimetro development, many of the more successful European light rail developments have been on routes that operate primarily on off-street surface trackage through low-density suburban and rural areas. This paper examines design and operations of light rail systems that serve areas of low population density. Six European and three North American examples are described, with attention to geographic, sociological, and financial aspects of their operating environments. Scheduling strategies, fare structures, and methods of traffic generation used by these systems are given special emphasis. The prospects for future North American interurban light rail developments are examined, with a view to San Diego's new system being a model for selected conversion of North American intercity railroad facilities to provide electric interurban services.

The words "light rail transit" often do not convey the technology or development philosophy symbolized by them. They are misunderstood by the public and even by some transportation professionals. Many Californians fixate on the word "light," and imagine light rail transit to be a form of automated people mover technology; this causes someone to explain that light rail is "modern streetcars." This simplified definition has been tolerated by transportation professionals, but it causes more misunderstandings. To describe the light rail systems being built in North America today in terms of streetcars is obviously inadequate. One can invoke such European terms as "pre-metro" or "Stadtbahn," but this does not help explain the attributes of light rail.

The model for light rail's development is not streetcars down Main Street but the interurbans' innovative use of a variety of rights-of-way. Light rail's future is not in

narrow, 45-foot cars based on street railway practice but in cars that are longer, wider, heavier, and owing more to interurban practice. The functional role proposed for most new systems is not to serve compact cities' local trips but to provide regional trunk services for the decentralized urban areas of North America, with bus services providing the local feeders.

The purpose and meaning of light rail transit are not simply modern streetcars—it is the creation of affordable metropolitan railways to serve regional travel needs. In view of this, suburban and interurban applications of light rail have the most to offer American cities in terms of relevant examples. (See Figures 1 and 2.)

THE EUROPEAN EXPERIENCE

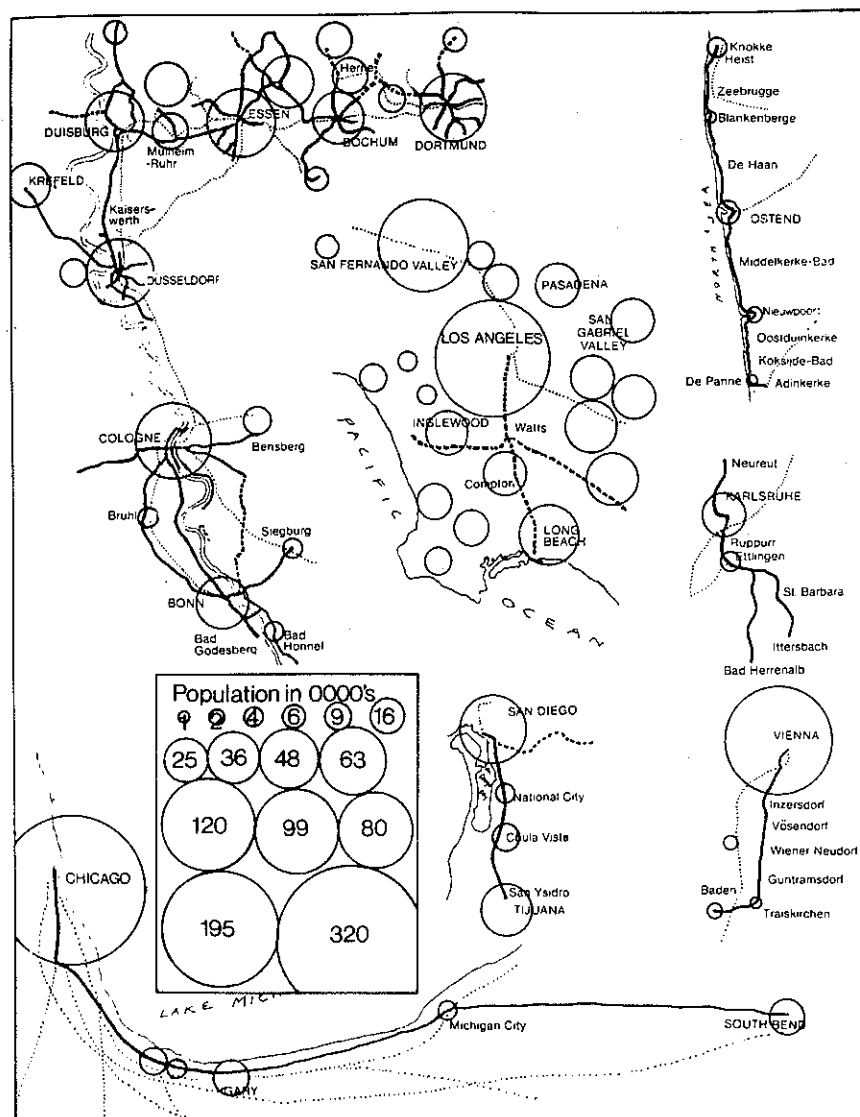
The technology used in Edmonton, San Diego, and Calgary came from West German Stadtbahn development, which also was heavily influenced by interurbans. Stadtbahn systems incorporated many elements of standard rapid transit practice; however, much of the Stadtbahn concept, including design of Stadtbahn cars, originated from the need to optimize existing interurban electric railways for modern transit needs. Cologne, Frankfurt, and Hannover, the first cities in West Germany to develop Stadtbahn systems, all began with interurban lines that influenced their system and vehicle designs.

Each of these cities created its Stadtbahn by linking high-standard suburban and interurban lines by constructing new sections of central city trackage to bypass restrictive curves and clearances. This allowed higher speeds and the use of wider, longer cars with rapid-transit-type capabilities. The station spacing, speed characteristics, and off-street rights-of-way of German interurbans were elements critical to the success of the Stadtbahn concept. These elements are now being attributed to light rail; however, where interurbans still survive, these elements, as well as a wealth of lessons about economics and expedients of the transit business, may still be observed.

The sources of interurbans' financial viability—freight haulage, charter traffic, resorts and other innovative side-lines, labor productivity, efficient equipment use, and unconventional traffic such as tourist and intercity trips—are important examples for transportation planners in an era when urban bus networks typically have a farebox ratio of less than 30 cents on the dollar. European interurbans today operate cost-effectively, even in environments that would be considered impossible territory for rail transit by North American transportation planners.

An examination of today's interurban networks and their operating environments may help define the limits of light rail—how sparse a population can support light rail or how large and dispersed an urban area can be and still have an effective light rail network.

Figure 1. Comparative population of areas with interurbans.



The Rhein-Ruhr agglomeration in West Germany is the site of the largest network of electrified urban transit services in the world. The German Federal Railway and local transit enterprises provide hundreds of miles of railway and tramway services spanning a 90-mile expanse from Bad Honnef and Bad Godesberg in the south; north through Bonn, Köln, Düsseldorf, and Duisburg; east through Mülheim, Essen, and Bochum to Dortmund. The Rhein-Ruhr urban area is even more decentralized than Los Angeles; it does not contain a single predominant center of business activity, but 3 primary ones and 6 secondary ones. Most jobs are outside these centers, in factories and strip commercial developments reminiscent of American regional cities. The northern tier of cities, from Düsseldorf to Dortmund with the cooperation of the German Federal Railway, recently organized all local rail and bus services into a consolidated tariff organization, the Verkehrsverbund Rhein-Ruhr. Four separate "schnellverkehr" (express transit) services are incorporated into the VRR: Düsseldorf's Rheinischebahn interurban lines to Krefeld and Duisburg, sections of the projected Rhein-Ruhr Stadtbahn, the German Federal Railway's S-Bahn services throughout the region, and Wuppertal's unique monorail.

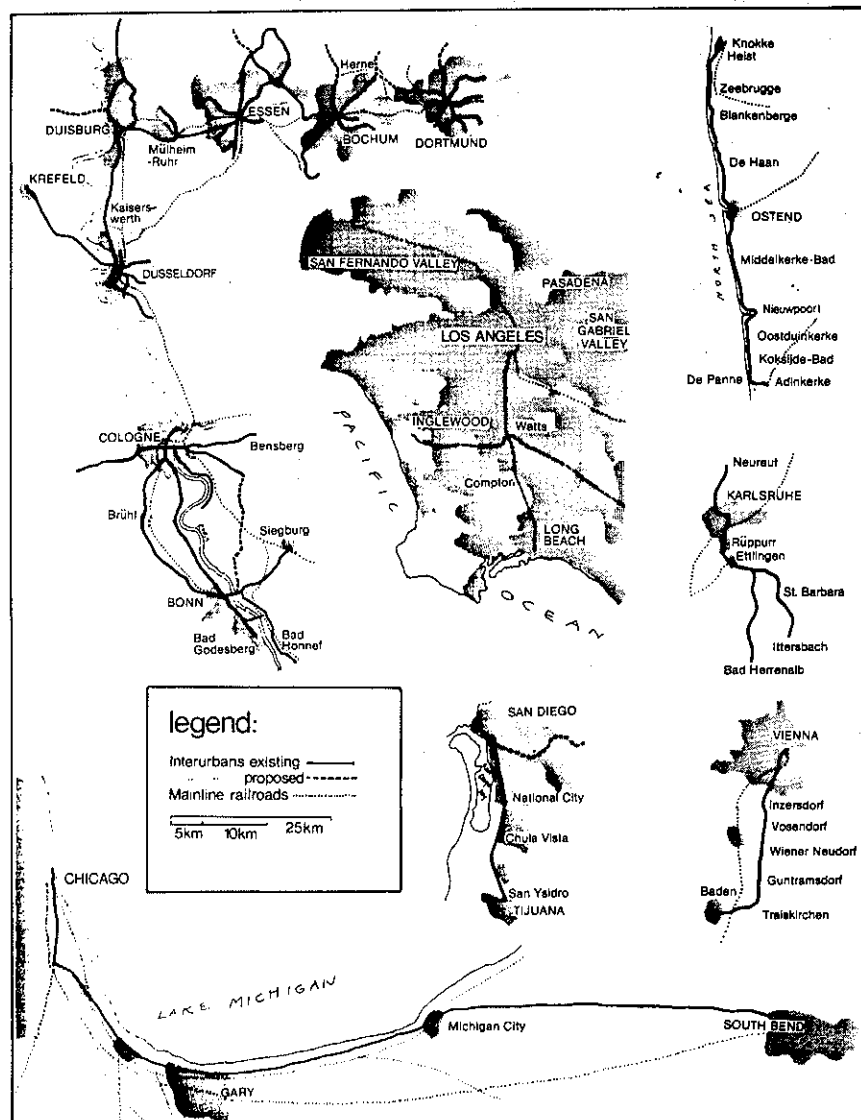
The southern tier of cities on the Rhein, from Köln's northern suburbs to Bonn's southern suburbs, now also have through tramway service and tariffs and have organized their lines into the Rhein-Sieg Stadtbahn.

The least densely populated areas served by interurbans in the Rhein-Ruhr are on the Krefeld (22 km) and Duisburg (25 km) lines of the Rheinischebahn, which roughly parallel the Rhein on opposite banks. The Krefeld-Düsseldorf line has no intercity railway competition; it has a heavy through ridership to Krefeld on its direct route. There are 20-minute headways, often using two 8-axle Düwag cars. The Duisburg-Düsseldorf line, which must compete directly with a faster, 20-minute headway S-Bahn service, has had less end-point-to-end-point travel. Its main ridership comes from intermediate towns unserved by the S-Bahn, but it also attracts some through passengers on its half-hourly service by providing a buffet car in the center section of its Rheinbahn cars.

These 2 interurban lines both went underground in Düsseldorf with the October 1981 start of U-Bahn service, and Düwag "Stadtbahn B" cars, similar to those of Essen, Cologne, and Bonn, are now assigned to these runs. The subway sections eliminated the last sections of line on the 2 interurbans that necessitated the sharper turning radius of the Rheinbahn cars. Duisburg is also constructing a section of subway trackage to be used by the Rheinischebahn line, as well as by the projected Rhein-Ruhr Stadtbahn, and Duisburg will also use the Stadtbahn B car.

The street railways of the Ruhr basin have become increasingly constricted by traffic congestion. Although their span is 25 miles and total trackage is in the hundreds,

Figure 2. Comparative scale of interurban electric railways.



these predominantly meter-gauge lines had few real interurban or light rail characteristics until recently, when the sections of subway and other grade-separated routes constructed for the Rhen-Ruhr Stadtbahn came into use.

The Stadtbahn was originally planned to be a wholly standard-gauge, grade-separated network that incorporated the strongest routes in the region. About 15 percent of its routes are still to be constructed to full metro standards, with grade separations and high platforms. Stadtbahn B cars have been ordered, indicating that some on-street or at-grade operations are anticipated. The main east-west route of the Stadtbahn is taking shape through separate construction projects in Duisburg, Mülheim, Essen, Bochum, and Dortmund; the Mülheim-Essen segment and a Bochum segment are already in operation. North-south links of the Stadtbahn, some of which may remain meter gauge, are to be constructed (or upgraded) to feed the east-west spine and its S-Bahn competition. The integration of the Federal Railway's S-Bahn and the Stadtbahn is particularly good, with common facilities at the main railway stations in Duisburg, Essen, Bochum, and Dortmund.

Köln (Cologne) may be said to have begun the Stadtbahn movement. Its Kölner Verkehrs-Betriebe accommodated interurban operators on its tracks; accordingly, many of its lines are constructed to impressive standards. Since completion of central city U-Bahn trackage, the KVB has operated large Stadtbahn cars virtually to the exclusion of 4-axle cars. The Köln-Bonner Eisenbahn, an interurban similar to Chicago's North Shore line in speed and facilities, has now had one of its 2 routes integrated into the U-Bahns of Köln and Bonn, as Route 16. This 45-km line links Köln, Bonn, and Bad Godesberg with half-hourly service, which lacks the 80-mph top speeds of the old KBE equipment, but makes up for that with improved connections and better coverage of the commercial centers of Köln and Bonn. Bonn's cross-Rhein suburban routes serve an area with the most Americanized landscape in Europe, including a Disneyland-like amusement park in Rheinau.

The Rhein-Ruhr provides the most pertinent model for transit development in large decentralized cities of the western United States, as it has combined the following techniques:

- Utilization of existing main-line railroads for trunk high-speed transit,
- Combination of existing interurban tramway trackage between cities with new grade-separated construction to tap commercial centers, and
- Full integration of these two "schnellverkehr" modes with each other and with local feeder buses and streetcars.

These techniques have effectively linked all major employment centers, commercial centers, and residential areas in the decentralized Rhein-Ruhr area with high quality transit at a reasonable cost.

Other interurbans show how less populated areas can support rail transit and how recreation areas can be developed without heavy investment in highway access. A recurrent issue in California is how to preserve popular coastal or mountain areas from overdevelopment and yet accommodate greater public use of these areas.

In the United States, development of recreational resources has almost always assumed that there is no alternative to highway-based access. Unfortunately, highway-based development for recreational use of scenic areas often results in marring the natural beauty that originally attracted the tourist traffic. Although parking lot proliferation and air pollution in western parks has been the subject of numerous newspaper articles and government studies, no alternative development model has emerged.

In Europe, interurban tramways have been widely used in place of, or along with, highways to provide access to

wilderness and scenic areas. The Tatra National Park in Czechoslovakia, for example, uses a narrow-gauge electric tramway to provide access to the park from the intercity main-line railhead in Poprad, 13 km away. There is also 20 km of additional tramway routes inside the park that provide access to certain areas where automobiles are banned. Switzerland has many such places where automobiles are denied access to areas served by tram, including mountain villages such as Zermatt and Wengen, whose lively tourist trade is because of their unspoiled tranquility. Switzerland's auto-free villages are pleasing to the eye, the nose, and especially the ear. It is an uncanny experience to be outdoors in a village where sounds of human activity predominate rather than those of internal combustion engines.

If the concept of auto-free recreation area development is too advanced for Americans, there are examples of European tramways that compete with automobile access in such areas. The coastal Vicinal tramway of Belgium and the Albtalbahnhof of West Germany illustrate the use of such recreation-oriented tramways.

Operated by the Societe Nationale des Chemins de Fer Vicinaux, Belgium's coastal tramway may be the longest continuous tramway corridor under exclusive passenger operation. Its 40-mile (65-km), narrow-gauge route follows the coastal dunes from the French border to Holland and links all Belgium's coastal towns. In the absence of any north-south railroad service along the coast, the line serves as a de facto part of the national railway system. Its Ostend terminal is located optimally, adjacent to the railway and channel ferry terminals. The line incorporates a wide variety of trackage, including mixed-traffic running in Ostend.

Until recently, its capital facilities had been allowed to deteriorate. The new 6-axle trams, built by BN Industrie in Brugge in 1981 to replace the 1940's 4-axle trams, have been accompanied by substantial reconstruction of portions of the route, new power supply equipment and overhead wire support, and a certain amount of relocation of tracks into reservations.

Inefficient labor practices and undercapitalization in the past limited the financial success of the line. Instituting a one-man operation system and providing new, attractive equipment and automated ticketing are likely to improve its performance. The nature of the line's traffic is more typical of a main-line intercity railroad than a transit line. It offers no peak-hour service except one short run morning and evening, because no major employment centers are on the line.

The Vicinal has a heavy summer peak; British and Continental tourists besiege the Belgian Coast in July and August. During these 2 summer months, the coastal tramway runs on 30-minute headways, compared to 60-minute headways in the colder months.

The decision by Belgian transportation authorities to invest substantial sums in the line to rebuild its capital facilities and provide new cars was made in the context of land use planning decisions that called for preservation of undeveloped areas of the coast. A tramway is more appropriate than further highway development for this area; it is less visually intrusive and requires less land. The tramway can provide access to beaches by simply stopping; auto access requires parking lots and other facilities that would despoil the beauty of the coast.

The Albtalbahnhof, operated by the Albtal Verkehrs Gesellschaft (AVG), is a standard-gauge interurban tramway that links Karlsruhe, West Germany, with its northern and southern suburbs and provides a regional service through the woods to several small towns and resorts on the northern edge of the Black Forest. Both the Ittersbach and Bad Herrenalb branches are sparsely populated, and a number of the Albtalbahnhof's relatively infrequent stops are made at locations where no urbanization is visible. South of Ettlingen, the last true suburb of Karlsruhe, the primary traffic on the Bad Herrenalb line is vacationers traveling to spas and Black Forest resorts. The traffic to Ittersbach

is more typical. Both branches use Düwag and Waggon-Union 8-axle, articulated cars to provide staggered half-hour headways during off-peak periods. A local service fills in from Ruppurr to Karlsruhe, so the closer suburbs have 10-minute headways all day.

The German Federal Railway interchanges freight traffic with the AVG near Ettlingen, and the AVG does a moderate freight business on its southern lines, using diesel switching locomotives for traction. Despite the presence of freight, there are gradient changes on the Ittersbach line that would preclude long trains, and the line's engineering appears to be optimized for tram use.

The Albtalbahnhof's financial performance is good. According to the 1979-1980 *Jane's World Railways*, the line has an operating ratio of 0.83. This profit may be partly due to such side businesses of the AVG as charter tours, rail freight, and motor transport, but the rail passenger business is a near break-even operation.

Some factors making the Albtalbahnhof so cost-effective merit examination. The Bad Herrenalb line has no peak-hour operations; the stations exclusive to it are beyond the commuter zone. Its equipment is shifted to the Ittersbach line during peaks; it actually has two 60-minute gaps in the schedule during the morning peak. This substantially reduces the need for equipment that would be used only in the peak hours.

Much of the Albtalbahnhof's traffic is linked to arrival and departure of midday intercity trains, so it realizes revenue during periods when most transit systems have light patronage. The tourist traffic is not as seasonal as that of the Belgian coastal tramway but has several peak periods, e.g., spa traffic in the spring, hikers in the summer and fall, and substantial winter sports traffic. Tourist traffic fares are appropriately priced to maximize revenues. Karlsruhe Hauptbahnhof to Bad Herrenalb had a 4-Deutschmark tariff (\$2.05 U.S.) in 1980, substantially higher than for equivalent distances on other transit systems or the German Federal Railway. At the same time, local commuter travel was reasonably priced.

Freight haulage is also an important supplemental revenue source for the Wiener Lokalbahn, a 30-km, standard-gauge interurban linking Vienna, Austria, with the resort of Baden. The Lokalbahn's right-of-way includes mixed-traffic street operations, sections of railroad-type right-of-way, highway-side, tramway-type reservations, and shared trackage with Vienna's light rail system in subways and on the surface.

The nonarticulated 1920s and 1930s interurban cars of the Lokalbahn are slowly being replaced by 8-axle cars similar to Düwag's Rheinbahn cars. Other investment in the line seems to have been postponed, and the Lokalbahn retains its quaint stations and arching catenary supports. Other such traditions persist as a conductor on-board, manned stations in place of automatic ticket machines, and charter parlor car service. The Wiener Lokalbahn also provides scheduled bus services that parallel and connect to the Vienna-Baden corridor and has a fleet of 3 switching locomotives to work the freight carried to its connection with the Austrian Federal Railway.

The Lokalbahn's operating environment is increasingly competitive, but its market share has not suffered greatly. Its terminal in Vienna is on the surface at the Opernring, a more central location than that of the S-Bahn trains. It also has an advantageous central location in Baden, while the S-Bahn must use a station on the edge of town. Additionally, significant traffic is generated by suburban stops 10 to 16 km from Vienna.

THE AMERICAN APPLICATION

The Chicago, South Shore, and South Bend Railroad, the last surviving interurban of Chicago's Insull empire, is a good example of integration with main-line railroads. It is owned by the Chessie system, and its trains enter Chicago on the tracks of the Illinois Central Gulf Railroad and share the ICG's Central Station on the lakefront.

The South Shore's adoption of railroad standards and practices and integration into the freight-hauling railroad system are the primary reasons for its survival. Its volume of freight haulage is substantial, with unit coal trains contributing a large proportion of ton-miles. The South Shore penetrates the primary industrial area of northern Indiana, a center for steelmaking, manufacturing, and other industries that require mass quantities of resources and must have ample freight traffic both inbound and outbound.

On the other hand, the South Shore's passenger services were a major financial liability for over a decade. The Illinois Regional Transportation Authority and the State of Indiana have stepped in to support these services. In the face of declining passenger traffic during the 1970s, the South Shore adopted a tactic from intercity main-line railroading—it cut back passenger services and raised fares. The public response was predictable and led to a subsequent round of service cuts and truncation of most of the trains at Michigan City.

The South Shore has gradually lost many attributes required to attract passenger travel. Its fleet of Pullman-Standard cars, dating from the 1920s, is literally falling to pieces. Service has been cut to an almost unsalable level, with only 2 daily round trips beyond Michigan City and 2-hour headways during midday between Michigan City and Chicago.

The appearance and condition of many of its stations deter ridership. The level of maintenance of vehicles and electric power facilities has reduced reliability and comfort of service.

The South Shore has also lost most of its interurban character by terminating on-street operations penetrating the commercial center of South Bend. This cutback lost most of the remaining South Bend traffic and is now recognized as having been a mistake.

New terminal facilities in South Bend and possible direct service to the South Bend Airport area are expected to recover the ridership losses there. New 85-foot main-line railroad-type cars are on order and will provide the foundation for reinstituting more frequent operations, the best hope for improvement of the South Shore's market share.

Although other surviving electric tramways in the United States are not now operated in conjunction with freight service, many of the more successful surviving lines have sections of off-street rights-of-way and station spacing typical of interurban operations. These lines include Boston's Riverside line; Philadelphia's Media, Sharon Hill, and Norristown lines; Cleveland's Shaker Heights line; and Pittsburgh's South Hills line.

America's new interurban, the San Diego Trolley, was fashioned out of the remains of a marginal freight-hauling railroad—the San Diego and Arizona Eastern. It has been a remarkable experience for Californians to observe how rapidly and inexpensively it was converted. Only 20 years ago, Los Angeles' Pacific Electric, a major passenger-hauling interurban, became a set of marginally viable freight branches with limited social utility.

The SD and AE's conversion into the San Diego Trolley was accomplished by adding electrification, new rail, and a new line tapping the commercial center of San Diego. The only station facilities are several parking lots and tile-roofed shelters located at major cross streets along the line. Total cost, including cars, was about \$5 million per mile.

The specifics of the facility have been discussed but what is important is the applicability of the development to other Californian cities. It would be just as easy to revive the Los Angeles-Long Beach line of the Pacific Electric as it was to convert the San Diego-Tijuana line. Despite protest of Los Angeles freeway apologists, it is difficult to imagine how something that works so well in San Diego would not work 100 miles up the coast.

Previous claims held that California was different from other places because its population density was so low

that it could never afford rapid transit systems extensive enough to serve its metropolitan regions. San Francisco's BART and San Diego's light rail system have put the lie to these suppositions.

San Diego's accomplishment is particularly embarrassing for Los Angeles because the San Diego-Tijuana capital works have been accomplished for about the same sum as Los Angeles public agencies have spent over the past 25 years on alternative analyses and engineering for never-built rail lines.

Whatever the eventual outcome of the Los Angeles debates over transportation policy, it should be obvious that population density is a not an issue in coastal California. The Los Angeles-Long Beach line has roughly twice the density of San Diego-Tijuana and roughly 20 times the density of the Belgian coast or the Karlsruhe area in West Germany, where the Albtalbahnhof operates.

Beyond about 100 passengers per trip, the economics of electric rail transit are superior to that of the bus, regardless of population density, length of the travel corridor, or category of traffic. There is little hope of fares ever covering 80 percent of bus system operating costs. San Diego's light rail system is already achieving this coverage rate, largely because of "recreational" traffic, such as tourists and intercity travelers.

Highway and air transportation systems derive a large percentage of their traffic from recreational travel, a trade that currently gives the airline industry its only profitable seasons. The transit industry's failure to attract a substantial noncommute traffic with buses shows the public's lack of acceptance of the all-bus mode. The recreational and intercity connection markets are particularly lucrative ones for the transit industry, because the trips are most often made during nonpeak hours when there is ample excess capacity. When transit systems were privately run, there was more promotion of recreational

travel, and amusement parks and other traffic-generating facilities often were purpose-built by the companies. If public transit enterprises are to be operated in a more businesslike manner in the future, the industry must recognize that off-peak discretionary traffic is good for business no matter what its purpose.

Finally, the potential revenues from freight haulage should not be overlooked. Even lines with marginal car-loading levels and lines that railroads consider abandoning may, with more efficient labor practices, offer a net gain by continuing freight service. The successful mixing of freight and transit on the Köln-Bonner Elsenbahn, the Albtalbahnhof, the Wiener Lokalbahn, the South Shore, and the San Diego Trolley shows that this practice is not hazardous and is by no means innovative.

CONCLUSIONS

The electric railway is a flexible, versatile, and inexpensive means of providing transportation of people and materials. Only when inadequate conceptions of its parameters and capabilities are applied do its form and abilities become limited. When conceived and constructed as a street-railway, it becomes limited in speed and passenger attraction because of traffic congestion. When conceived as a subway with full grade separation, it becomes unduly expensive to construct and limited in range. Under either conception, it loses the ability to provide freight haulage or attract significant recreational traffic and also becomes limited in its applicability to modern cities.

The term "light rail transit" has been moderately successful in breaking through the inadequate conceptions of what rail transit can be. To continue the breakthrough, a definition of light rail that incorporates all the capabilities and potential uses of the electric railway must be applied.

Maintaining Transit Service During Light Rail Rehabilitation in Newark: A Case Study

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The Newark City Subway is a 4.3-mile (6.9-km) light rail system with 11 stations and an average weekday ridership of 12 600 passengers. As part of the \$15 million rehabilitation of this New Jersey Transit Corporation line, alternative transit service will be required during off-peak periods when rail service must be suspended. Suspension of service at night and on weekends is necessary to accommodate rehabilitation of the track, stations, and right-of-way. In developing alternative service options, the advantages of light rail service along the corridor became apparent, both from the perspective of the passenger (travel time) and the operator (operating cost). This paper documents the planning methodology used to develop ridership data and operating plans for alternative bus service. As a result of the alternative service planning, it was determined that the light rail system required significantly fewer vehicle and crew hours than did buses to provide equivalent service and capacity.

The Newark City Subway is one of the few streetcar subways remaining in operation in the United States. Completed in 1935 and operated continuously to the present time, the line has gradually deteriorated as the

financial problems of its owners and operators limited the resources available for maintenance and rehabilitation.

During the 1970s, state agencies' increased concern with mass transit led to renewed interest in preserving the mass transit infrastructure of urban areas. This concern caused state and local officials to take a fresh look at the Newark subway and to include it in an overall program of transit rehabilitation in New Jersey called "Transpac." Under the terms of Transpac, funds from a bond issue and from the Port Authority of New York and New Jersey would be used as a local matching share for an UMTA capital grant. Approximately \$14 million was earmarked for improvements to the Newark City Subway.

The subway rehabilitation program was to stress renewal of the fixed facilities of the system. Procurement of new vehicles was to be included in the program's later phases. During the planning of the rehabilitation design and engineering work, it became obvious that normal service would need to be suspended for extended periods to expedite the trackwork and right-of-way rehabilitation. As part of the engineering design, an operations planning task was undertaken.

This paper reports on the methods used to plan for

maintaining service during the rehabilitation process. In the course of this analysis, some of the operating efficiencies of light rail were highlighted. This paper has the following goals:

- To document some of the characteristics of the Newark City Subway,
- To report on the operations planning methodology, and
- To compare the operating characteristics and costs of the LRT with alternative bus service.

LINE CHARACTERISTICS

The Newark City Subway is a 4.3-mile (6.9-km), 2-track streetcar subway that starts at Penn Station in downtown Newark and extends northward to Franklin Avenue within a mile (1.6 km) of the city limit. From Penn Station, the system operates in subway for approximately 1.4 mile (2.2 km) and serves 4 underground stations. For the remaining 2.9 mile (4.6 km), the line runs in open cut and at grade and serves 7 (3 at-grade and 4 in-cut) stations. At the terminal stations (Penn Station and Franklin Avenue), loop tracks are used to reverse the cars for the return trip. The system has only one grade crossing, located adjacent to the Orange Street station.

The line operates approximately 20 hours a day. Cars operate at 2-minute headways during peak hours, at 5- to 6-minute headways during the midday period, and at 10- to 15-minute headways during the early morning (5:00-6:30 a.m.) and early evening hours. From 11:00 p.m. to shutdown at 12:47 a.m., service is provided at half-hour headways. On weekends, Saturday headways vary from 7 to 10 minutes during the day and extend to 30 minutes in the late evening. Sunday service is provided on 15- to 20-minute headways during most of the day.

At Penn Station, the subway offers connections to Amtrak's northeast corridor trains, the Port Authority Trans-Hudson (PATH) services to lower and midtown Manhattan, NJ Transit commuter trains to the north Jersey shore and central New Jersey, and to numerous local and intercity bus lines. At several other stations, transfer service is provided to NJ Transit bus lines. The line serves downtown Newark, several local colleges and universities, and the densely populated North Ward of the City of Newark. Average weekday ridership is 12 600 passengers.

Service is provided by a fleet of 30 Electric Railway Presidents' Car Conference (ERPCC) streetcars built between 1945 and 1947 and purchased secondhand from Minneapolis in 1954. Average line speed is 21.5 miles per hour (34.4 km/hr). Cars are single-ended with doors on the right side only and have 55 seats. Stored underground on layover tracks at Penn Station, the cars appear to be in remarkably good condition, with fresh paint both inside and out. They are kept clean and do not suffer from the graffiti epidemic that plagues other northeastern transit properties. Direct current for traction power is distributed from an overhead trolley wire. Station lighting is also fed from the traction power system.

Fare collection is a curious mixture of both on-board and in-station that changes throughout the course of the day. Passengers boarding cars southbound to Penn Station pay upon boarding; outbound passengers on northbound cars pay on-board as they leave. However, at the downtown stations during the afternoon peak, fares for northbound passengers are collected on entry to the station. At certain other stations, attendants are present during the morning peak to collect transfers and cash fare receipts from southbound passengers.

HISTORY

Around the turn of the century, Public Service Coordinated Transit Co. (PSCT) absorbed most of the independent trolley lines serving northern New Jersey, creating an 850-mile (1360-km) network with 2500 streetcars. Newark

served as a major hub for this system; in 1910, as many as 525 streetcars per hour traversed the intersection of Broad and Market Streets.³ This undoubtedly led to the subway development which provided ramps connecting to surface car lines at four locations to expedite through service to downtown. By 1935, when the subway was built, PSCT's network was in the process of diminishing to 8 lines and 74 miles (118 km) of route. By about 1950, the connecting surface trolley routes had been converted to bus, and the subway was operated as a closed system.

The subway itself was constructed in the bed of the abandoned Morris Canal. While the cars were owned and operated by Public Service Coordinated Transit, the subway structure was owned by the City of Newark and leased to PSCT. A separate corporate entity, Transport of New Jersey, was established to run both the subway and bus lines when PSCT sought to separate the money-losing transit operations from the profitable electric and gas utility companies. In 1979, the State of New Jersey set up NJ Transit, a public corporation, to take over all commuter rail and bus operations in the state, including the Newark City Subway.

REHABILITATION PROGRAM

The rehabilitation program focused on renewing deteriorated system components. Specifically, the following eight objectives were identified for the program:

- Providing increased security for passengers;
- Providing increased safety and reliability of operation;
- Maximizing efficient use of energy;
- Creating aesthetically pleasing stations for the riding public;
- Providing an upgraded system with respect to track, stations, right-of-way, and maintenance facilities;
- Keeping the public well informed on the nature and progress of the work;
- Accomplishing construction with minimum impact on transit operations, patronage, and adjacent communities; and
- Completing the entire project by November 1983.

The major components of the project involve improvements to tracks and rights-of-way, stations, the maintenance shop, and the electrical power system.

Track and right-of-way rehabilitation will constitute the major portion of the project and will extend over a 2-year period. The entire track structure, from subgrade drains to rail top, will be renewed and rehabilitated. Most of the track will be rebuilt with new, continuous-welded rail.

Station rehabilitation will be the most visible aspect of the renewal program. It will include considerable work on repairing and modifying stairs to improve station access and visibility, new lighting and graphics, and resurfacing platforms. New canopies and shelters will be installed at the above-ground stations.

Improvements to the mechanical system include installing new car hoists at the Penn Station maintenance shop, new sewage injectors, and new rectifiers for the traction power system.

RIDERSHIP AND OPERATIONS DATA

(Ed. Note: The information provided in this section was prepared during the spring of 1981. Since then a fare increase and some bus route changes have occurred. Adjustments have been made to accommodate these changes.)

The Newark City Subway carried an estimated 3 429 990 passengers in 1980, according to information supplied by the operator, Transport of New Jersey. Monthly ridership varied from a high of 317 522 in January to a low of

234 007 in August. Reduced ridership during the summer months signifies that this is the vacation season for many patrons and that the colleges served by the subway are closed for the summer.

Average weekday ridership in 1980 was 12 632, with Monday typically the highest day of the week and Wednesday the lowest. Average Saturday ridership was 3238 passengers, while Sunday ridership was typically 1381.

The estimated hourly distribution of passengers for a typical weekday, Saturday, and Sunday is shown in Figure 1. The distributions are based on information in "Weekday Bus Usage in the Tri-State Region"⁵ and on-board passenger counts of ridership conducted by the Division of Commuter Services, New Jersey Department of Transportation, July to December 1980.

The hourly distribution of subway trips for a typical

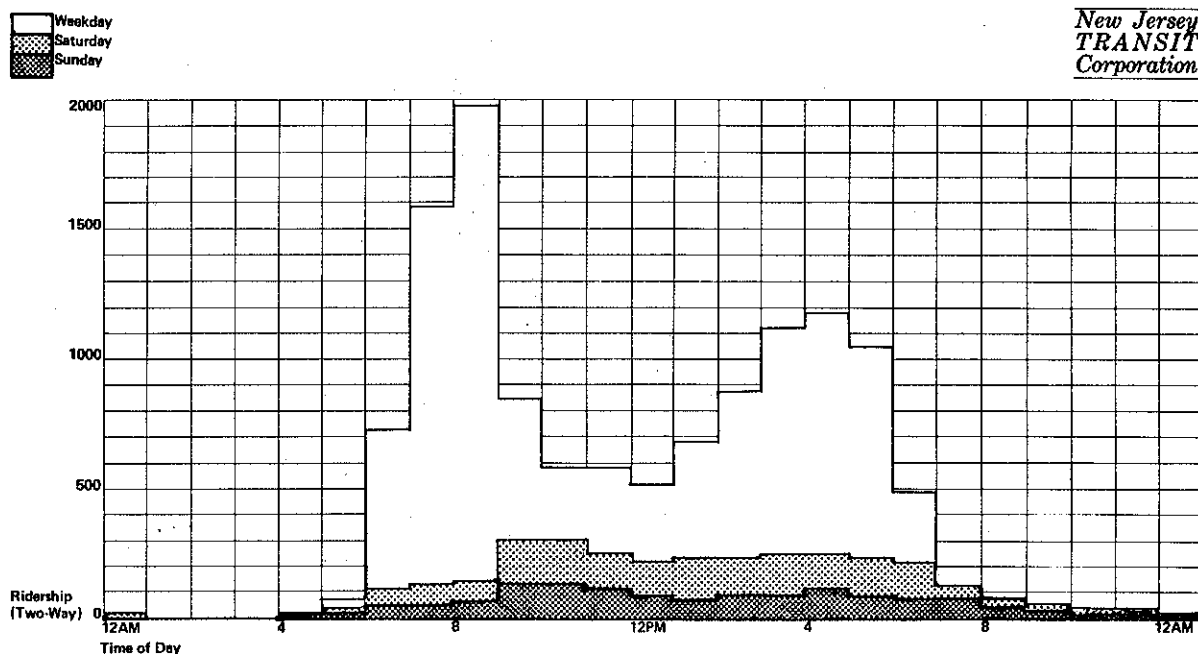
weekday is about what would be expected for a downtown-oriented transit route. The hourly distribution of trips for Saturdays and Sundays is more or less evenly distributed throughout the day and does not exhibit the weekday peaking characteristics.

Trip tables were developed showing estimated station-to-station passenger volumes for the subway at various periods of a typical weekday (Figure 2). Trip tables were also developed for Saturdays and Sundays. In Figure 3, for example, of the 2936 persons who boarded the subway on a typical weekday at Penn Station, 705 debarked at the Broad Street Station, 424 at the Washington Street Station, 251 at the Warren Street Station, 94 at the Norfolk Street Station, 171 at the Orange Street Station, 443 at the Park Avenue Station, 325 at the Bloomfield Avenue Station, 133 at the Davenport Avenue Station, 123 at the Heller Parkway Station, and 241 at the Franklin Avenue Station, etc.

The trip tables are based on data from passenger counts taken on board the subway by the Division of Commuter Services, during July to December 1980, and on

Figure 1. Hourly distribution of subway ridership.

The Newark City Subway Rehabilitation, Phase I



New Jersey
TRANSIT
Corporation

Figure 2. Station-to-station passenger volumes, typical weekday, all day.

FROM (ON)	TO (OFF)	PENN STATION	BROAD ST.	WASHINGTON ST.	WARREN ST.	NORFOLK ST.	ORANGE ST.	PARK AVE.	BLOOMFIELD AVE.	DAVENPORT AVE.	HELLER PARKWAY	FRANKLIN AVE.	TOTAL
PENN STATION		705	424	251	94	171	443	325	133	123	241	2936	
BROAD ST.	717		102	118	44	94	212	158	64	59	443	2111	
WASHINGTON ST.	809	442		29	10	25	54	39	15	15	183	1611	
WARREN ST.	362	246	62		5	5	10	10	5	5	29	739	
NORFOLK ST.	100	77	15	8		5	10	5	0	0	44	272	
ORANGE ST.	562	242	62	15	8		10	10	5	5	39	778	
PARK AVE.	416	293	77	15	8	0		0	0	0	34	843	
BLOOMFIELD AVE.	470	324	77	23	8	0	0		0	0	10	912	
DAVENPORT AVE.	54	31	8	0	0	0	0	0		0	10	103	
HELLER PARKWAY	162	100	23	8	0	0	0	0	0		0	301	
FRANKLIN AVE.	940	809	177	47	15	0	15	15	0	0		2026	
TOTAL	4408	3317	1127	514	192	326	794	562	222	207	1003	12 632	

Northbound : 4926
Southbound : 7706

Figure 3. Station-to-station passenger volumes, typical weekday, all day.

FROM (ON)	TO (OFF)	PENN STATION	BROAD ST.	WASHINGTON ST.	WARREN ST.	NORFOLK ST.	ORANGE ST.	PARK AVE.	BLOOMFIELD AVE.	DAVENPORT AVE.	HELLER PARKWAY	FRANKLIN AVE.	TOTAL
PENN STATION		705	424	251	94	171	443	325	133	123	241	2936	
BROAD ST.	717	102	118	44	94	212	158	64	59	443	2111		
WASHINGTON ST.	809	442		29	10	25	54	39	15	15	183	1611	
WARREN ST.	362	246	62		5	5	10	10	5	5	29	739	
NORFOLK ST.	100	77	15	8		5	10	5	0	0	44	272	
ORANGE ST.	362	242	62	15	8		10	10	5	5	39	778	
PARK AVE.	416	293	77	15	8	0	0	0	0	0	34	843	
BLOOMFIELD AVE.	470	324	77	23	8	0	0	0	0	0	10	912	
DAVENPORT AVE.	54	31	8	0	0	0	0	0	0	0	10	103	
HELLER PARKWAY	162	100	23	8	0	0	0	0	0	0	0	301	
FRANKLIN AVE.	940	809	177	47	15	0	15	15	0	0		2026	
TOTAL		4408	3317	1127	514	192	326	794	562	222	207	12 632	

Northbound : 4926
Southbound : 7706

the Inventory Report, Newark-Elizabeth Local Bus Study.² Station-to-station trip factors were developed from the data and applied to estimated passenger volumes for the various time periods to produce the trip tables.

The results of this analysis show that Penn Station is the busiest of the 11 stations. Broad Street, Washington Street, and Franklin Avenue are also heavily used. The stations at Heller Parkway, Davenport Avenue, and Norfolk Street have the lowest use.

On a weekday, the total southbound traffic is greater than the total northbound traffic. This is caused in part by Newark downtown-bound riders who take a bus in the morning as far as a connecting subway stop and transfer to the subway for the rest of the trip, even though the bus route continues into the downtown. The subway has a travel time advantage over the bus. However, on the return trip, passengers board the bus downtown in order to get a seat, thus sacrificing the travel time benefit of going part of the way by subway. Another reason for the difference in the directional flows is the 15-cent reduced fare available for trips between Penn Station and the Warren Street station. The reduced fare is applied at all times in the southbound direction but is not in effect in the northbound direction between 4:00 p.m. and 6:00 p.m. on weekdays.

The numbers shown on Figure 2 are estimates of station and subway use during specific time periods. Individual values should not be taken literally but only as an indication of relative travel activity. This is particularly relevant where low values and zeros appear; they indicate only that these origin-destination pairs have very little activity during the day.

MAINTENANCE OF SERVICE ALTERNATIVES

According to available ridership information, 96.4 percent of daily traffic is carried between 6:00 a.m. and 7:00 p.m. If the subway were shut down from 7:00 p.m. to its usual closing time of 12:47 a.m. and from its usual start of service at 4:38 a.m. until 6:00 a.m., less than 4 percent of the ridership, about 455 patrons, would be affected. This would provide an 11-hour construction shift during the night. Substitute bus service could be provided during the shutdown period.

Construction activity should not interrupt weekday peak-period service (6:00 to 9:00 a.m., 4:00 to 7:00 p.m.). The subway operates during these periods at 2- to 4-minute headways and carries over 55 percent of the total daily traffic (around 6950 passengers). The morning peak traffic flow is generally from the stations at the northern half of the line, such as Franklin Avenue, Bloomfield Avenue, and Park Avenue, south into the CBD stations of Penn Station, Broad Street, and Washington Street. There is also a substantial northbound flow from Penn Station to the Broad Street and Washington Street stations. The high ridership level and slow bus operating speeds due to peak-hour traffic would make adequate substitute bus service difficult to provide. Approximately 30 buses and drivers would be required to carry the passengers. That number of buses may not be available during peak periods. Also, on some streets, that many buses may cause local capacity problems.

Midday (9:00 a.m. to 4:00 p.m.) ridership on the subway accounts for 41 percent of the total traffic (around 5180 passengers). The subway runs at 5- to 6-minute headways during this 7-hour period. This is a fairly busy period for the subway and would not be a desirable time to suspend service. Minor delays, single-track operations for short sections of track, or occasional shutdowns might be tolerable if certain work or deliveries of material or equipment cannot be handled at night or on weekends. However, full service would have to be restored by the beginning of the evening peak period. If midday service is suspended, substitute bus service at 5-minute headways would be required.

Saturday subway service is provided at 7- to 10-min-

ute headways for most of the day, while Sunday service has 15- to 20-minute headways. Early morning and late evening service is provided at 30-minute headways. Because Saturday and Sunday ridership could be easily accommodated by buses, the subway could be shut down on weekends to provide an uninterrupted work-time slot of over 52 hours.

If the subway could shut down on weekends and in the early mornings and evenings on weekdays, an uninterrupted time slot of 59 hours would be available for construction work (7:00 p.m. Friday to 6:00 a.m. Monday) in addition to 4 weeknight shifts (Monday to Thursday) of 10 to 11 hours each.

In addition to these recommended construction periods, the following alternatives were examined and rejected:

- Total shutdown of service for the duration of construction. While this alternative would have benefits in terms of construction time and cost, approximately 30 buses and drivers would be needed to provide peak-period service to the subway patrons. It would be extremely difficult and costly for the operator to make this many vehicles and drivers available during the peak periods for any length of time.
- Shut down parts of system (one track at a time) as needed for construction; run single-track service. Single-track operations would not be practical; PCC cars used on the Newark City Subway have doors on one side only and could not easily serve passengers in several of the stations. Peak-period service, with headways as close as 2 minutes, would be nearly impossible to maintain because vehicles would have difficulty making more than one peak-period round trip. Construction would also be slowed by the "live" track adjacent to the work area.
- Shut down sections of the system (two tracks at a time); provide shuttle bus service. The Newark City Subway is a closed one-way loop; vehicles cannot operate efficiently in reverse and therefore must be able to make the complete loop between Penn Station and Franklin Avenue. Transit service cannot be maintained if sections of the track are taken out of service.

Suspending only weekend and early morning and evening weekday service minimizes the negative impact to the ridership, allows the operator to use excess buses and drivers available in the off-peak periods for substitute service, and allows the construction crews a useful period of time.

SUBSTITUTE BUS ROUTE

Transit service can be maintained during the period when the subway service is suspended by providing alternative bus service along a route parallel to the existing subway route. This is the same route used for emergency service in the past by Transport of New Jersey. It includes all 11 subway stops.

The current round-trip time for the subway is 26 minutes. Round-trip running time for a bus along the alternative route has been timed at 50 minutes, with adjustments made for dwell times and traffic signals. Allowing for layover and unanticipated delays, it is assumed that 1 bus and driver could make 1 round trip per hour. Therefore, 1 round trip per hour requires 1 bus and 1 driver for that hour (1 bus-hour). For the proposed route, 1 round trip requires 9.4 bus-miles, meaning the bus must travel 9.4 miles (15.1 km) to make 1 round trip. The bus route distance is nearly the same as that of the subway. Bus-miles are used to estimate fuel and maintenance costs.

LEVEL OF SERVICE ALTERNATIVES

Four alternative service levels were examined. They vary

only in the frequency or level of service at various times of the day.

Alternative 1 would provide service at a level sufficient to meet anticipated demand (although the maximum headway would be 1 hour). The demand for the service was derived from the trip tables developed previously. Some minor adjustments were made to account for NJ Transit's proposed changes in bus routes serving the subway. Some routes are being eliminated or consolidated. Other routes are being altered and extended to act as feeder services to the subway. In addition, because the travel time of the alternative bus route is about twice that of the subway, some trips can be made faster by using an existing or proposed regular bus service or by walking.

The level of demand to be served by the buses was determined from the hourly peak-direction, maximum line volume (generally between the Broad Street and Washington Street stations). By providing capacity for this level of demand, adequate capacity would be provided along the entire route.

Alternative 1 would require the fewest buses and drivers of the four alternatives; it would, however, result in long headways and a reduced level of transit service for the riders, compared with the existing subway service.

Alternative 2 would use approximately the same number of drivers as the subway now uses during the various time periods, according to information supplied by the operator. By using the same number of drivers as the subway, the operator can use the same driver schedule. The operator avoids the expense of overtime and extra drivers. (The subway drivers are also able to drive buses.) Since the bus route travel time is twice that of the subway, the resulting level of service is roughly half that provided by the subway. Thus, headways would be longer than the existing subway but generally less than Alternative 1.

Alternative 3 would match the headway or frequency of service currently provided by the subway. Although patrons would receive basically the same level of service as on the subway, and better service than they would receive under Alternatives 1 and 2, the operator would need almost twice the number of drivers normally required, since the round-trip time on the substitute bus route is twice as long as the subway. The operator may be required to pay these extra drivers at an overtime rate.

Alternative 4 presents a compromise between providing a high level of service to the patrons (Alternative 3) and keeping operating costs reasonably low (Alternative 2).

EVALUATION OF SERVICE LEVEL ALTERNATIVES

Table 1 shows the total bus-hours and bus-miles for each of the four alternatives. It is based on estimates of the total number of weekdays, Saturdays, and Sundays the subway would be shut down for construction and on the bus-hour and bus-mile requirements for each of the alternatives.

Of the four alternatives, Alternative 1 requires the fewest drivers and least equipment and produces the fewest bus-hours and bus-miles; however, it provides the poorest level of service. Alternative 2 allows the operator to maintain the drivers' schedule, although in some in-

stances the level of service is poor. Alternative 3 provides the best service to the patrons; however, it requires the most bus-hours and bus-miles and the most bus drivers and equipment. Alternative 4 presents a reasonable level of service for the patrons while keeping the operating costs relatively low. The recommended level of service for the substitute bus service, therefore, was Alternative 4 (Table 2).

COMPARISON OF LIGHT RAIL AND BUS SERVICE

One of this study's first findings was that the Newark City Subway would have to remain in service during peak periods while the rehabilitation work is performed. Transporting the current volume of people requires peak-period service at headways as frequent as 2 minutes. In each 3-hour morning (6:00 to 9:00 a.m.) and evening (4:00 to 7:00 p.m.) peak period, 61 vehicle trips are provided in each direction by the subway. Based on the ERPCC car's seated capacity of 55 and total capacity (seats plus standing room at 2.7 square ft per person) of 88, 3355 seats and 5368 places are provided during each peak period. Sixteen PCC cars are required to service the peak. To match this capacity with buses (assuming advanced design buses with 48 seats and 27 standees), 70 peak-period trips would be needed to match existing seating capacity and 72 peak-period trips would be required to match total capacity, at increases of 14.8 percent and 18.0 percent, respectively. Twenty-four buses would be required to handle the same ridership accommodated by 16 streetcars. To match the 2-minute peak-period headway currently provided by the subway, 30 buses (an 87.5-percent increase) would be needed. Unlike the subway cars, which can make 2 peak-period round trips per hour, the bus (running on the street) can make only 1 trip per hour.

Operational cost savings achieved by the LRT system over a roughly equivalent bus service are obvious. Because bus running time per trip is twice that of the subway, there would be some erosion of patronage by noncaptive riders, which might create a larger deficit. The impact on traffic in downtown Newark created by an additional 30 buses is likely to be severe and might also increase running time.

CONCLUSION

The Newark City Subway represents a form of light rail transit that offers better service to a large population than would be possible by bus. On the basis of operating and labor costs, it also appears to be more economical. Although this study did not examine the total economic picture of the system, it would be useful to determine if the full cost of operating the system, including debt amortization for rehabilitation and maintenance, was cheaper than bus. It appears that LRT is more economical in this corridor, but there is no conclusive evidence.

If only the costs of the operator are considered, which are mostly attributable to labor, LRT offers undisputed savings over bus. With the scheduled phase-out of federal transit operating subsidies, it makes sense for transit operators to invest in rehabilitation of existing LRT sys-

Table 1. Alternative levels of substitute bus service: bus-hours and bus-miles.

Alternative	Per Weekday		Per Saturday		Per Sunday	
	Bus-Hours	Bus-Miles	Bus-Hours	Bus-Miles	Bus-Hours	Bus-Miles
1. Meet demand	9	85	45	425	23	216
2. Maintain drivers' schedule	18	169	67	630	33	310
3. Match headways	29	273	113	1 062	73	686
4. Recommended	22	207	73	686	52	489

Table 2. Maintenance of transit service: Alternative 4; recommended service level.

Hour Round Trips Ending	Weekdays		Saturdays		Sundays	
	Headway Per Hour	Round Trips (minutes)	Headway Per Hour	Round Trips (minutes)	Headway Per Hour	Round Trips (minutes)
5 a.m.	2	30	1	60	-	-
6	3	20	3	20	1	60
7	a	a	3	20	2	30
8	a	a	3	20	2	30
9	a	a	4	15	2	30
10	a	a	4	15	3	20
11	a	a	4	15	3	20
12 p.m.	a	a	4	15	3	20
1	a	a	4	15	3	20
2	a	a	4	15	3	20
3	a	a	5	12	3	20
4	a	a	5	12	2	20
5	a	a	5	12	3	20
6	a	a	5	12	3	20
7	a	a	4	15	3	20
8	4	15	3	20	3	20
9	3	20	3	20	3	20
10	3	20	3	20	3	20
11	3	20	2	30	2	30
12 a.m.	2	30	2	30	2	30
1	2	30	2	30	2	30
Total bus-hours: 22			73		52	
Total bus-miles: 207			686		489	

^aNormal weekday subway service, no buses required.

tems and new high-capacity lines for which UMTA capital grant assistance is still available.

The Newark City Subway was developed in an era when streetcars were being forced off the streets as the auto became dominant. In several other cities, including Cincinnati and Rochester, similar streetcar subways were constructed and abandoned but still exist as untapped resources. Today, the continued survival of the Newark City Subway is assured, and it will play an increasing role in providing mobility to its patrons and reducing congestion in downtown Newark. It is hoped that this paper will inspire planners in other cities to reexamine abandoned streetcar rights-of-way and perceive in them an effective and economical means of creating high-capacity transit corridors for the future.

REFERENCES

1. Stephen P. Carlson and Fred W. Schneider. PCC—The Car That Fought Back. Interurban Press, Glendale, California, 1980.
2. Chase, Rosen and Wallace, Inc. Inventory Report Newark—Elizabeth Local Bus Study. New Jersey Department of Transportation, December 1979.
3. William D. Middleton. The Time of the Trolley. Kalmbach Publishing Co., Milwaukee, 1967.
4. Parsons Brinckerhoff Quade & Douglas, Inc. The Newark City Subway Rehabilitation, Phase I, Project Definition Report No. 7, Operations—Maintenance of Passenger Service During Construction. New Jersey Transit Corporation, October 1981.
5. Tri-State Regional Planning Commission. Weekday Bus Usage in the Tri-State Region. Technical Report 106, June 1980.

Light Rail and Development: Constraints and Conditions

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This paper discusses work carried out for the Urban Mass Transportation Administration (UMTA) on the economic impacts of the Buffalo Light Rail Rapid Transit System

(LRRT). The system is the culmination of two decades of corridor planning that saw appreciable changes in planning criteria and justification of system benefits.

Two major policy issues are addressed. The first issue is the extent and scope of economic development that will depend on or derive from the LLRT system. The second is the role transit system policy will play in regional development policy. In Buffalo, population decline, intraregional population and employment shifts, and the effectiveness of the existing transit system were major considerations as these issues were discussed.

Recent retail activities are examined to show how critical the focus of activities around the transit system will be. Current development (paid for by both private and public sectors) are then analyzed to demonstrate how development policies can reinforce or conflict with transit. It has become evident that a strong, well-coordinated regional development policy is necessary if the Buffalo LLRT is to be effective.

In April 1979, ground was broken for a new 6.5-mile light rail rapid transit system in Buffalo, New York. This event had national significance for a number of reasons:

- It was the culmination of a complex and changing planning process that had begun in the early 1960s.
- It demonstrated that a strong citizen-participation process, coupled with a strong coordinated community planning effort, could result in a well-designed system.
- It represented a significant public investment in a transportation system for which user benefits were not the sole or even major justification.
- It was part of the federal program of the late 1970s to revitalize urban central cities through well-planned public investment.

While initially (1962-1964) conceived as a link in a revitalized regionwide transportation network, the Buffalo Light Rail Rapid Transit (LLRT) is currently seen as the unifying component of a revitalized central business district.

In a time of decreasing federal and local budgets, large capital investment projects take on special significance. When planning for a new transit system, regional planners and investors must examine carefully the link between transit and regional development. How the returns (i.e., the public value received) on such large public investment must be carefully measured and evaluated.

Transportation planners in the 1960s assumed that user benefits might justify new transportation systems; now, however, it is felt that a major transit investment must generate returns through its catalytic effect on new office development and retail, commercial, and even residential activity. This transit investment is seen as perhaps the most critical of a number of policies, public and private, that must be carried out in concert to ensure a successful return. Such policies have the potential to be mutually reinforcing in urban revitalization. They are designed to encourage transit development, economic development, and other local growth.

BACKGROUND

The LLRT system is the culmination of nearly two decades of transportation planning in the Buffalo Standard Metropolitan Statistical Area (SMSA). The planning efforts of the early 1960s were directed toward systems that would serve the rapidly growing suburban areas and accommodate the large number of autos predicted to be on the region's highways by 1985. It was decided that mass transit improvements were most feasible in the high density, rapidly growing corridor linking the CBD, an existing university center at the northern edge of the central city, and a new university center and new town several miles to the north.

At the start of the planning process (1970), the transit system was expected to be heavy rail; it was to be part of

the orderly renewal of the deteriorating downtown. By 1980, massive population losses, employment shifts, and severe adverse economic pressures had so affected the city that the system was viewed as the essential ingredient in downtown revitalization. After much discussion of corridor concepts and with extensive community participation, a 6.4-mile light rail system was agreed upon. The system totally contained within the city of Buffalo and focus on the CBD was ultimately justified not only by user benefits, but also by the economic benefits the system would generate. Transit-related projects—a mall, new offices, new retail areas—were seen as necessary components of this revitalization process, and the concepts of joint development and codevelopment evolved. Joint or codevelopment programs are intended to capitalize on impacts of transit development. Public investment is used to provide the stimulus for private investment. The joint programs force planners and potential developers to consider the large investments in a fixed-rail system, busway, or pedestrian area in light of their potential to inspire such land-use changes as new offices and retail or residential development.

Fixed-rail transit projects are considered ideal for codevelopment because they provide highly focused areas for development. These areas can be single stations, such as Philadelphia's Gallery, or a series of stations linked together in a high-activity area, such as the mall in Portland or the at-grade transit mall proposed for Buffalo. Neither transit nor urban development alone can impart new life or vigor to a decaying or declining area, but together they can create a positive change.

The success of joint development projects depends upon both maximizing the investment strategies in the area of focus and minimizing the adverse effects of other policies through coordinated regional planning and development strategies.

In areas that have declined or experienced only slow growth, the inflow of large amounts of capital over a short period of time is intended to be a signal to private investors to participate in the overall development process. (In Buffalo, \$450 million of public money will be allocated over 5 years.) Joint development programs (urban initiatives) and Urban Development Action Grants (UDAGS) are further incentives to private investors to participate in targeted programs of development.

For the CBD revitalization to succeed in Buffalo investment in a light rail system is a necessary but not sufficient condition. The success of LRT, both as an element of public service and as a component of development, also depends on maintaining current levels of activity and generating new activity in targeted areas of investment. In Buffalo and other major urban areas, other policies, can affect these targets:

- Auto-related policies: highway, parking, and other policies that do not discourage auto use to the targeted areas or that stimulate development in nontarget areas; and
- Development policies: policies that would stimulate retail, office, and other development in areas other than those of transit development.

In major growth areas the effects of such policies might be absorbed in the short run. In Buffalo, such policies cannot be sustained, even in the short run, because the population, employment, and economic conditions cannot tolerate a diffusion of effort.

A declining region or a constantly stable one can be thought of as a finite pie. The pie may be jobs, retail sales, or total daily travel. In Buffalo, the CBD generated only 5 percent of SMSA retail sales. If the LLRT is to generate new development—some of it retail activity—and if the new development it is to be successful (return some of the public investment), new sales levels must be achieved within the CBD. If regional income remains constant (with declining population), additional CBD retail

sales must be generated at the expense of non-CBD (neighborhood or suburban) sales.

LRRT, RETAIL SALES, AND CONSTRAINTS

The Buffalo system was initially proposed for a region that was projected to continue to grow or become stabilized by 1985. Although the population of Buffalo decreased 23 percent in the past decade, employment within the city increased, and over the past 5 years, CBD employment has increased by 10 000. Employment is primarily white collar (service industry).

A large part of this increase has resulted from the influx of women into the labor market. In 1978, women made up 52 percent of the Buffalo area population, a slight increase over 1970 and 1975. It is estimated that 228 000 women are now in the labor force in the two-county SMSA, an increase of 15 percent over 1970. This is 40 percent of the total area labor force, compared to 37 percent in 1970. This follows the national trend. A decade ago, women constituted one-third of the nation's labor force; they now constitute nearly 50 percent.

The distribution pattern of personal income within the region is also changing. As total regional income increases due to increased per household income, retail sales will increase in proportion. The retail shopper is predominantly a female head (or co-head) of a household, and more retail expenditures will be made by women who are employed. Because of new time constraints in households where both heads work, assessing the cost and times of travel for shopping will be more critical than in the past. Because one method of minimizing such costs is to shop near work, any system that facilitates retail CBD shopping will be important.

Women are the largest segment of transit riders (70.6 percent in 1975), and nearly 30 percent of the total

daily transit use is in the Main Street corridor.

Figure 1 shows a history and projection of transit ridership in the Buffalo region. The data, based on a 1975 survey by the Niagara Frontier Transportation Committee, also project the proportion of ridership expected in the Main Street corridor. The growth of employment in the CBD, the increase in women on the labor force, and the heavy use of transit by women are all factors that forecast a demand for the new LRRT system by the market segment.

Figure 1 shows a transit decline in the region since 1968. However, projections incorporating those data have led the NFTA to assume that ridership on the entire transit system would increase and that a growing share would go to the Main Street corridor. By 1990 the LRRT is expected to serve approximately 80 000 to 100 000 passengers a day, with over one-half expected to be in the CBD population (primarily visitors and employees).

However, transit's share of the rush hour modal split is estimated to increase only from the present 12 percent to 14 percent by 1985. Transit's share of all trips in the region will remain at less than 10 percent, and car use will remain high even after the transit system is built. Also, more than two-thirds of the population will continue to live outside the central city.

Clearly, the success of the transit-linked development projects will rely on their being unique (i.e., hotels, a convention center, government business) or on a demand for space adjacent to both transit and the CBD (service employment). Ancillary development will be to serve the needs of the CBD population or of those who find transit a unique and inexpensive way to travel. Some users will take advantage of the farefree zone (lunchtime shoppers, or theatre goers who travel to restaurants, etc.), others will be drawn to specific sites downtown (hotels).

As population and some sectors of employment have gone from Buffalo to the suburbs and beyond, so has the retail industry. New construction of retail centers in the region has been at an ever-increasing distance from the inner city, and transportation to these centers is largely by car.

The regional share of CBD retail sales has decreased over the years. On a per capita city resident basis, retail sales in the CBD have increased at an average annual rate of 3.9 percent, a rate lower than the overall inflation rate, indicating that a smaller percentage of true yearly regional income is being spent in the CBD.

A movement toward stabilizing, or at least lessening, the outward movement of the retail industry would be an important step toward revitalizing Buffalo's inner city. The growth of office buildings, financial institutions, and related service facilities in the CBD in the past decade lends justification to current and planned reinvestment efforts taking place in the city, from both public sources (the LRRT) and private sources (hotels, restaurants).

Although the CBD has lost much of its retail dominance to the suburban areas, with proper transit and development planning, it still can be a major center of shopping activity.

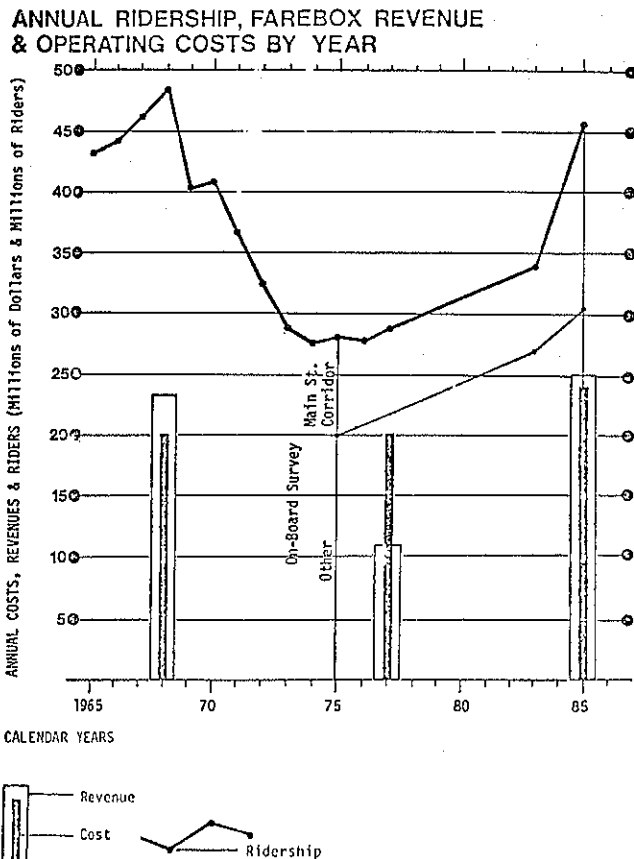
TRANSPORTATION TRENDS

A major factor in suburbanization was the development of the highway system in the 1950s and 1960s. Buffalo has extremely well-developed highway and expressway systems that enhance the region's accessibility. The average journey to work by car in the SMSA is less than 20 minutes.

The present public transportation, the bus network that complements the highway system, will be augmented by the LRRT line in 1985. Based on current and projected modal split figures and population and employment levels in the region, changes in overall accessibility by the LRRT are predicted. These zonal accessibility measures were calculated for work and service trips.¹

Accessibility as used in this study compares the relative attractiveness of the regional sectors. Attractiveness

Figure 1. Transit ridership, Buffalo, N.Y.



is based on the likelihood of a particular activity (work or nonwork) being in that given sector, and how easy it is to get there from other sectors. Therefore, the more retail activity a region has, the more attractive it should be. However, if travel time to that region from other areas is greater than travel time to a competing region, its accessibility would be diminished.

Service trip accessibility based on the LRRT was calculated for the region. Since people want to shop close to home, zones with both high population levels and attractive retail areas, mostly inner-ring suburbs, will rate highest in service accessibility. Although the CBD is a major retail center for the daytime downtown labor force, it is not more accessible for service trips because so few people live there. Any increase in CBD shopping will have to draw from daytime suburban shoppers. By making the downtown more attractive as a shopping area, suburban dwellers may be made to regard it as worth the effort needed for shopping and other service activities.

Travel time alone is not the best determinant of area residents' preferences of shopping location. Although people do try to minimize travel costs (time, effort, and money (fare)), the size and attractiveness of the retail center is by far the most important determinant of preferred shopping location.

City shopping areas are accessible to more people than are suburban centers. Travel time is less, particularly for transit riders, because the transit network is far more extensive in the city than in the suburbs. The actual relative strength of each retail center is, however, not consistent with the overall accessibility levels. The strongest suburban shopping mall in terms of total retail sales is the least accessible with respect to numbers of households; it is accessible to only about one-half as many auto drivers as are the CBD and Central Park shopping areas, for instance, but is 1.5 and 15 times stronger than these two city retail centers. Conversely, one of the more accessible centers, Central Park Plaza, is the weakest in terms of retail sales; therefore, factors other than size, safety, and overall attractiveness determine retail patronage.

These data reinforce the theory that the CBD retail share, all other factors remaining constant, will continue to decline. To reverse the trend, new demand must be created from:

- A daytime work force that will increase as service employment increases, and
- A new, nonwork, CBD population generated by the "new" downtown; i.e., transit, transit mall, and new facilities.

RESPONSE TO THE LRRT STIMULUS

The impacts on economic investment of the light rail system in Buffalo can be evaluated using the following components:

- Federal and local investment in the LRRT system itself during the period 1978-1983,
- Other public investments related to the construction of the LRRT, and
- Corridor and regional changes that might occur because of the rail investment, including both public and private investment in CBD and nearby stations.

Transportation may be an important link in the functioning of an urban system, but returns from a large public investment in transit cannot be taken for granted. Planners forecasting economic impacts from a new transit investment must ask whether government policies or programs at all levels have reinforcing or conflicting influences on the transit investment and its subsequent relationship to economic development.

High capital transit investment may generate other

related investments, but it may not be the only major investment in the region. Others may be occurring, justified by highly localized costs and benefits. An overall regional cost benefit analysis for all projects should be done.

If the transit investment is justified partially because it will encourage CBD revitalization, federal, state, and local policies and programs that help implement this objective would be considered advantageous, and federal, state, and local programs and policies that create competing development in other regions and detract from CBD redevelopment and transit system growth would be considered disadvantageous. In the past several years a number of programs, at federal, state, and local levels have been available to assist local development.

Examples of reinforcing planning are projects started with funds from HUD, EDA, and DOT programs. In a declining area such as Buffalo, targeted for massive urban aid, these agencies have the power to promote or deny projects through grants, loans, or underwriting bond issues. Private sector funds are unlikely to flow in such an area without such incentives. However, the programs of these agencies are not always coordinated, and local officials must create "packages" of programs to generate the private developers' interest.

It is possible for a region to adopt many of these programs without assigning one program a specific priority, and it is also possible for package programs to encourage conflicting development programs simultaneously. No rail system will result in specific growth without coordinated planning. Assumptions that a new, well-planned rail investment will encourage proper placement of new residential and commercial ventures are not realistic unless such vital issues as zoning, tax abatement, and other public tools are coordinated.

By building a rapid transit line below grade through outer residential areas and at-grade in the CBD where it will be the focus of a pedestrian/transit mall and by creating a feeder bus network throughout the region that will serve the CBD-oriented rail system, the transit planners in Buffalo have responded to the wishes of the city population. The transit mall in particular will facilitate the use of joint private/public development, and should attract investment that would otherwise go to other areas within the region. One such project—a major hotel/office complex—is currently underway.

However, conflicting policies at the local planning level have complicated the development program. A major arterial highway on the eastern edge of the Buffalo CBD was recently completed as part of the long-term highway planning in the region. This multilane, at-grade road serves as a connector to the main expressway leading out of Buffalo to the northeast and southwest. The New York State Department of Transportation (NYDOT) feels that this arterial will not conflict with the proposed light rail system. It will ease rush hour congestion in the corridor and help handle traffic diverted from an auto-free zone on Main Street when the light rail and associated transit mall open. However, as this connector will increase auto access and reduce travel time to the CBD, it may divert some potential users from the LRRT. This ease of access may actually place more autos on the few side streets in the CBD that will still cross the path of the rail system. The irony is that both the transit and highway plans came from planning assumptions generated in the 1960s. Seen at that time as complementary projects in a dense growth corridor, they may now emerge as conflicting projects, each diverting from the maximum potential of the other.

Another example of a conflicting project is the Audubon Industrial Park. At the local level, two agencies, The Erie County Industrial Development Agency (funded by federal EDA programs) and the New York State Urban Development Corporation (UDC), generate development through a number of regulated mechanisms. The most widely used is bond authority. The proceeds from bond issues can be used for industrial and residential develop-

ment and are currently being used within the entire county rather than for a particular region, i.e., the CBD. During the early 1970s the UDC was mainly responsible for development of a large residential and industrial park that began in the suburban town of Amherst. The area, Audubon Community (residential) and Audubon Industrial Park, is attracting significant investment from private sources. This planned development is attracting millions of dollars of private investment into the suburbs, and is concentrating it in one well-served area. The Urban Development Corporation and the town of Amherst have drawn small industries from Buffalo through more attractive sites, infrastructure, and expansion funding.

PROSPECTS FOR PRIVATE INVESTMENT

To support the assumption that transit is the catalyst for the resurgence of the downtown, a series of structured interviews were conducted with 30 regional leaders. While not a statistical sample, these responses are important because the people involved are responsible for directing, inducing, planning for, or investing in the growth of the region. Their responses to the transit project reflect the decisions that will be made by local investors. Those responsible for coordinating development in the CBD are optimistic about its success.

Approximately 60 percent of the community leaders believed that present efforts to revitalize the downtown centered around the light rail show definite signs of success. When asked for personal ideas for downtown revitalization, 45 percent said that current investments should be sustained; 15 percent singled out the importance of the rapid transit. Factors considered important in revitalization included new employment, current and planned improvements, and the transit system.

More than half the respondents saw a conflict between CBD and regional development. Forty-seven percent believed that the regional strength came from a strong core. Fifty-three percent felt that increased growth in the CBD (retail sales, jobs) would occur at the expense of other areas in the region. Forty percent believed the transit system would generate more CBD business, and all the respondents noted positive aspects of the LRRT on CBD growth. Eighty-five percent projected the 10-year future of the CBD as an attractive new retail commercial center. Thus, those directly responsible for investment (bankers, developers, planners, political leaders), confirmed their commitment to the CBD and transit's role in its restructuring.

These qualitative descriptions provide a reinforcement for investors who then provide the more tangible aspects of new projects. The largest private investments are in hotels and office space. Office space development reflects the growth of the service sector, and hotel space complements service sector needs. The sustained high growth level in the suburban areas illustrates the level of competition between these areas within the region. During the first year of transit construction (5 years until completion), \$253 million of related construction was undertaken or is planned in the CBD. This puts the current private investment level ahead of the public investment level. It is anticipated that 8 percent of transit investment will be made in the first year and 20 percent in the second year.

The transit investment timetable and the scheduled private projects indicate a synergistic effect of public and private investment is possible. The private investments were all announced at about the same time—after the opening of the Buffalo Convention Center (\$20 million public investment) and the start of light rail construction (\$90 million public funds for initial contract awards).

Based upon the resurgence of service-oriented employment and the desire to locate this employment in the CBD, the potential for new development both of employment and employment-related services in the CBD is high. There is currently a 98 percent occupancy rate in the city's 58 most sought-after office buildings. In response to a growing

market for CBD office space, approximately 480 000 square feet of downtown office space are planned to be available by 1982 to supplement the 1.4 million currently utilized. Much of this development is linked to transit planning.

Suburban development is also proceeding, but on a smaller scale. Suburbs have an inherent advantage over cities where investment is concerned. While city investment has a private-to-public ratio of 1 to 2, the ratio in suburban areas is 40 to 1. The reasons are obvious: the projects are much smaller (needing less capital), and so are the risks.

OTHER REGIONAL DEVELOPMENT IN THE BUFFALO AREA

Conflicting interests will always exist when decisions are made that affect citizens in more than one municipal jurisdiction. Possible extensions of the initial 6.4-mile LRRT line in Buffalo are under study. Although the major focus of development is now on the CBD, the attention of developers could be diverted to other attractive sites, particularly in the most rapidly growing suburbs. A future corridor concepts study may be able to highlight the best alternatives for extension by using criteria that include both the impact in the CBD and the development potential in the suburbs. In any case, the city of Buffalo can begin revitalization efforts and consolidate development programs before any new extensions are begun.

SUMMARY

It is certain that public transit will capture a larger share of total personal travel in the future. Rising costs of car ownership and operation have already caused many urban residents to switch from cars to buses or rapid transit. In cities with large populations or consolidated corridors of travel, line haul systems (rapid transit, light and heavy rail) and ridesharing (HOV facilities) are seen as major modes that meet the demand, reduce congestion, and, of increasing importance, affect activities around the system.

A major difference between bus and rapid transit service emphasizes this point. Bus service is essentially continuous. Buses take people to where activities are and can follow the movement of activities over a wide geographic pattern. On a rapid transit line, there is a more active land use/transportation relationship. Large numbers of people are concentrated at specific spots, and activities become linked to the stops. Transit induces changes in station areas that often would not occur if no transit were there.

Evaluations of transportation systems must be tied very clearly to the type system investigated. In any formal analysis of transportation systems, variables used to compare alternative systems are not congruent. While such traditional transportation variables as travel cost and total trips can be used to look at transit's effectiveness in meeting travel demand, land use impacts or generated development do not have synonymous effects on all transit modes.

Because of their high initial capital cost, rail rapid transit systems must generate more returns than ridership. For example: the \$400 million invested in the Buffalo system with its expected 40-year life span would be equivalent to \$40 million a year if the discount rate is 10 percent. When the inflation rate is high, the short high-investment span for capital projects becomes extremely attractive, and it is unlikely that local or state agencies would assess themselves \$40 million per year for capital costs and other such annual costs as operation, maintenance, and fare subsidy.

If rapid transit systems are built in nongrowth urban areas, it is essential that those involved in policymaking ensure that the investment is optimized. The decision to invest in a rail system must be unanimous and have strong regional support; its effectiveness and impacts must be

delineated; and its benefits must be greater than those of any possible alternative. A decision must be based on factors other than ridership or the travel cost advantage to the single rider (which is often marginal). The decision must consider the overall regional economic impacts on labor shifts, growth, housing location, and nonwork activities.

In addition to determining direct transportation benefits, a study of rail rapid transit benefits should ask and determine the following:

- Is there regional support?
- What associated land use and activity changes are involved?
- What is the timetable for these changes and are they affected by the transit investment?
- Will there be long-term (post construction) changes in the labor force created or influenced by the transit decision?
- Will the transit system affect the intraregional mobility of labor?

In a region of decline (urban areas of the northeast and north central states), economic and demographic indicators must be determined and used as planning constraints.

In many declining urban areas there is strong intraregional competition. Encouraged by HUD, EDA, and DOT programs, suburban areas compete with urban areas for the same resources.

Transit investment has the potential to minimize such competition and LLRT to catalyze new economic development. Transit development (light or heavy rail) forces planners to focus on land use and development; relocating bus stops or creating express bus systems does not. Bus systems usually follow development; rail systems shape development.

Rapid transit systems must be linked to areas with demonstrated growth potential. Growth potential (in regions of decline) can be measured by the following indicators:

- Changes in the employment force. Even declining areas may have subregions with increased employment, particularly in service-based industries. These can be broken into two major groups: those that must be near other service organizations, and those independent of specific locations. The former (mostly financial, government services, and wholesale and retail that serve those markets) still tend to congregate in CBDs, areas logically served by transit, so long as transit competes with auto use in terms of cost and access. Changes in regional employment patterns can be tracked, and new office construction or renovation planned both for the expanded market and access by rapid transit.
- Changes in composition of the labor force. The most significant change is the increase in the number of women in the labor force. This creates new household travel patterns and new income as well as new demands for the capability to carry out such nonwork activities as shopping near place

of employment or near home.

- Auto and transit policies. Where the car remains the preferred travel mode, growth potential can involve highway system improvements as well as transit improvements. Regional policies must encourage growth in areas where investment is desired, and conflict must be minimized. If the CBD is targeted for development, regional policies that improve access to other areas where competing growth can occur must be critically examined. The retail model cited in this study is an example of this policy analysis. Shopping centers have developed and thrived in a suburban ring tied to expressway development of the 1960s and 1970s. Now, when money is being poured into the CBD to generate new growth or revitalize the area, the retail component of the CBD is critical to further development. The retail shopping must be unique and dynamic enough to attract people from the entire region. Because a declining region is limited as to the amount of growth it can sustain in a given area, and because retail is one area where no major growth can be expected, investment in the CBD cannot coexist with new investment in competing areas.
- Ability to deal with nontargeted regions. In addition to such target areas as the CBD, rapid transit creates a focus at station areas. They can be targets of intense development efforts to reinforce ridership and increase economic activity. An accessibility model shows the joint influences of travel time savings and land development in zones directly adjacent to transit. In Buffalo these changes were not sufficient to overcome the strong attraction of zones with high auto accessibility, but rapid transit changes did increase the potential level of activity in adjacent zones. Because of their growth, these zones will have intraregional attraction. Public intervention must precede private development in these nontargeted station areas to ensure the highest and best use of the land in accordance with local objectives.

We have the capability to measure, access, and analyze these factors. Such analysis is crucial to determining the return on transit investment.

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REFERENCE

1. R.E. Paaswell and J. Berechman et al. An Analysis of Rapid Transit Investments. Department of Environmental Design and Planning, State University of New York at Buffalo, Buffalo, New York, July 1981.

Light Rail Potential in Rochester, New York

SIGURD GRAVA, Parsons Brinckerhoff Quade & Douglas, Inc.

The development of public transit in the United States is again at a crossroads. The administration in Washington has made policy statements and begun to implement programmatic changes that significantly differ or diametrically oppose trends that dominated the recent past. What the future holds, or what adjustments will be required to existing transit services and to plans for system expansion, is uncertain. It is clear, however, that a turning point has been reached. Light rail is regarded differently than heavy rail or buses. Heavy rail is in considerable disfavor because of high capital costs; buses are in favor because they are simple and responsive; light rail is left somewhere in the middle. A recently "discovered" mode, light rail does not have the documented use in North America to allow nondebatable forecasts and estimates of its merits. Therefore, any information exchange is particularly significant; e.g., the Rochester case—a potential transit service in an available corridor that once accommodated streetcar operations but lost them. If a commitment is not made soon to reactivate such service, the opportunity (the physical channel) may be lost. Not long ago, the overall decision about a light rail service in Rochester might have been favorable, and it would probably have been backed with generous assistance from Washington. Today, in a different policy climate, the same facts and findings might have a different interpretation. This paper will examine the corridor, the participants, and the possibilities and discuss speculations about the future.

The Erie Canal was dug through New York State and the City of Rochester in 1822. It served well for many years and changed the economic life of the country. Technological changes and traffic volumes eventually demanded an expanded channel; in 1914, the larger New York State Barge Canal was built south of the city. There was a long debate locally over what to do with the abandoned bed, including the masonry viaduct crossing the Genesee River in the center of Rochester. In 1922, it was decided to place various rail services within the bed and, in the process, restructure the metropolitan transportation network. Part of the canal was decked over, creating a tunnel and expanding the surface street network. The principal concern at that time was to accommodate interurban trolleys and to bring them into downtown Rochester on an exclusive right-of-way. These lines reached other cities of New York State; however, this service soon faded and disappeared from the scene across the entire nation.

Rail freight service also used the channel (a small special operation still exists today), but the major user of the "ditch" was a streetcar line, locally known as the Subway because of the central covered portion. It started revenue service in 1927 and was operated by the New York State Railways Company, also responsible for a number of other surface trolleys in Rochester.

This 9-mile line is well known among streetcar buffs, and its characteristics are thoroughly recorded. Its principal feature was the grade-separated channel between the two terminals of Rowlands in the southeast and Driving Park Avenue in the northwest. Left-hand running was employed, which allowed the use of standard single-end cars with a center platform serving both directions at all stations.

One of the problems was that the Subway led its own life and was never fully integrated with the other transit services, even when the Rochester Transit Corporation took over the system and despite many proposals to extend branch lines and coordinate services. All of Rochester's surface lines were converted to buses by 1940, but the Subway remained. It was never a profitable venture, and

farebox revenues exceeded operating expenses in only one year (1943). Patronage peaked at 5 million in 1949, but slid to about a million in the mid-1950s. By then the line was becoming dilapidated because of deferred maintenance; after disputes between the city and the corporation as to financial responsibility, service was discontinued in 1956 (the year of the Interstate Highway Act).

For several decades thereafter, the "ditch" in Rochester stayed in the memories of transit specialists and planners: "Shouldn't the service be reactivated?" "What are they going to do with it?" A partial, although negative, answer was provided in the context of the highway building boom that swept the nation in the 1960s. Rochester is one of the few cities in the United States that actually built a tight loop with several radials around the CBD. It was opportune to place one of these roadways along the southeastern leg of the old canal/Subway, because historically and currently it traverses a high travel-demand corridor.

This left the tunnel through the downtown, the viaduct crossing the Genesee River, and the 2 miles of open cut northward. General railroad freight and passenger service eroded in Rochester as it did elsewhere, and rail rights-of-way could be considered for other uses. Thus, it was not difficult to identify possible channel extensions all the way north to the lake and southward through and beyond the entire urbanized area.

Various suggestions and scattered evaluations took place before a major study was organized and completed in the early 1970s.¹ Its findings were overoptimistic: the line would be rebuilt along 19 miles; it would have more heavy rail rather than light rail characteristics; it would carry 53 000 passengers per day by 1990. In addition, substantial induced development along the channel and around the stations was envisioned.

Forecasts and plans were met locally with widespread disbelief, if not outright hostility. More public involvement during the study process might have built confidence and support, but the principal difficulty appears to have been a dramatic, fundamental change in community perceptions and expectations. The consultants used state-of-the-art techniques; they did what was expected of them; and they were no different than most who were practicing the art of transit planning at that time.

The 1970s study started in an era when metropolitan growth was an article of faith throughout the country and Rochester was in a boom mood—the new towns of Gananda and Riverton are two examples of the great expectations. But it was soon apparent that urban regions in the older parts of the country were approaching stability. Miraculous rebirth of downtown areas does not often occur, and economic development is not based on wishful thinking. Questions of local share of capital costs and continuing operation and maintenance costs also surfaced. The study was shelved, but the concept was not forgotten by those who believed that a viable urban transportation system must have a strong transit component.

In the meantime, energy issues became more critical, light rail's reputation improved in North America, and UMTA restructured its study, planning, engineering, and implementation procedures. In the late 1970s, under the leadership of the Rochester-Genesee River Transportation Authority (R-GRTA), it was decided to start again, but to proceed carefully within a conservative framework. UMTA provided the usual share of study funds and decided to designate this effort a "pre-alternatives analysis," without answering the question of exactly what specificity was expected. The principal differences in scope were that the study would concentrate on the two main modal choices (busway and light rail), that alternate alignments off the

channel would not be examined in depth, and that a full alternatives analysis would be undertaken if the findings were positive.

The most important objective in the pre-alternatives analysis phase was to determine if the corridor (the Subway bed and various surface rail rights-of-way) held any promise at all for transit operations. If so, further evaluations would be undertaken of all possibilities and implications; if not, the land would be used for other development purposes that presumably would permanently preclude a transit service in the channel.

A new group of consultants was selected, and work on the study started in the fall of 1980.² The following observations and findings are from this just-completed study.

The normal monitoring mechanisms were applied and the following agencies were active in the review process: the Board of the R-GRTA and a special committee, City Hall and the Planning Department, the Genesee Transportation Council (as the regional planning agency), the New York State Department of Transportation, and UMTA. Each has special concerns; most of them will be highlighted in the following discussion.

The principal supervisory responsibility, however, rests with an ad hoc Corridor Advisory Committee; it has met frequently and taken its assignment seriously. Its organization and performance, as well as its antecedents and likely follow-up, are of interest and can help in the understanding of the process.

The first task the consultants undertook was a community leaders' survey that sought to include those with a role in transportation decisions, those who represented potentially affected groups or districts, and those who simply were in visible positions. In addition to being asked about their concerns and attitudes, each person was asked both to serve on an advisory board and to identify other leaders. Because of the previous planning experience, the prevailing community attitude toward transit in the channel was negative and one of "show me."

The early survey provided many attitudinal insights. It was never intended to be a referendum, but it did identify concerns and issues that the study should address. Those who expressed support mentioned all the benefits that generally can be expected from an improved public transit system, which need not be specifically elaborated. Of greater interest are the negative observations that were made before any technical work on this study project was begun.

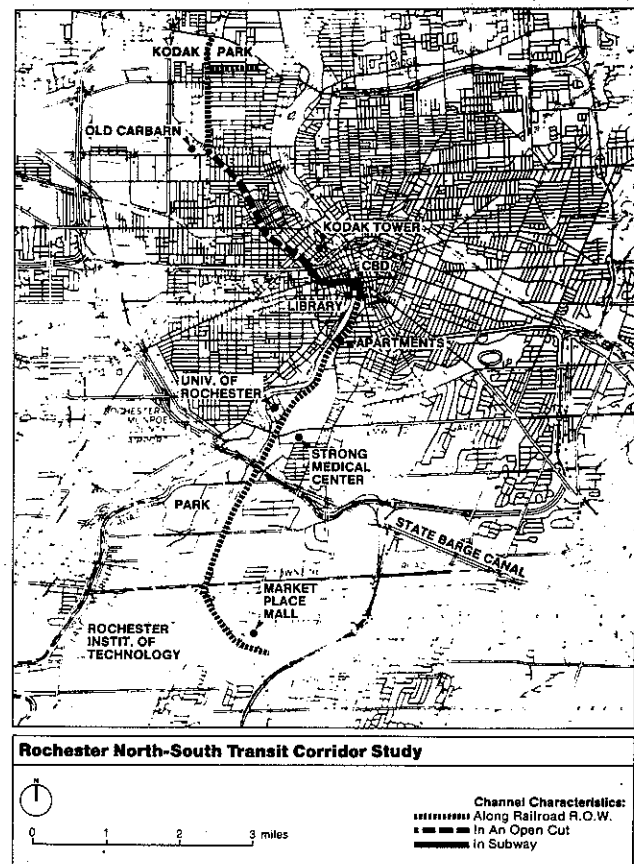
Most original opponents expressed skepticism that sufficient patronage would be generated. The corridor itself with its north-south orientation was not regarded as the most promising location in an area with high transportation needs. Some people indicated that the existing bus and park-and-ride services were adequate and that there were no real transportation problems. A number of respondents believed that Rochesterites were not likely to give up their automobiles for a classless public service. Many opponents raised questions about funding and possible local subsidy requirements. Some individual but interesting responses included the following observations: that winters in Rochester were too cold for residents to use transit; that a line connecting to suburban retail centers would likely siphon shoppers away from the CBD; and that use of the land for industrial development would be more beneficial to the community.

All these and the many other viewpoints that emerged during the interviews were given consideration in the subsequent planning work. The interviews were far-ranging, and other specific suggestions or indications of problems provided the consultants with a rich inventory of qualitative information for guidance during the study.

DESCRIPTION OF THE CORRIDOR

The alignment under consideration proceeds north to south for 11 miles; downtown Rochester is at the approximate midpoint (Figure 1).

Figure 1. Proposed corridor.



The northern terminal of the light rail line and that of the busway are to be in the vicinity of West Ridge Road, a major east-west artery of the city. West Ridge Road also parallels and serves the massive Kodak Park complex; with its thousands of workers, the complex constitutes a significant traffic generator. But there are some concerns: the workers are spread over a large area; most of the space is preempted by industrial development and proprietary parking lots; and the Kodak Park management does not feel compelled to vigorously support a new public transit service because it has always provided all the parking spaces demanded.

The urbanized districts north and west of the proposed terminal area must also be considered. Many people live between Kodak Park and the lake, but at low densities. An extension of the light rail line northward would most likely not be cost-effective under these conditions; but, if a busway is the modal choice, these districts will be tapped directly by bus lines that converge in and out of the terminal node and require no passenger transfers. This affects the comparative patronage estimates between the two principal modes.

The first section southward from Kodak Park for almost 2 miles would share a wide rail right-of-way that has excess width and capacity at present. It runs past primarily residential areas at modest densities and income levels. A significant node exists where the rail right-of-way crosses the old canal bed at Lexington Avenue. There are physical problems with different elevations and a knot of various alignments and bridges, but it is possible to bring the line from the rail embankment into the "ditch." This location is also interesting because the old Subway terminated here (the car barn still exists), and there is extensive industrial development nearby.

Proceeding southward, the empty 80-ft-wide canal bed

is still intact, with heavy retaining walls along both sides. The problem is that, when the 6 bridges crossing it were in danger of collapse, the city replaced them with earth embankments. The channel would therefore have to be "unplugged" for both a light rail and a busway alternative. Light rail would need access stairs for passengers; buses would need vehicular ramps at the major cross streets. Unfortunately, the channel has also been used as a depository for debris, both by private citizens and by the City of Rochester, but no irreversible damage has been done so far.

The neighborhoods along this section of the alignment are old, working-class districts. They exhibit mixed use and some deterioration, but, by and large, the area is very much alive and can be expected to contribute a good share of patronage.

However, the tightness of development that is a feature of such areas creates design problems. Local shopping centers are clustered on the cross streets near the channel; most streets are narrow; and intersections are constraining. Although patronage forecasts indicate considerable access demand for both principal modes by feeder bus and park-and-ride patrons, adequate parking space and efficient access channels for services and vehicles will be hard to provide at the designated and logical station or stop locations. Near the end of this section, just before the alignment enters the downtown tunnel, there is a district with considerable vacant land that the city earmarked some time ago as a potential organized industrial district. The problem was that the channel curves through the area and creates awkwardly shaped lots on both sides. Decking over is not even remotely feasible from an economic standpoint, so a compromise proposed a realignment of the line (straightening) that would both preserve the physical integrity of the designated industrial district and not diminish hope for the plan's implementation.

Another notable factor is Kodak Tower (national headquarters). Although it is located several blocks away from the channel, it is an obvious but isolated traffic generator; the decision had to be made not to curve out the proposed line to serve it directly. This is a complex situation with an interplay of several forces. The CBD to the southeast would be connected to Kodak Park at the northern end of the line, but there is not much business linkage between those two centers. Kodak Tower, on the other hand, would remain separate and, presumably, would continue to interact with Kodak Park, largely through the use of cars and existing surface bus lines. The constraints to putting all these nodes on the same chain are, simply, the canal bed's immobility and the noncommittal attitude of the largest employer in the city.

The next section of the line is the core segment that curves through the western half of the CBD and crosses the river. This section is a completely enclosed tunnel that is well suited to the pollution-free operation of a light rail service; a busway would require extensive ventilation arrangements. The tunnel is in good structural shape and well protected from intrusion and most other uses. Its only function at present is the entry by way of a railroad siding to deliver newsprint rolls to the local newspaper plant and the recent conversion of a section of the tunnel into a storage location for these rolls. This obviously is a conflict in use, but two transit tracks can be routed past the warehouse operations. The logical alternative to transit service is the subdivision of the underground space for similar support activities. This part of the CBD has been largely an adjunct to the principal core across the river, but it shows recent signs of growth in its own right. It contains the War Memorial Auditorium, some new buildings that have been constructed, and several renovation projects that are under way or have been completed.

The heavy masonry viaduct with its arches opening up to the Genesee River has landmark status and brings the line almost to the very center of the CBD on the east side. Here is located one of the major issues associated with the transit concept: Is a 2-block distance between the

100 percent corner on Main Street and the nearest station excessive? Popular wisdom maintains that one reason for the demise of the early streetcar service was the Rochesterites' reluctance to walk this distance. Considerable effort was spent in previous studies to structure schemes that would bring service directly into the very center of the CBD. Such loops are physically possible, but penetration to street surface, portal placement, and use of scarce circulation space are obvious difficulties. In this analysis, it was decided that such attempts would not be cost-effective under the scarce resource conditions that exist today. Another important new element is the convention center to be built between Main Street and the transit alignment on the river front. This structure will effectively draw the activity core toward the line and will extend and incorporate the developing skyway system of Rochester and lessen the possibility of any linkage problems.

After the viaduct and past the "knuckle" in the line at the library, the alignment turns south and progresses from urban to suburban districts. The special nodes on the northern leg were industrial complexes, and the southern leg is blessed with significant institutional clusters. The alignment now diverts from the old canal bed, which extended eastward, and uses existing rail rights-of-way. The selected path is the east side of the river, although an alternative on the west bank was considered. The west bank path, however, has a structural problem—leaving the channel at the viaduct, it interferes with the War Memorial site, does not touch major traffic generators, and misses the core by an even greater distance. Because the winters are quite severe in Rochester, (another argument in favor of a rail-based, as compared to a road-based, system), potential transit users probably will not patronize a line that is further from the core.

The first section of the line beyond the Inner Loop Highway crosses an open zone that is designated and equipped as an industrial district. There are no problems here—and no patronage—because nothing has yet been done. But recently, directly south of the zone, the New York State Urban Development Corporation built a housing project for low-income families directly along the river. This development has not fulfilled all expectations, but it is occupied and has a riverbank promenade on top of the old rail right-of-way. The original design allowed for transit passage and recognized that such a possibility could emerge in the future, but the situation must be evaluated today on its own merits. Frequent bus service along this stretch is not compatible with the linear park concept, but streetcars at 10-minute intervals also may not be tolerated along the promenade. Depressing the line right next to the river would be expensive and probably subject to flooding; placing the line behind the buildings on the land side would interfere with the parking lot, a major artery, or other built-up blocks. This is a major question that has to await further detailed study. Various solutions are conceivable, but none of them will please everyone.

Moving southward, the line follows an abandoned rail channel with no apparent difficulty and, after about a mile, reaches the University of Rochester. This is a significant traffic generator, although the campus is self-sufficient, with its internal dormitory groups.

The problems here are different, but they can be solved. The first is a single-track bridge that carries the rail right-of-way across a major boulevard. Short headways for transit vehicles undoubtedly require a parallel structure—an almost mandatory condition with the busway scenario unless reversible one-way operations are instituted during morning and afternoon peak periods. With light rail service that incorporates proper signals and controls and operates at the 10-minute intervals that appear to accommodate the expected loads quite well, the short, single-track bridge should be able to allow alternating passages with no safety or capacity problems.

Another issue that will require local adjustment is the established use of the old alignment as university parking

lots. This is not a physical obstacle, but negotiations will be required.

Just south of the university campus is one of the major east-west regional arteries (Elwood Avenue); it is crossed by existing bridges. Several large institutions are in the adjoining district, notably a medical center. This district is an obvious strong node where feeder services and other access possibilities should converge. Proper interchange arrangements will have to be made within space that is constrained and valuable.

The next section of the alignment, about 2 miles, traverses a lightly developed part of the region. The right-of-way is well segregated, and the few crossings of minor streets at grade should present no problems. Some other issues, however, must be addressed.

One is the presence within the right-of-way of a track used occasionally to service the university power plant from the south. The questions involve the joint use or crossing of light rail and freight tracks. A solution is possible but may take various forms, depending on what final agreements are reached.

At one point along this segment, the line crosses the State Barge Canal and a parallel, limited-access highway (the Outer Loop). This, too, could be a node but, unfortunately, the new highway provides only a single-track overpass. Either alternating operations or a parallel bridge is needed.

Another question concerns a major park toward the river. It is relatively lightly used at present and generates little traffic, but with upgraded service it might become a major attractor.

The last major node of this study alignment is Jefferson Road, the most important east-west artery of the southern half of the region. It is a typical suburban corridor, lined with commercial activities with an automobile-oriented configuration, and more development is on the way. Several large institutions and clusters, notably the Rochester Institute of Technology, are in the vicinity, but beyond walking distance. It is not possible to route the transit service past all the important centers, particularly if existing rail rights-of-way are to be used. Thus, a system of feeder services becomes essential.

One alternative is to stop the line just short of Jefferson Road to avoid crossing problems and expense. However, the demand from the south is sufficiently heavy to justify a major, grade-separated overpass to reach behind several large shopping centers on the south side. A terminal can be placed adjacent to one of the largest centers and joint use of the parking lot can be arranged.

The right-of-way continues further south, but estimates indicate drastically reduced patronage volumes—development here is still sparse. Physical linkage to several expressways, including the New York State Thruway, indicates little potential added traffic. The logical point of termination appears to be this fringe district of the urbanized area.

SUMMARY

The current study extended over the entire year of 1981 and was a pre-alternatives analysis. Its principal aim was to determine whether the channel had a reasonable potential for transit use or whether Rochester should finally abandon the idea. The tasks involved in this effort covered the usual ground and require no special elaboration. The effort used a highly conservative framework to ensure that every finding is completely defensible and that the concept is not based on questionable assumptions. For example, it was decided not to consider any induced development and the consequent patronage in the corridor generated by the presence of a new transit service. The plan had to stand on its own direct merits so the residents and officials of Rochester could arrive at unbiased conclusions. These were, perhaps, harsh and unusual constraints, but the history of the channel allowed no other approach.

A critical task was to estimate potential patronage.

The methods employed were innovative and based on a sketch-planning model with interactive graphics capability and extensive follow-up elaboration of assumptions about feeder services, elasticities, and service levels.³ Although this effort was interesting, the technical details go beyond the scope of the current discussion; they should be presented in a separate paper outlining modeling procedures useful for preliminary alternatives evaluation. A summary of the tentative findings will have to suffice here.

A pre-alternatives analysis was not expected to arrive at precise estimates, nor was this possible; too many operational scenarios regarding feeder and access services are still open. The aim was to define reasonable ranges regarding the operations of the system and its major elements. Socioeconomic data were obtained from state and regional sources that focused on present and future urban level travel behavior. The study area defined consisted of a wide band that ran through the region and centered on the line and its immediate corridor. The basic study units consisted of 82 zones; trip interchanges, mode choices, access opportunities, and many other relevant factors were determined for each zone. For follow-up analyses, these zones were grouped into 13 districts, each with a specific relationship to the line service. Strictly differentiated calculations for busway and light rail operations were not made, but the basic variable was the ease or difficulty with which patrons could enter or leave the line by various access modes. This took into account real or logical interchange possibilities, as well as penalties for transfer among modes. Certain access and transfer conditions are peculiar to each of the two principal alternatives; therefore, discussion of the associated implications throughout the entire range of estimates is possible.

The first calculation produced an approximate figure of 35 000 riders per day on the line. Although far below the estimate made in the 1974 study, it caused questions to be asked locally and in Albany and Washington about the assumptions and factors used. The results actually were overgenerous toward access conditions, and a subsequent exploration focused on the other end of the scale. By virtually eliminating such factors as feeder buses, two transfers, and park-and-ride use, the new estimated use was slightly more than 26 000 riders per day. This is still a respectable figure, but so conservative that the viability of mass transit in the community is suspect. After several more modeling runs and further adjusting estimates, light rail ridership of about 30 000 per day is predicted, pending more detailed analyses of the data and more elaborate modeling procedures.

The second major area of inquiry was the cost of constructing and operating a new transit service. The Rochester community is deeply concerned about this matter, as are most cities.

Methodology does not require discussion; the approach was straightforward and relied on preliminary engineering estimates and recent experiences of cities now building light rail or busway facilities.

The tentative figure for building and equipping the 11-mile light rail line is close to \$100 million; this is relatively low on a mileage basis because the channel is there and ready for use. But \$100 million is not easy for any community to raise for a specific project. Funding sources are uncertain under current conditions, as is the federal attitude toward such endeavors, no matter how promising. Private financing is conceivable but highly doubtful, even without more detailed evaluations of potential returns. Local government is hard pressed to maintain even current services, much less consider major expansions; even a 20 percent share will generate much debate.

The construction costs for the busway alternative were estimated at about \$75 million, but this figure is flexible and depends on what associated elements of the total surface system are included in the calculation.

The final component of the evaluation is estimated operations and maintenance costs and how they compare

with expected revenues. This might be the critical element, given today's concern with financial performance.

CONCLUSIONS

More work must be done, but certain conclusions have already emerged. One is that there is little doubt that a light rail line can provide more economical service than an all-bus operation. A fleet of only 8 vehicles could carry the estimated passenger loads. In Rochester and most other places examined recently the rail concept has a clear advantage. It is not as certain that light rail can be self-sufficient, but the indications are favorable. It depends primarily on fare levels and revenue allocation.

No decision has been reached in Rochester. To some, the situation is encouraging, and light rail service is most attractive. Others see dangers and uncertainties. But the greatest concern is the amount of capital resources needed to implement it and where the resources will come from. Basically the issue is how society perceives the role and

benefits of efficient mass transit. The evaluation will never be purely quantitative and explicit. Even using the worst set of assumptions, a light rail service in Rochester would draw 5000 riders away from automobiles and place them on public transit. This result will be interpreted differently by different people—as an additional burden on hard-pressed, subsidized public operations or as a welcome strengthening of an appropriate and efficient urban service.

REFERENCES

1. Charlotte-Henrietta Transit Corridor. Corddry, Carpenter, Dietz, and Zack, 1974.
2. Parsons Brinckerhoff of New York City, together with Bergmann Associates of Rochester.
3. This work was the responsibility of Jerome Lutin of Parsons Brinckerhoff.

Cologne's Contribution to the Light Rail Concept

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West Germany has been one of the most active countries in the development and application of light rail transit. Cologne (Köln) is the largest West German city to rely upon LRT (Stadtbahn) instead of full rapid transit (U-Bahn) as the primary rail transit mode. The LRT system, operated by the Kölner-Verkehrs-Betriebe (KVB), has developed in a well-planned, gradual manner from a basic streetcar system to a high-performance LRT network. The system was built by adapting the right-of-way to the physical and operating environment. Therefore, most of the 30 km of fully separated right-of-way are located in the heavily congested city center. Most lines reenter the surface after leaving downtown, but retain some form of priority right-of-way.

To operate on the improved rights-of-way, the KVB developed and purchased the B-car, one of the highest performance cars in West Germany, but a car that is still flexible enough to operate on all surface sections, including conventional streetrunning. Other areas of investment, such as electrification, signals, and track, have kept pace with the overall system improvement. The result of these developments has been steadily improving performance and a ridership level that totaled 175.8 million passengers (LRT and bus) in 1980.

Many of the technical and operating elements can be seen in the new intercity light rail line that runs from Cologne to Bonn. The route was converted from a declining commuter railroad operation to LRT in 1977 after several technical and institutional problems had been overcome. Improved service and integration of the former rail system into the LRT networks in Cologne and Bonn led to dramatic ridership gains.

The city of Cologne (Köln), with a population of 1 million is the fourth largest city in the Federal Republic of Germany (West Germany). It is located along the Rhine River in the heart of the industrial and commercial center of West Germany.

Three larger German cities, West Berlin, Hamburg, and Munich, have transit systems that emphasize rapid transit; thus Cologne is the largest German city to rely upon transit LRT as the major rail mode for local travel.

The combination of an extensive network and implementation of important technical and operating concepts makes Cologne a major contributor to the international development of light rail.

Public transportation in Cologne is carried out primarily by the Kölner-Verkehrs-Betriebe (KVB), a transit company owned by the city of Cologne. The backbone of the KVB network is the Stadtbahn, or light rail system.

The light rail system has experienced constant growth in terms of ridership, line length, and performance. This trend is the result of a well-planned effort to upgrade the rail transit system from a conventional streetcar to a high-quality light rail mode. The success of this effort in Cologne provides an excellent example of how a basic LRT system can undergo gradual, evolutionary changes to become a high-performance transit operation.

HISTORY

The streetcar system in Cologne was almost totally destroyed during World War II. The first priority after the war was to rebuild quickly a basic and inexpensive system. By 1954, the KVB was a stable system consisting of 144 km of streetcar lines and 148 km of bus lines.

Over the following decade, certain inadequacies became apparent. There was no north-south route through downtown and only one indirect route to the large commercial area around the train station. As the city became more motorized, automobiles were not only taking riders away from the transit system, but were also hindering the flow of streetcars in the city. There was a need for a transit service that offered higher speeds, more attractive service, and better downtown distribution. In 1962 the city began planning for the construction of downtown subway sections.

LIGHT RAIL CONCEPT

Although sections with complete right-of-way (R/W) separation (U-Bahn) were to be built, the system was not intended to be a full rapid-transit mode. The operating concept chosen from the General Transportation Plan of

1956 was that of an underground system, in which streetcars would operate in tunnels through congested areas. This was viewed as a less costly alternative than rapid transit, but one that would still provide adequate capacity and level of service for a city the size of Cologne. A unified transportation plan for the city of Cologne was completed in 1972.

SYSTEM OBJECTIVES

The system was planned to operate as a Stadtbahn, or high-performance LRT. Routes could thus operate over the following types of right-of-way:

- Type A—fully separated (U-Bahn);
- Type B—partially separated, with longitudinal, physical separation from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections; and
- Type C—surface streets with mixed traffic and no separation.

Any one route could encompass operations on one or all types of right-of-way, although no route is yet strictly a U-Bahn line.

This mode of operation has several advantages. A fully separated subway system provides safe, high-speed, reliable service; however, its high investment costs limit the number of lines that can be built and force a heavy reliance upon a trunk feeder system. In Cologne, the rapid-transit sections are but one component of the light rail system, and the system's lower overall investment cost enables a greater number of lines to be operated. For example, from the busy downtown Dom/Hauptbahnhof station, a passenger may travel to five destinations in one direction and to four destinations in the other.

RIGHT-OF-WAY

Rapid-transit sections are concentrated in the inner city or other areas where demand is high and potential hindrance from automobile traffic is greatest. As of January 1982, 30 km, or 21 percent, of the rail network consisted of U-Bahn sections. The inner city of Cologne, like many other German cities, is characterized by narrow and winding streets that are too small for any streetcar priority. Plans call for most remaining surface lines in the downtown area to be replaced by subway sections by the end of the 1990s.

Other high-priority locations for construction of tunnels are the heavily used but narrow arterial roads, such as the Kalker Hauptstrasse, Venloer Strasse, and Neusser Strasse. In the two latter sections, tunnels are to be built where heavy traffic conditions on the surface warrant a grade-separated alignment. The U-Bahn has also been used for new sections or extensions where right-of-way is easily available and new residential development produces high ridership demand. A prime example of this joint development is at Chorweiler, a "new city" built in the mid-1970s on the outskirts of Cologne. A new light rail line (KVB), a regional rail line (German Federal Railway), and an automobile expressway were built to coincide with the opening of Chorweiler.

The U-Bahn can be divided into subway tunnels, elevated viaducts, at-grade rights-of-way, and open-cut rights-of-way. Tunnels are all double-tracked and constructed by the cut-and-cover method. They are built in rectangular cross sections and without center supports unless required when passing under large structures. After tests with ballastless and tieless slab track proved successful, a reduction in tunnel height of 15 cm to 4.70 m was achieved.

The design speed of the subways is 80 km/h (50 km/h in parts of the inner city); however, allowable speeds are limited to 70 km/h due to signal, vehicle, and safety considerations. Other important design features are the following:

- Maximum gradient, 4 percent;
- Minimum radius, 120 m; and
- Maximum superelevation, 16.5 cm.

The elevated viaduct is located over part of the Gürtel highway that forms a semicircle around the outskirts of the city. Unlike most other U-Bahn lines, this route provides completely new service, as surface lines did not previously operate in this part of the city. Construction of viaducts is significantly less expensive than subways; however, for aesthetic reasons, viaducts are limited to the outskirts of the city.

All U-Bahn lines are equipped with automatic block signals and automatic train-stop and speed-control devices. Automatic train operation was not judged to be necessary, since manual control is required when the vehicles reach the surface. Most of the heavily loaded downtown stations have a signal at midplatform that enables two trains to board simultaneously. The maximum capacity of the system is 60 trains per hour; currently, 44 trains (both one- and two-car trains) per hour per direction operate over the most heavily used section between Appellohofplatz and Neumarkt. This is significant because of an at-grade crossing at Appellohofplatz.

Outside of the center city, extensive efforts are made to provide as much separation as possible using a right-of-way Type B, as both rail transit and automobile traffic flow better when the modes are separated. As a result of this policy, about 80 percent of all route kilometers have various forms of priority rights-of-way (types A and B) for rail vehicles.

The types of priority right-of-way include private right-of-way with at-grade crossings (both protected and unprotected) and physically separated right-of-way along highways. The physical separation is provided by low concrete curbs, raised concrete barriers, and shrubbery. In addition, ballasted roadbed and wooden ties prevent automobiles from conflicting with rail vehicles.

There are still a few remaining sections of conventional streetrunning; however, these are generally in locations with light traffic volumes. Two surface routes with heavy traffic conditions (Venloer Strasse and Kalker Hauptstrasse) are planned for eventual conversion to U-Bahn.

Suburban lines that do not run along highways have allowable speeds of up to 70 km/hr. These lines are not signalized except before crossing gates, where two signals are located to indicate whether the gates have been activated and lowered.

SUBWAY-SURFACE RAMPS

An important part of Cologne's transit policy is the attempt to bring a completed U-Bahn section (generally 3 to 10 km long) into operation as soon as possible. This will bring a quick return on the high investment for building subway tunnels and avoid having finished sections lie unused for years while the remaining U-Bahn network is completed.

When a section is completed, a temporary ramp is constructed to connect it to the existing surface network. Meanwhile, work continues on extending the subway. When the next tunnel section is completed, the temporary ramp is closed, and trains operate only in the U-Bahn for that section. This method brings sections of U-Bahn immediately into service and reduces public criticism of subway construction for the years of inconvenience before any benefits are realized.

VEHICLES

An important characteristic of the KVB rail network in the 1970s and 1980s is the mixed operation of conventional streetcar-type (primarily 8-axle) and 6-axle light rail vehicles. A summary of the KVB rail fleet is shown in Table 1.

The 4-axle vehicles are used only as supplements

during the peak period. They are 15 m long and have a top speed of 60 km/h. Each car has two trucks, only one of which is powered by a single motor (monomotor). The 4-axle cars are operated in two-car trains and will probably be retired when new vehicles arrive. Many 4-axle cars have been converted into work cars.

Since the older streetcar-type vehicles have steps arranged only for low-level boarding, all U-Bahn stations had to be built with these platforms. All new vehicles purchased since 1972 must have the capability for the present low-level boarding and for the high-level boarding that will prevail after all U-Bahn stations are operating only with the new light rail vehicles. New vehicles must also have the flexibility to operate on rights-of-way ranging from high-speed U-Bahn and interurban (right-of-way type A) to conventional streetrunning (right-of-way type C).

In response to these needs, the KVB, in conjunction with Duewag, designed the concept for the Stadtbahnwagen B (type B Light Rail Car). The success of this design is demonstrated by its acceptance as the standard light rail vehicle of the state of Nordrhein-Westfalen, which has one of the world's largest concentrations of light rail networks. B-cars are currently operating in Mülheim/Essen, Bonn, and Düsseldorf and will soon be running in Duisburg and Dortmund.

Table 2 compares the major features of the two main types of vehicles in the KVB fleet. The increased width and longer truck center distance and wheel base prevent B-car operation on certain surface lines. However, with only 59 cars currently in service, this is not a major problem, and the restricted lines are gradually being reworked to allow B-car operation. In 1981, the KVB placed an order for 60 additional B-cars, which should be delivered by 1983. The B-cars are being phased in gradually to prepare for their operation and because the older, 8-axle cars are still in good structural and mechanical condition.

As indicated by Table 2, the B-car represents a major upgrading of design standards. Two large 235 kW motors (longitudinally mounted monomotors), one on each end truck, enable the car to accelerate at a rate of 1.2 m/s² to a top speed of 100 km/h, making it the fastest transit vehicle in Germany. Control is through resistors mounted under the car, and acceleration and deceleration are electronically regulated to provide smooth starting and braking rates.

Retractable steps allow boarding from high- or low-level platforms. Even after U-Bahn station platforms are raised to a height of 900 mm, many surface stations will retain low-level platforms, and the system will still require a dual-purpose vehicle.

Table 1. KVB rail fleet.

Type	Number	Builder	Year Built
4-axle	39	Westwaggon	1956
8-axle	65	Duewag	1964-66
8-axle	39	Duewag	1968
8-axle	21	Duewag	1969-70
8-axle	18	Duewag	1971
8-axle	56	Duewag	1963-65
6-axle (Stadtbahnwagen)	2	Duewag	1973-74 (prototypes)
6-axle (Stadtbahnwagen)	57	Duewag	1976-77

Table 2. Comparison of vehicles in KVB fleet.

Item	B-Car	8-Axle
Number	59	199
Years built	1976-77	1963-77
Builder	Duewag	Duewag
Length (m)	28.0 ^a	29.70
Width (m)	2.65	2.50
Height (m)	3.36	3.22
Truck center dist. (m)	10/10	7.10/8.65/7.10
Wheel base (m)	2.10	1.80
Floor height (m)	1.00	0.89
Minimum radius (m)	25.0	15.0
Tare weight (t)	39.0	29.0
Weight/m ²	0.55	0.39
Maximum train length (# cars)	4	1
Driver's cabin (#)	2	1
Seats	72	82
Capacity (0.25 ² /standee)	183	208
Acceleration rate (m/s ²)	1.2	1.0
Maximum speed (km/h)	100	70
Motors (kW)	2 x 235	2 x 175
Power/weight (kW/T)	12.05	12.07
Passenger boarding	High/low	Low
Body construction	LAHT steel	LAHT steel
Door channels (#)	10 (each side)	10 (one side)
Door type	Sliding plug	Folding

^aLength over couplers; body length is 26.9 m.

TRACK

The KVB has been a leader in the development and application of concrete slab track, which does not use ties or ballast. This type of track is favored for several reasons: it allows tunnel height to be reduced up to 20 cm; it reduces weight on bridges and viaducts; it has lower track maintenance costs (ballasted track must be reworked every 3 to 4 years to maintain proper rail level); and it decreases noise levels to a range of 19 to 25 dB.

The track fasteners use rubber pads to perform the energy- and vibration-absorbing function of the ballast. The KVB recently developed the Type 1403/c fastener, or the "Cologne Egg," named for its oval shape. In this type of fastener, the rail rests on a baseplate permanently attached to a rubber collar through vulcanization. Both the baseplate and outer sleeve narrow toward the base. Directly under the baseplate is an air space that allows the plate to sink 5 mm without developing any compressive stresses in the collar, which then can resist shearing stresses. Because lateral forces are about twice those developed along the axis of the rail,^{2,3} maximum absorption of shearing forces is accomplished by placing the elliptical mountings at right angles to the rail.

Use of Type 1403/c also increases the permanency of the track. Fatigue tests with 2.1 million loadings revealed the maximum elastic gauge widening to be 7 mm (it is estimated that this would be only 3 mm under normal loading conditions), and the permanent gauge widening after 2.1 million loads was only 1 mm. Even a gauge widening of 7 mm is well within the allowable safety tolerances, given the wheel dimensions.

To avoid the difficulty and expense of boring the bolts into the concrete floor, the KVB has developed a new track-laying method in which the concrete is poured around the bolts and allowed to harden. First, the track and its mountings are held in place with temporary ties under the rail while necessary adjustments in rail height and gauge are made. Wooden borders are constructed under the temporary ties to form a frame for the poured concrete. The concrete is then poured into the frames from a self-propelled vehicle on a temporary side track. The concrete fills in around the bolts and soon hardens. The temporary ties are removed, and the track is made ready for service.

The KVB now has over 22 km of slab tracks. Compared with ballasted track, slab track produces a savings in maintenance cost of DM 30 000/year. This results in an annual savings of DM 650 000 (approximately \$300 000/year) in systemwide maintenance costs.⁴

The type of rail normally used in the U-Bahn is the S 41 (41 kg/m). Girder rail is used on much of the surface track. A major problem in rail maintenance is the excessive wear and high noise levels on curves. The KVB has developed two methods for solving these problems.

The first method is a setup that automatically lubricates the flanges of a passing train before it reaches the outside rail of a sharp curve (reducing the friction on the flanges of every passing train). The oil is sent through small holes drilled into the rail head from a pump activated by a train-actuated magnetic loop. The excess lubricating oil drains into a trough beside the rail, where it is filtered and sent for reuse in the pump. This method ensures that every vehicle receives proper lubrication and avoids maintenance costs involved in operating a special work train for subway track lubrication. The recycling of lubricating oil increases the time between refills and further reduces costs.

The other method involves culling out part of the rail head and rebuilding it through welding. The rebuilt rail is then grounded and put into service. Although this method costs four times more than rail in an as purchased condition, it has increased rail life on curves by as much as 12 times and its average maintenance costs are only a third of the normal costs.

The KVB places great emphasis upon standards for high-quality track. This has resulted in long-term benefits

of low noise levels and lower track maintenance costs and underscores the willingness of the KVB to adopt and even take the lead in developing new technology.

OPERATIONS

The KVB operates 14 light rail and 31 bus routes daily. In 1980, KVB carried 175.8 million passengers, an increase of 1.7 percent over the previous year. A summary of 1979 KVB ridership is given below:

Category	Average Weekday	Average Saturday	Average Sunday
Total rides	886 127	440 047	258 842
Percent rail	73.0	73.1	76.2
Percent bus	27.0	26.9	23.8
Passenger/km (million)	3.505	1.681	1.063
Percent rail	76.5	76.5	79.5
Percent bus	23.5	23.5	20.5
Percent of weekday ridership	100.0	49.7	29.2
Peak hour	7:00-8:00	11:00-12:00	14:00-15:00 or 2:00-3:00
Percent rides during peak	13.1	10.5	10.7

Headways during the peak period generally range from 4 to 10 minutes; however, in the U-Bahn, several routes use the same stretch, effectively reducing headways. Most rail routes begin at 4:30 a.m. and operate until 1:15 a.m. During the peak hours, an average of 214 vehicles are required to meet demand.⁵ All routes, with the exception of line 16 (the intercity line to Bonn), operate throughout the day with one-car trains.

All vehicles, buses and rail cars, are designed for one-man operation; conductors have not been used since 1967. Station loading and unloading are performed by the driver; no additional station or platform personnel are required. This one-man operation is made possible by the relatively short length of the trains (compared to rapid transit), mirrors on the side of the car, and safety devices that prevent doors from closing on a passenger. Door control devices include pressure plates, sensitive edges, and photo-sensitive cells (on B-cars and some 8-axle vehicles).

Operations control is handled primarily by four supervisors who patrol designated areas in mobile vehicles. These field supervisors act in conjunction with a supervisor in the central control tower and provide an important communication link for responding to delays and other conditions. With the many lines and junctions in the KVB rail network, there are many possibilities for diversions around a blocked section of track to avoid the loss of too much running time.

Reducing deadhead and unproductive time is an important scheduling goal. Because there are four rail and two bus depots in different parts of the city, an individual route can be supplied with vehicles from more than one depot. This reduces deadhead time from the end station to the depot. A computer optimization program obtained from Hamburg Consult is currently used to schedule bus routes and will be tested shortly for the light rail system. The objective of the program is to reduce unproductive time (layovers, running time to terminals, etc.) and minimize the number of drivers required.

Buses serve largely as feeders to the light rail network and operate mainly on the outskirts of Cologne. The KVB maintains a fleet of standard buses, but has recently purchased articulated buses to serve the rapidly growing population in outlying areas.

FARE COLLECTION

A self-service fare collection system is used that allows,

boarding and alighting from all doors, reduces labor requirements, and speeds service. To reduce the number of transactions, passengers are discouraged from buying single-ride tickets by a 50-percent price differential over the cost of multi-ride tickets. Only the more expensive, single-ride tickets are available from drivers, which further discourages the purchase of tickets on board the vehicle.

The following table shows a breakdown of the types of fares used during a typical weekday:

Type Fare	Number	Percent
Single-ride (adults and child)	62 303	9.5
Multiride	225 735	34.6
Weekly (adults)	106 890	16.3
Monthly (adults)	22 270	3.4
Senior citizens (monthly)	57 126	8.7
Handicapped pass	11 615	1.8
Student (weekly, monthly, yearly)	156 985	24.0
Other	10 948	1.7
Total	653 872	100.0

The effort to discourage purchase of single-fare tickets has been a success: they are used by less than 10 percent of all passengers, and only a fraction are purchased on board vehicles. A large number of school children use the system, which has enabled the city of Cologne to avoid the expense of purchasing and maintaining a separate fleet of school buses.

The only fare collection duty of the driver is to sell single-ride tickets, which, because of the pricing policies described earlier, account for only a small percentage of total ticket sales. Single-ride tickets are not available from drivers at stations on U-Bahn and other light rail sections (mainly the high speed suburban lines) because of the high speeds on these lines and the heavy passenger volume. At these locations, all tickets must be purchased in advance and are available from manned ticket booths at some subway stations or automatic ticket vending machines at all subway and designated light rail stations. Since most light rail stations are not enclosed, the machines must be sufficiently weatherproof to withstand the elements. Multi-ride tickets are available at numerous small stores and shops.

To use the system, a passenger must insert the ticket into a cancellation machine, which marks a code on the ticket, giving time, date, and location. Cancellation machines are carried on all vehicles and are also located at U-Bahn station concourses to speed flow in boarding vehicles. Weekly or monthly tickets need not be cancelled.

Key to the effectiveness of a self-service fare collection system are the roving fare controllers. These controllers travel around the system in groups of three or four and check the tickets of all passengers in the vehicle. Passengers without a valid ticket must pay a surcharge of DM 40 (\$20).

Inspections are particularly vigorous at times when passengers are more likely to try to avoid paying fares, such as during off-peak hours or at night. (An irregular or intermittent rider is more likely to try to avoid payment.) On average, 5 percent of passengers receive a fare inspection, and 1.6 percent of these are without valid tickets.

INTERCITY LIGHT RAIL LINE BETWEEN COLOGNE AND BONN

A major success story of recent years is the light rail line (the Reinfur Route 16) to Bonn, the capital of West Germany. This line, 44 km long and with 48 stations, starts in the northern outskirts of Cologne, runs through the downtown and the fringes of downtown to the southern suburbs, along the Rhein to Bonn, and finally through Bonn

to the suburb of Bad Godesberg.

This project was completed in 3 years at a cost of DM 60 million. It was made possible by using and upgrading the light rail systems in both Cologne and Bonn and the heavy rail network of the Cologne-Bonn Railway (KBE, a private railway) between the two cities. Before light rail service was introduced, the KBE operated its own heavy rail passenger service between Cologne and Bonn alongside its freight trains. However, this line, which operated along the Rhine River for its entire length, had only one station in downtown Cologne and it was not centrally located. A similar situation existed in Bonn. Integration of KBE heavy rail services into the light rail networks of the KVB in Cologne and SWB in Bonn has provided superior downtown distribution and easier connections with the rest of the system.

To integrate these three separate systems, each with its own characteristics, and to make the conversion from conventional heavy rail to light rail, a number of problems had to be overcome:

1. Vehicles — The KBE railroad passenger cars, with a truck center distance of 12 m, were too large for the clearances of Cologne's subway tunnels, designed for a maximum truck center distance of 10 m. The streetcars in Cologne and Bonn had a maximum speed of 70 km/h—too slow for railway operation—and they could not be coupled to form trains.

The development in Cologne and Bonn of the Stadtbahnwagen B-car provided a vehicle compatible to all networks. With a truck center distance of 10m, it can run in Cologne's subways, and its top speed of 100 km/h makes it suitable for high-speed running on the KBE. Many of the high-performance features of this vehicle were designed for operation on the Cologne/Bonn line. Bonn also has purchased the B-car, so one vehicle type can provide all service. Except for their color, the cars in Cologne and Bonn are identical.

2. Electrification — The KBE, which operates at 1200 DC, was the first German rail mainline to be electrified. The KVB was later electrified to operate at 800 DC, and the Bonn network to operate at 600 DC. The KBE vehicles could operate at the lower KVB voltage, but acceleration and speed were unacceptably low over long sections.

The solution was to adopt a uniform current of 750 DC. This involved an increase in Bonn from 600 to 750 DC, a decrease on the KBE from 1200 to 750 DC, and a nominal drop in Cologne from 800 to 750 DC. The large decrease on the KBE has had little adverse effect; freight traffic on the Rheinufer is handled exclusively by diesel locomotives, and the old (1200 DC) passenger vehicles can be used on this line.

3. Track — In Europe, rail wheels on freight cars are wider than those of light rail vehicles or streetcars; that is, the back-to-back distance between the wheels is greater for light rail vehicles than for railroad cars, since light rail vehicles must be able to operate on girder rail in street sections. Also, the flanges on light rail vehicles are not as deep as those on railway cars.

Despite these profile differences, light rail vehicles normally have no problem operating over straight or curved railway sections. Problems do occur, however, over frogs at switches where one wheel passes over a gap. The smaller profile of the light rail wheel allows enough lateral movement in these switches (designed for railway vehicles) for derailments to occur.

The solution was to install movable frogs on all switches used by both light rail and freight vehicles. This eliminated the gap of conventional switches and provided a safer operation. Movable frogs also eliminated most lateral acceleration and resulted in a much more comfortable ride over switches. The KVB had previous experience in joint passenger-freight operation through its operation of the Köln-Frechen-Benzelrather Eisenbahn (KFBE).

4. Stations — Original plans called for high-level platforms at all stations. However, several factors hindered these plans, including the continued use of a large number of streetcar-type vehicles in Cologne and joint operation with freight vehicles, whose profile does not permit running by high-level platforms.

The solution was to build all stations in Cologne and those on the KBE (where freight trains still operate) at an intermediate height of 350 mm. In Bonn, all stations have high-level platforms, including a nonsubway section where the line runs in the middle of a highway. The flexible Stadtbahnwagen B-car can operate from platforms of either height.

5. Organizational Difficulties — The operation of the Cologne/Bonn line involved facilities of two public transit companies (the KVB and Stadtwerke Bonn-SWB) and one private railway (KBE). This provided the impetus for development of the coordinating agency Stadtbahngesellschaft Rhein-Sieg (SRS). SRS provides the framework for unified fares, schedules, planning, and operations. The coordination task has become relatively simpler since the KVB purchased KBE's freight and passenger operation on August 2, 1980.

After these problems were solved, the line was completed and has become a successful showcase for light rail. The entire line is separated from traffic by a variety of means—subways in central Cologne and Bonn and separate rights-of-way in the middle of highways with conventional street crossings. All grade crossings on the KBE railway section have automatic protection at crossing gates. The section from the end station of Mülheim in northern Cologne to Barbarossaplatz on the southern fringe of downtown now has a fully separated right-of-way.

Normally two-car trains are run, except late at night when one car is sufficient. Signal systems in the Cologne and Bonn LRT systems are similar; the KBE has German standard railway signals. Drivers are trained on all signal systems. Trains operate through from Cologne to Bonn and vice versa; drivers, however, change in Wesseling near the halfway point. Through operation by drivers is not yet possible because of different pay rates for workers in the two systems.

The average (1979) daily ridership patterns on line 16 are as follows:

Day	Ridership
Weekdays	47 475
Saturdays	22 118
Sundays	13 761

The success of the new light rail line is illustrated by the following figures showing passenger growth since completion.⁵

Section	Area	1965	1977	1979	1977-79 Percent Growth
Marienburg-Rodenkirchen	Cologne	16 200	12 880	18 100	+41
N. Wesseling-Wesseling	KBE	8 500	5 700	8 200	+44
Buschdorf-Tannenbusch	Bonn	8 100	4 500	8 100	+80

Before the implementation of light rail, these sections

were served only by the heavy rail services of the KBE, and between 1965 and 1977, ridership continued to decline despite population gains in the area. Ridership gains since the implementation of light rail have been dramatic and are expected to continue.

The success of the Rheinufer light rail conversion has led to similar plans for the other KBE line between Cologne and Bonn—The Vorgebirgs, or "foothills," line. This route travels between the two cities on a more circuitous, westerly path. Vehicles are still the conventional rail type and, therefore, do not use the subways in Cologne or Bonn, but terminate at stations located in fringe downtown areas. Conversion is slated for the mid-1980s, and work (including the purchase of new B-cars) is already in progress.

FUTURE SYSTEM GROWTH

The KVB continues to expand and upgrade its facilities in all parts of the city. Subway construction was recently completed in Vingst and is currently underway in Deutz (open-cut) and Friesenplatz, near downtown.

The pace of future expansion and construction will depend largely on the financing available. Germany has enthusiastically supported transit and currently dedicates one-half of the federal gasoline tax for public transportation capital projects. The federal government provides 60 percent of the funding for the Cologne light rail capital projects; the state of Nordrhein-Westfalen provides 30 percent, and the City of Cologne, 10 percent. The city is also responsible for covering 100 percent of the operating deficit. Because of recent funding difficulties in the public sector, particularly the city, plans to build a subway under the ring highway around the CBD had to be postponed. The LRT, therefore, will continue to operate on the surface with priority right-of-way in the median.

Funding difficulties may slow the pace of future expansion, but the system is still expected to improve in terms of performance, ridership, and modern facilities. It has been built gradually, so it does not experience major disruptions if certain components of the transportation plan are altered; it is less sensitive to funding shortages than a more expensive rapid transit system. Most of the basic elements of a high performance LRT network are in place and the KVB will continue to make incremental improvements to the system. As the rate of new automobile ownership slows and energy costs increase, the LRT will continue as a major factor in transportation and in the urban structure of Cologne.

REFERENCES

1. Generalverkehrsplan der Stadt Köln, 1956 and 1972.
2. Hans Braitsch. "Das Kölner Ei (Oberbau 1403/C)" Sonderdruck aus *Verkehr und Technik*, Hefte 7, 8, 10 und 12, 1979.
3. Hans Braitsch. Köln Lays Egg Track. *Railway Gazette International*, December 1980.
4. Hans Braitsch. "Neves zum Kölner Ei (Oberbau 1403/C) und zur Kostensparenden Eindämmung von Körperschall an Nahverkehrsbahnen." *Verkehr und Technik*, Hefte 11 und 12, 1981.
5. Kölner-Verkehrs Betriebe. Verkehrszahlung, 1979.

Light Rail Transit System in Hanover

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Light rail transit systems can be developed in various stages, from a streetcar system that shares its right-of-way with other traffic up to a transportation system that operates substantially on exclusive rights-of-way (underground, at-grade, or elevated). Hanover's LRT system developed from an existing streetcar system by constructing a tunnel system in the inner city. This tunnel system allows a high performance level in that part of the city where the streetcar service had become unreliable because it shared its right-of-way with private cars. By incorporating elements of rapid transit and streetcar operation, the light rail system meets the city's demand for attractive transit services at an acceptable cost level. The system components, infrastructure (rights-of-way, stops, stations), vehicles, and operations are developed to a level tailored to Hanover's local conditions and the desired service quality. Buses used as a feeder and distribution system are also integrated into the transit concept. The infrastructure is characterized by an exclusive right-of-way (tunnel) in the inner core of the city and a separate right-of-way in the surface sections, mostly in the median of arterial streets. The Hanover LRT vehicle is a bidirectional, articulated 8-axle car. Trains are operated in 2-or 3-car units. Retractable steps allow passengers to board and alight at both low and high level platforms. The electronic DC chopper control provides smooth, jerk-free acceleration and deceleration. Savings in traction current, including energy recovery during braking, amount to about 25 percent. The system combines signal control on the sections with exclusive right-of-way, with visual control on all other sections of the network. Special control devices for traffic lights that reduce waiting times for transit vehicles and a computerized vehicle monitoring and operating control system ensure a high performance standard. The results of traffic surveys and studies clearly illustrate the success of the light rail system in Hanover. Increases from 30 to 50 percent in the number of passengers are reported on the LRT routes in revenue service today. In addition, private companies have invested extensively in the CBD area where public investments for the LRT system are combined with a redesign program of major parts of the city center.

The greater Hanover area, consisting of the provincial capital of Hanover and 15 surrounding communities, belongs to one of the most densely populated areas of the Federal Republic of Germany. Over a million people live on a surface area of 2275 square kilometers; approximately half of them live in the city of Hanover on a surface area of 204 square kilometers.

The data in Table 1 characterize the monocentric structure of the whole area. The relatively large and constantly growing number of people living in the surrounding areas and the high concentration of employment and central institutions in the city of Hanover indicate that there is a close and extensive interaction between the city and its surrounding areas.

As in other comparatively dense areas, a great deal of commuting traffic is allocated to the transit system.

In the greater area of Hanover, the public transportation system as a whole is coordinated by the Verkehrssverbund "Grossraum-Verkehr Hannover" (the regional transit federation). Within its service area is the ÜSTRA AG (Hanover's transit company), which carries of about 75 percent of all passengers using transit systems in this region. In the greater area of Hanover, more than 160 million people are transported by public transportation annually.

Currently, the modal split in Hanover shows the following data:

Item	Transit/Car
Total traffic in the city of Hanover	40/60
Commuters in the city area and from the surrounding areas to the city district	45/55
Commuters from the surrounding areas to the inner-city area	65/35

The overall service concept for the public transportation system in the greater Hanover area is based on the following integrated operation of rail and bus systems:

- Commuter rail by DB (Deutsche Bundesbahn)—The commuter rail system run by the DB provides a fast link between the CBD and the areas outside the city of Hanover.
- Light rail by ÜSTRA—The LRT system is the backbone of the inner-city transit system.
- Bus service—Buses supplement the light rail system and functions as the feeder and distribution system and as a supplementary service for areas not (or not yet) served by LRT lines.

The bus lines are connected with the LRT system at transfer stations. Thus, it is possible to integrate services of bus and rail lines according to demand and avoid uneconomical, parallel services.

LIGHT RAIL SYSTEM IN HANOVER

In the middle 1960s, the long-range plan for the LRT

Table 1. Hanover population and employment data.

Location	Population				Empl. Area
	1961	1970	1981	1981	(km ²)
City of Hanover	613 000	582 000	554 000	367 000	204
Rural district of Hanover	373 000	486 000	575 000	124 000	2071
Greater area of Hanover	986 000	1 068 000	1 129 000	491 000	2275
Commuters into the City of Hanover (pass./day)	90 000	125 000	145 000		

system in Hanover was developed. The assigned network of light rail consists of 4 routes: A, B, C, and D. These routes combine underground sections (exclusive right-of-way) in the inner-city area with separate right-of-way sections of the surface operation outside the CBD. The network is based on the old streetcar network; route extensions are planned to further serve densely populated suburban areas (e.g., at Misburg, Kirchrode, Kronsberg, and Wettbergen in the city boundaries; Langenhagen, Garbsen, and Hemmingen outside the city boundaries). The current network has a total route length of 94 km (8 km in tunnel); the long-range network will consist of a route length of 107 km (22 km in tunnel).

On April 4, 1976, the first LRT route, route A, from Lahe/Fasanenkrug (northeast) to Mühlenberg (southwest), went into revenue operation. Its total length is 18 km, of which 4 km in the inner city and 0.6 km at the southwestern end are tunnel sections. The second route in operation today is the northern part of route B. Route B-south will be opened for revenue service in September 1982. The tunnel section for the western branch of the LRT route C is now under construction. This entire section will probably be in operation in 1985. Further expansions of the LRT system include the route extension of B-north to Langenhagen and C-west to Garbsen as well as the eastern section of route C (including the extension to Roderbruch).

In the analysis of an LRT system, the following components should be considered:

- Infrastructure (rights-of-way, stations, transfer stations);
- Vehicles; and
- Operations.

With respect to these components, the LRT system development covers a wide range of operational and infrastructural characteristics.

Light rail is a railbound form of transport that can be developed in stages, from a modern tramway to an underground or an elevated transport system. Each development stage can be the final stage but should permit further development to the next higher stage.

For cities of about the size and structure of Hanover, this city's light rail system shows the state of the art: well proofed and experienced. Hanover's system will be described by the three components mentioned above.

Rights-of-Way, Stations, Transfer Stations

In general, LRT systems have three different categories of rights-of-way:

- Shared right-of-way—Track areas are also used by other traffic.
- Separate right-of-way—Tracks physically separated by curbs, barriers, and from other traffic except for at-grade crossings with pedestrians and vehicles.
- Exclusive right-of-way—Fully controlled right-of-way without any legal access for other traffic (e.g., tunnel).

Currently, the Hanover LRT system network has a route length of 33 km, with 7 km in tunnels (exclusive right-of-way), 18 km on separate right-of-way, and 8 km on shared right-of-way.

The tunnel sections are predominantly used in the center city area (i.e., in those parts of the city where the old streetcar service operated at very low speed because of the lack of a separate or exclusive right-of-way). Streets in Hanover's CBD are rather narrow, and the only way to upgrade the streetcar service and enhance the quality of service offered was to plan and construct a tunnel system in the inner core of the city, thus increasing substantially the operating speed, regularity, and punctuality of service.

This decision is based on the basic design standards of subway system tunnel sections. The tunnel sections are constructed for a design vehicle with 290-m width. In the tunnel sections, a signal system is installed that provides automatic train protection. The capacity of this tunnel system, including station dwelling times, is approximately 35 trains per hour.

The capacity of the tunnel system influences the overall capacity of the whole system. In order to provide a reliable service at this capacity, the surface operations outside the tunnel system have to achieve a high standard of regularity and punctuality. This is the main reason for a design standard that demands separate right-of-way for the surface operation.

Stops on the surface parts of LRT routes are designed with a length of 60 m and low-level platforms for the "normal" 2-car-train operation. The only exception is route B-south, which has a platform length of 90 m, allowing for 3-car operation to the Hanover Fair, an international industrial fair held annually in Hanover that attracts thousands of visitors.

Platforms in the tunnel stations are designed with a length of 103 m, corresponding to the former U-Bahn requirements. These stations can accommodate a 4-car train of the Hanover LRT vehicle. In tunnel stations, high-level platforms (82 cm) are used to provide comfortable and fast boarding and alighting.

Among the surface stations, only the northeast branch of the route B-north has high-level platforms, because only in this section of the network could the more extensive width requirements for high-level platforms be met.

The concept for public transportation is based on an integrated bus/LRT service and, therefore, much attention has been put into planning, constructing, and operating transfer stations. A safe, convenient, and comfortable transfer between LRT vehicles and buses is crucial.

Vehicles

The basic design features for the Hanover-type light rail vehicles are determined to a large extent by the different kinds of operation for which this vehicle is used:

- Operation on the existing streetcar network with low-level platforms and visual control, and
- Operation on the exclusive right-of-way (tunnel) with high-level platforms and signal control.

The existing streetcar network in Hanover, with a minimum radius of 25 m and standards defined by BO-Strab (Verordnungen über den Bau und Betrieb der Strassenbahn), restricted vehicle width to 2.40 m and recommended an 8-axled articulated vehicle with a length over couplers of 28.28 m.

The following provides further technical data:

Arrangement of axle	"B"2"2"B" (4 motored axles, 2 braked, and 2 unbraked trailing axles;
Track gauge	1.435 m;
Bogies	Single-motor bogies provided with DUWAG drive, rubber scroll spring suspension, and Megi primary suspension;
Motor power	2 x 217 = 434 kW/60 min. at 600 V = 80 km/h;
Floor height	0.943 m;
Height of steps	388/294/261 mm, retractable steps for high and low platforms;
Tare weight	38 800 kg approx.;
Adherence weight	60 percent approx. of the tare weight;
Seated capacity	46; and
Standing capacity	104 (4/m ²).

The vehicle is designed for bidirectional operation

with 5 electromechanically operated double-folding doors on both sides of the vehicle. The doors are operated by the passengers or by the driver. All doors are provided with an automatic closing device. Safety to passengers is ensured by a pressure wave system in the finger protection profile, a light barrier, and door step contacts.

For operations with low- and high-level platforms, the vehicles are equipped with retractable steps that are automatically controlled to correspond to the design of the next station at which the train arrives.

The trains may operate in single- or multiple- unit operation (up to 4 units).

Drivers' compartments, separated from the passenger area by glazed screens, are located at both ends of the car. Good driving visibility, neat and convenient control groupings, and antiglare instrument layouts contribute to safety and comfort. The cabs are adequately ventilated and have adjustable seats.

The vehicle offers seating for 46 passengers with integral molded GRP seats containing nondestructive GRP seat inserts. The seats are mounted on aluminum seat boxes that serve for storing sand and accommodating electrical instruments, heaters, and other equipment.

The main feature of the electrical equipment is the chopper control, which provides a smooth, continuous acceleration and deceleration. According to the results of a research project sponsored by the Federal Ministry for Research and Technology, the chopper control equipment provides not only a lower energy consumption during acceleration but also approximately 25 percent energy recovery during deceleration.

Other equipment, such as a public address system, fully automatic destination indicators (can be read from both inside and outside), ticket cancelling machines, on-board speed control, automatic emergency brake system connected with the signal control, etc., are provided in accordance with the latest engineering principles.

Operations

The predominant characteristics of LRT operation in Hanover result from the combination of visual control on street sections with separated (or, in some short sections, shared) right-of-way and signal control on the exclusive right-of-way in the inner-city tunnel sections.

As mentioned earlier, the capacity of the overall system is set by the line capacity of the tunnel system. The tunnel signal control system restricts the capacity to about 35 to 40 trains per hour for each direction, depending on station standing times and including some time reserved for maintaining a reliable schedule at a high service level.

The offered line capacity of the LRT system cannot be utilized at the desired operational speed unless the trains arrive with the scheduled headways at the ramps (i.e., the beginning of the tunnel sections with signal control). Therefore, much attention is given to operating strategies that provide punctual and regular service. The following are two major fields in which special efforts were undertaken:

- Special control strategies for traffic lights, and
- Use of a computerized vehicle monitoring and operation control system.

Preferential treatments for individual transit vehicles at signalized intersections are successfully used in a number of cities. On LRT routes in Hanover with scheduled headways of 4 minutes, a control strategy that provides a "green wave" for all LRT vehicles in both directions, along a set of intersections in succession, is (or will be) used on all surface sections of LRT routes. This strategy has theoretically and practically proved itself substantially superior to other such measures as actuation of a special treatment signal (e.g., leading or lagging green) by each vehicle. Frequently, improving conditions for one vehicle means giving additional delay to others. Basic data neces-

sary for design of a control strategy that gives the LRT vehicles a "green wave" are average standing times for each station, station-to-station operating speeds, and the distances between stations. Special treatments for vehicles with long station standing times or other delayed vehicles are an additional feature of the control strategy. The computerized operating control system is used to select delayed trains that need an additional treatment. Thus, light rail vehicles more than 2 minutes late activate an additional leading or lagging green. This is one potential advantage of a computerized operating control system linked with other control systems.

Computerized operating control systems have operated in Hanover for several years. Five years of operating experience with the COCS on all LRT routes show that the systems have become an important part of the punctual and regular service provided by LRT. A computerized operating control system can also improve transit planning, maintenance, and operations. Computerized operating control systems may be seen as the core of a management system for public transportation that includes planning, information, and control systems.

The experiences acquired from daily operation (i.e., with the LRT system in Hanover) not only supply convincing evidence of the high efficiency of these systems but also show that further effort should be made toward developing systems with the following characteristics:

- Universal application (LRT, streetcar, bus, with scheduled service as well as demand-responsive operation);
- Standardization of hardware and software components to achieve lower costs; and
- Comprehensive and effective utilization of the data recorded and processed in the operating systems.

Sponsored by the Federal Ministry for Research and Technology, ÜSTRA, Hanover's transit agency is developing and testing a control system called BON (Betriebsleitsystem für den Öffentlichen Nahverkehr) with the characteristics listed above.

The BON system has the following components:

- Central equipment (process computer and terminals in the control center),
- Vehicle equipment, and
- Line equipment.

By improving communication between the vehicle drivers and the dispatchers in a control center, the following objectives can be achieved (on-line functions):

- Detailed information for control center personnel on current operating conditions, i.e., the actual position of vehicles in service with respect to time and position compared with the scheduled position;
- Selective information for control center personnel on trouble spots and provision of aids for their elimination; and
- Information for vehicle drivers that indicates actual positions and possible delays the vehicles may encounter and transmission of coded instructions to the vehicle drivers.

The following are other important on-line functions:

- Information for passengers corresponding to the latest operating situation, and
- Improvement of operation through coordinated control of traffic signals and selection of delayed vehicles to receive special preferential treatment.

Vehicle Equipment

Much of the data on vehicles required for the operating

control system are also processed or made available by other information equipment in the vehicle. Therefore, it is appropriate that this equipment be jointly controlled with the operating system functions via a modular integrated on-board information system (IBIS).

Much information is supplied continually to the driver while the vehicle is in operation. Other necessary information supplied to the driver through the BON vehicle terminal include destinations in the event of diversions, departure times when timetables are changed, and instructions to await for connections.

Updated Passenger Information

The use of computerized operating control systems allows relaying selective information on the operating situation to passengers. The continuous data exchange between the vehicles in service (light rail and buses) and the control center provides passengers with the most current information available on the latest operating situation.

Until now, the visual information systems used in public transport gave passengers static information on the type and extent of the scheduled services. The use of computerized operating control systems permits dynamic information (i.e., information related to the latest operating situation) to be given them.

A display unit is located at stops that can be controlled via the operating control systems computer. It contains the following information:

- Name of stopping place,
- Time,
- Line number with direction, and
- Probable departure time.

To achieve effective use of the information collected in the central computer of the operating control system, it is advisable and logical to connect computerized operating control systems for light rail to the secondary systems for train protection equipment and traffic lights.

In addition to the on-line tasks of the operating control system that prepare or bring about direct intervention in the operation, the following off-line functions can be performed based on the data determined by the operating control system:

- Record of daily faults and incidents—This record is printed daily and provides information on the irregularities during the day.
- Continuous statistics—These statistics are printed at fixed intervals (daily, weekly, monthly). They contain data on operating and transport volumes and can be used as a basis for annual statistics.
- Planning statistics—These statistics show special operating, traffic, and technical data linked to specific problems. The results serve as a basis for improvement of transport services and technical equipment.

The data that can be used for off-line evaluation can be placed into the following categories:

- Traffic data (passengers boarding and alighting, number of passengers in vehicles); and
- Operating data (running and stopping times, personnel data, vehicle data).

The operating control system employed in Hanover analyzes performance by plotting speed/distance diagrams derived from data that recorded the actual journey time on the route for a chosen number of vehicles.

State of Development and Forecasts for Computerized Operating Control Systems

Previous experience with computerized operating control systems has supplied convincing evidence of the high efficiency of these systems. Further development in the field of operating systems should include the following objectives:

- Universal application of the systems (LRT, streetcar, bus);
- Standardization of hardware and software components; and
- Comprehensive and effective utilization of the data recorded and processed in operating systems.

These three items provide a starting point for the development of a standardized operating control system for public transport now being developed and tested in the Federal Republic of Germany under the abbreviation BON (Betriebsleitsystem für den Öffentlichen Nahverkehr (operating control system for public transport)) by ÜSTRA Hannoversche Verkehrsbetriebe AG in collaboration with other transport undertakings and Verband öffentlicher Verkehrsbetriebe (Association of Public Transport Undertakings). In the summer of 1982, the first 150 vehicles (90 LRT vehicles and 60 buses) will be fully equipped with vehicle systems by AEG, SEL, and Siemens. The entire system will then be tested.

FINAL REMARKS

Transit ridership in Hanover has increased from 98 million passengers/year in 1969 to 137 million passengers/year in 1980. This 40 percent increase in transit ridership parallels the approximately 60 percent increase in the number of passenger automobiles in the greater Hanover area. The 20 percent net gain in transit riders between 1976 (opening of the first LRT route) and 1979 verifies the important role that LRT plays in this development.

On route A (Lahe/Fasanenkrug—Mühlenberg), daily patronage is approximately 108 000 passengers, which reflects a growth of more than 50 percent since the days of the streetcar routes. Some of the attracted passengers use the bus feeder and supplementary systems and then transfer from bus to the LRT. Over 30 to 35 percent of current riders did not previously use transit.

Before, the opening of route B-north, and one year after, an extensive study was carried out to get detailed information about changes in demand corresponding to the new LRT line. Results indicating ridership increases of over 30 to 35 percent demonstrate again the success of Hanover's LRT system in attracting "new" transit riders.

The following conclusions are drawn from a representative household survey conducted in 1981 for the coverage area of route A:

- Seventy-eight percent of all CBD trips are made by LRT.
- Fifty percent of all persons with a private car at their disposal use LRT for their CBD trips.
- More than 90 percent of those interviewed remarked that Hanover's LRT successfully meets the criteria of punctuality, regularity, comfort, and speed.

Over 90 percent of those interviewed considered the money spent for LRT to be a good investment. This demonstrates the positive attitude of both users and non-users toward the LRT system.

LRT has played an important role in Hanover. The high level of service it offers and the acceptable cost level for its construction and operation have contributed significantly to this successful LRT system.

Part 3

Facility Design and Railcar Technology

Conceptual Design--From Planning to Design

L.J. MILLER

This paper describes the transition from planning to design and implementation for a multimodal transportation facility in Santa Clara County. Numerous planning studies were completed for Santa Clara County before an UMTA alternatives analysis Draft Environmental Impact Statement (AA/DEIS) was begun. During the analysis, but about 6 months before a transportation alternative was selected for implementation, a conceptual design program was undertaken.

The three primary goals of the conceptual design program were to (a) investigate the most promising alternatives in greater engineering detail in order to ensure their successful implementation and operation; (b) provide supplementary engineering and cost information for consideration during the AA/DEIS review process; and (c) develop the engineering basis for the preliminary engineering work efforts.

The results of these efforts helped to bridge the gap between project planning and project design.

The 20-mile Santa Clara County transportation corridor has been the subject of many planning studies. A broad-scoped study, the Rapid Transit Development Project, completed in January 1975, suggested the development of a localized rail transit system in the county. The more recent Santa Clara Valley Corridor Evaluation, performed in cooperation with the Regional Transportation Planning Agency, recommended a focus on transportation needs in the Guadalupe Corridor, which includes two freeway segments—long planned, but with little possibility of ever being built.

The most recent assessment, the UMTA Alternatives Analysis/Draft Environmental Impact Statement (AA/DEIS), was completed after a year and a half of study. The governing bodies then selected for implementation a preferred transportation alternative with a broad base of political and community support.

About 6 months before this analysis was completed, an independent consultant was commissioned to conduct conceptual design analyses for the four transportation alternatives defined in the study. Such a study, it was felt, would be beneficial both in the decisionmaking process and in the early implementation of the selected transportation alternative.

Conceptual design can be described as pre-preliminary engineering undertaken to provide local staff and officials with additional detailed environmental, design, and cost information beyond the planning study level. It gives them information to use in responding to questions raised during public discussion and planning study review processes. It also helps them select, from an engineering design perspective, the best alternative for implementation.

CONCEPTUAL DESIGN FOR THE GUADALUPE CORRIDOR PROJECT

The purposes of conceptual design for the Guadalupe Corridor transportation project were to

- Investigate four of the Guadalupe Corridor transportation alternatives in more engineering detail than was practical during the AA/DEIS study process,
- Verify the requirements expected for the successful construction and operation of each alternative,
- Obtain estimates of the capital and operating costs for each alternative in order to increase the level of confidence in the relative and absolute values of the AA/DEIS cost estimates,

- Develop the engineering basis for a quick start on preliminary engineering when an alternative was chosen for implementation, and
- Initiate interagency and intraagency involvement in the planning, design, implementation, operation, and maintenance of the project facilities.

The conceptual design activities involved investigating the engineering aspects of implementing and operating each alternative. Activities included

- Reviewing geotechnical, utility, and drainage information,
- Analyzing traffic requirements at 16 key intersections,
- Drafting design criteria for busway and light rail systems,
- Defining institutional relationships and requirements,
- Preparing geometric layouts (1 inch = 50 feet) for selected key locations for each alternative,
- Simulating light rail and busway operations,
- Defining with utility suppliers the electrification system,
- Reviewing maintenance activities and maintenance facility requirements, and
- Estimating capital, operating, and maintenance costs.

These tasks were approached from the engineering rather than the planning standpoint, that is, the focus was on actual implementation of an alternative.

The major conceptual design products were as follows:

Technical Memoranda

- Utility location data
- Storm drainage data
- Geotechnical data
- Traffic control system inventory
- Institutional setting
- Operating strategies
- Platform/vehicle fare collection
- Traction power
- System controls and communications
- Street traffic controls
- Maintenance and operations policy
- Station/stop alternatives
- Southern Pacific interface
- Yard and shop sites
- Drainage
- Preliminary engineering program

Working Papers

- Design criteria
- Busway/high-occupancy vehicles (HOV) and light rail operations analysis
- Capital costs
- Operating costs

Drawings

- Typical sections
- Station/stop designs
- Track/road layouts
- Electrification and control systems

In addition to these products, problems and concerns were also identified. Initially, the automobile traffic

demands and the transit patronage projections developed for the AA/DEIS were thought to be adequate for preliminary engineering. It was soon discovered in conceptual design that these needed to be better defined and specified in more detail for design engineers to establish appropriate geometrics. For example, projected turning movement volumes for the design year were needed for proper evaluation and design of at-grade intersections.

It was also discovered that (a) at-grade intersections of major arterial streets with the Guadalupe Corridor would have to be designed for greater capacity than that envisioned in the planning process; (b) levels of congestion on a segment of existing street along which express transit services were to run would be higher than anticipated or considered tolerable in the earlier planning efforts; and (c) the use of preemption and preferential signalization for transit would not be as feasible as originally thought.

These discoveries helped make the transition from planning to design.

Several findings of the conceptual design study related specifically to transit services. In the AA/DEIS study, there were some indications that the busway/high-occupancy vehicle and expressway alternative would involve some serious operational and safety concerns, especially if the busway or expressway were adjacent to heavily congested automobile lanes. These concerns were confirmed and clarified in conceptual design, and an investigation of the busway/HOV and expressway engineering design options was undertaken. Agency staffs were able to agree on the most acceptable design option, although the solution was not as initially planned nor was it felt to be the ultimate answer. As a result of the exercise, the facilities required for the successful operation of the busway/HOV alternative were more precisely defined, and, therefore, better cost estimates could be prepared. The trade-offs between level of service (speed and reliability) and operational and implementation costs were more clearly revealed.

Another significant finding related to transit services involved the relationships among the total fleet, the number of revenue vehicles deployed, and transit service

reliability. The planned transit vehicle deployment was found to be incompatible with the current bus deployment policy of the Santa Clara County Transit District. A greater percentage of the total fleet was proposed to be in revenue service than district operating experience indicated was possible if the district's 99 percent service reliability level were to be maintained. This issue has not been resolved. The conflict, however, is now widely recognized, and agency staffs are more aware of the capital cost differences between bus fleets of different sizes.

SUMMARY

Conceptual design proved effective in making the transition from AA/DEIS planning to engineering and design implementation. Many of the concerns and issues identified in conceptual design were taken into consideration during the decisionmaking process.

Conceptual design is a sensitive tool; it can enhance or destroy the balance between planning and decisionmaking. Conceptual design is best performed by individuals independent of the planning efforts. Planning and conceptual design staff or consultants, however, should report to the same person to ensure coordination between the two activities.

Conceptual design is a demanding exercise. It cannot begin until the planning process has reached a plateau in the definition of problems and the description and analysis of alternative solutions. The conceptual design staff then has a short time to assimilate what has gone on in the planning effort and to evaluate the engineering implementation aspects.

Conceptual design provides the opportunity not only to question and refine the planning efforts, but also to direct the start of the engineering design activity. Months of engineering preparatory time are saved, and the designers can become familiar with the project by the time the preferred alternative has been selected for implementation.

A Case for the Reevaluation of Subsurface Power Collection for Light Rail in Sensitive Downtown Areas

JOHN P. EDGAR, Louis T. Klauder and Associates

Because of rapidly increasing costs and the disruption of the urban environment during construction, a subway is no longer the automatic choice for light rail operation in downtown areas. As a result, street surface alternatives are more frequently being considered.

In the past, streetcars powered by overhead wires were in widespread use. However, objections were raised on aesthetic grounds to the use of overhead wires in environmentally sensitive areas. To meet these objections, an alternative power collection system was developed that used conductor rails located in a ductway below the road surface. Extensive subsurface power systems functioned successfully for many years in several cities, including New York, London, and Washington, and smaller systems were operated in Brussels, Berlin, Paris, Budapest, and Dresden. Several new subsurface collection systems have since been built using modern materials and construction methods. The success of the subsurface power systems for light rail in such cities as Calgary and San Diego, where careful

planning has blended the light rail operation into area traffic patterns, points the way to greater use of such systems in the future.

Construction economics and concern for the quality of urban life have made the subway a less desirable alternative as a means of meeting the growing transit demands of cities. At the same time, the lower capital costs and greater flexibility of the light rail system have increased its attractiveness. In the past, most light rail systems were powered by overhead wires. To meet objections to overhead wires in areas of special significance, an alternative, the subsurface power supply system, was developed. Several such systems functioned successfully on a large-scale in London, New York, and Washington for many years. Small installations were operated in Brussels, Berlin, Paris, Budapest, and Dresden. Several new subsurface collection systems have since been built by using modern materials and construction methods. The success

of the subsurface power systems for light rail in such cities as Calgary and San Diego, where careful planning has blended the light rail operation into area traffic patterns, points the way to greater use of such systems in the future.

THE PRIOR ART

The various subsurface power collection systems of the past were constructed by using the best available materials of the day and, apart from variations in detail, were similar in design and operation.

Power was distributed by two conductor rails of opposite electrical polarity. The rails were spaced about 6 inches apart and housed in a concrete subsurface duct that ran along the center of the guideway. The conductors were supported by insulators suspended from a specially shaped steel section, the top edge of which formed a durable lining to the edge of the access channel. A current collector suspended from the vehicle made contact with the conductors through a continuous slot-like channel in the duct.

The entire guideway substructure was formed from concrete. Additional reinforcement was provided by cast iron members, which also served to stabilize the assembly during construction. Figures 1 through 6 show details of some of these older systems:

- Figure 1 shows details of a conductor, insulator, and steel section forming an access channel and insulator support.

Figure 1. Half cross section of subsurface power supply assembly, showing insulator (a), "Tee" conductor rail (b), and "Z" guide rail. Positive and negative conductor rails were used, making the other half section a mirror image of this section.

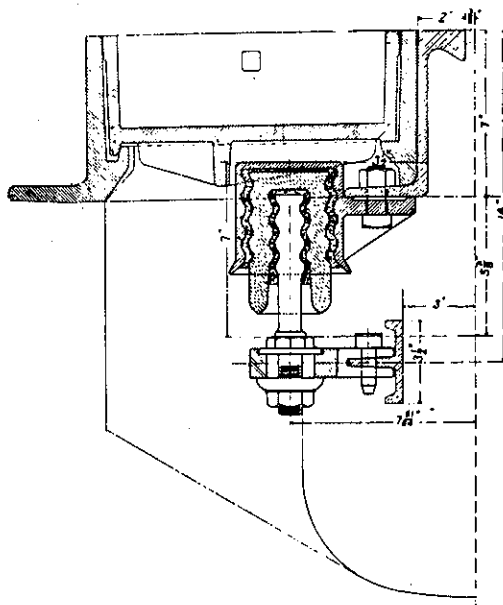
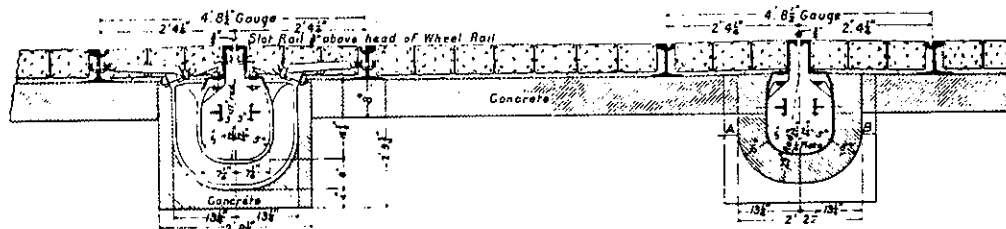


Figure 2. Original form of subsurface installation, showing the concrete foundation complete with ducts for conductor rails.



- Figure 2, a cross section of a completed guideway, shows the track structure and the supply rails in the duct beneath.
- Figure 3 shows one of the cast-iron reinforcing members.
- Figure 4 shows an actual section of a subsurface installation under construction. The various components described above can be identified.
- Figure 5 shows the position of the current collector and the enlargement in the ductway to accommodate the insulators.
- Figure 6 provides a three-dimensional view of a complete subsurface system.

Switches for subsurface collection were equipped with two interconnected orientation systems, one controlling the direction of the wheels on the rails and the other deflecting the current collector in the same direction.

The surface finish of the guideway area was in keeping with the surrounding roadway. The width of the access channel was approximately 1 inch. Thus, the subsurface collection provisions, although evident, were in no way obtrusive.

Figure 7, a photograph of a guideway in London, illustrates the low visual and physical profile of the subsurface system in its finally developed form.

THE DESIGN ADVANCE — FROM PRIOR ART TO STATE-OF-THE-ART

Technological advances have changed greatly the techniques for construction and operation of the subsurface power collection system. The discussion below will compare the past construction and operating methods with current practices and state-of-the-art techniques.

Construction

Several construction features could change as a result of technological development.

Excavation and Concrete-Forming

In the past, excavation and concrete preparation and placement were performed by manual labor. Now, the hundreds of laborers with their shovels and the expensive and time-consuming manipulation of formwork have been replaced by advanced power excavating and semiautomated continuous concrete-forming techniques. Excavation for subsurface power systems often requires realignment of public utility lines. Rather than posing a problem, this offers an opportunity to consolidate underground utility lines, as substantial ductways for utilities can be readily incorporated into the power collection infrastructure.

Guideway and Ductway Metal Constructional Members

In the past, iron castings or rolled steel sections were used in the guideway duct. Although the quantities of iron and rolled steel used were large with respect to a particular subsurface installation, they still represented a small part of the total production of the industry. Consequently, unit costs were high, particularly for rolled sections, where the

cost of the special rolls had to be amortized.

Modern automated cutting and welding techniques, which permit the production of long special sections from off-the-shelf materials, could save both time and cost. Figure 8 shows how such materials can be used for conductor and access channel rails.

The need for massive iron castings can be reduced by use of continuous concrete-forming techniques, but where such equivalent members are needed, units fabricated from standard steel sections or from reinforced concrete can be used. Figure 6 shows such units in place.

Insulators

Insulation made of iron and porcelain components

Figure 3. Cast-iron reinforcing members used in original construction.

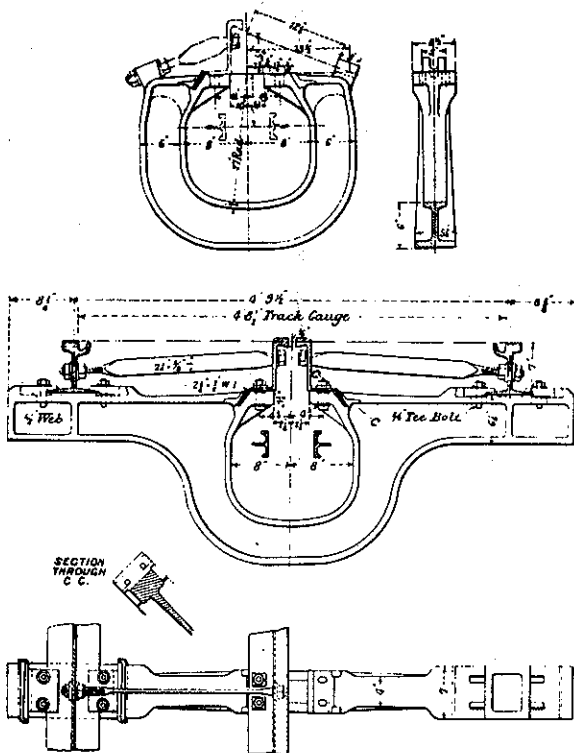
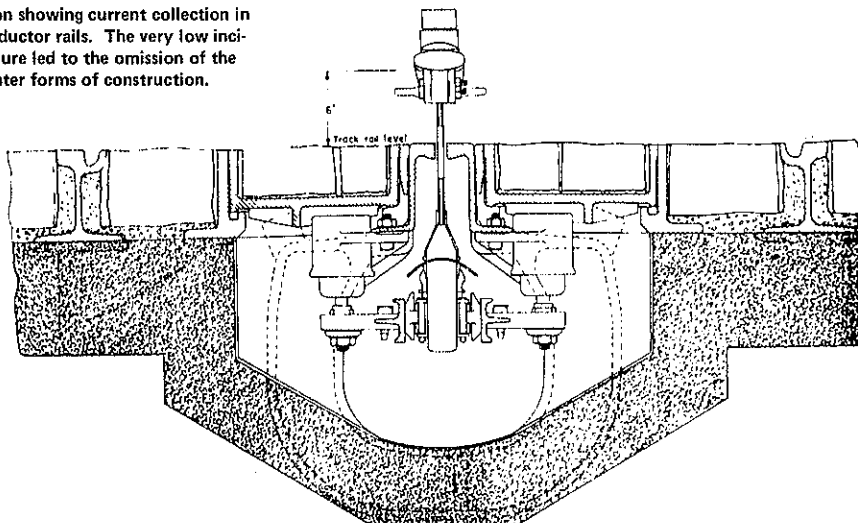


Figure 5. Cross-section showing current collection in position between conductor rails. The very low incidence of insulator failure led to the omission of the removable covers in later forms of construction.



cemented together by hand is still used for third-rail and overhead trolley wire and for public utility power lines. However, one-piece insulators made of synthetic resin are gaining in popularity because of their superior electrical and mechanical properties and lower cost.

Similar one-piece insulators could be developed for the subsurface or insulators could be fabricated from modern line components. Figure 8 shows such an insulator in place in a subsurface assembly.

The Current Collector

Figure 9 shows typical subsurface collectors used in the past. They were constructed from hardwood and rubber, with steel wearing surfaces and organic varnishes as the impregnating medium.

Now, collectors can be made of a one-piece molding of insulating resin with deeply embedded conducting elements. Low-friction plastic can be used on the wearing surfaces, and carbon contact surfaces can minimize wear of the conductor rails. Such new construction could lower initial costs and subsequent maintenance requirements significantly.

Switches

The track switching elements in the modern subsurface system would be identical to those used in a regular overhead power system. However, profile cut and welded elements can be used for the access channel orienting

Figure 4. Completely new subsurface installation under construction in London in 1950. (Photo: Julian Thompson)



ration, and the light rail right-of-way is segregated from all other traffic.

The road vehicles themselves have changed. Animals are no longer used for hauling, and attendant pollution problems have vanished. Inspection laws have relegated the ramshackle automobile or truck shedding odd items of hardware onto the street to the world of vintage movies. The loads carried have changed; rather than loose, insecurely tied piles of miscellaneous goods, loads are now packed in containers and shipped in box trailers and vans. Even garbage trucks are more sophisticated.

Weatherproofing of Subsurface Systems

Good drainage in a subsurface system is vital to prevent flooding, although the effect of flooding is no worse than with regular overhead supplies.

In the past, it was usual for the subsurface ductway to be tied into the regular sewer system, and this technique can still be used today. The application situation is ideal where both the subsurface guideway and the utility require upgrading, as construction for ductway drainage can be integrated into the general street drainage improvement program.

Where substantial snowfalls occur, the same snow clearing procedures—frequent sweeping or plowing to prevent excessive buildup—would be used as for all types of light rail operation. Icing, a frequent problem in overhead line systems, is not a serious concern with subsurface systems. However, compacted ice can be a problem in subsurface collection systems when road traffic forces it into the access channel, where it sometimes freezes solid. To solve this problem, rod-like electric heating elements, developed for rapid transit, people mover, and railroad systems, are now available. These could readily be installed in areas of high vulnerability directly under the upper surface of the access channel lining, as shown in Figure 9. The heat input required would be quite small, since preventing ice buildup is the only objective.

Changing from Subsurface to Regular Overhead Power Collection

It is unlikely that subsurface collection would be adopted for an entire light rail installation; rather, it would be confined to the area where it was most appropriate. Several techniques have been developed to perform the transition from subsurface to overhead wire:

1. The collector can be winched up into the body of the vehicle through a hatch in the ductway.
2. A worker in a subterranean chamber can manually insert or remove the collector from beneath the vehicle.
3. The collector can be ejected or inserted at street surface level.

Methods 1 and 2 have been of particular interest because the collectors can be circulated easily through inspection and repair procedures if there are a larger number of collectors than vehicles in service.

The third technique is the most highly developed and well tested in practice. The old London transit operation had about 2000 streetcars operating over 246 miles of subsurface collection track and 18 locations where the change was made from subsurface to overhead collection. The overhead collector was the traditional trolley pole, the

time for the performance of the complete procedure was only about 20 seconds.

Even if manual insertion were retained in state-of-the-art designs, the time gained by using an automatic pantograph rather than manual manipulation of the trolley pole would be considerable.

In practice, both methods 1 and 3 would be candidates for use in a modern installation.

ADVANTAGES OF SUBSURFACE INSTALLATIONS

Subsurface power collections have a number of advantages.

Immunity to Damage

Although normal overhead line construction is now highly reliable, it is still vulnerable to accidental damage.

For example, a defective pantograph can quickly cause failure on the best overhead line; in fact, a minor overhead line defect can trigger a "snowball" reaction in which the line and the pantographs damage each other slightly until one or both components fail. A truck with an overheight load can also present a serious problem if it strikes the wires.

The equivalent vulnerability in the subsurface system, obstruction of the access channel, is less of a problem.

Elimination of Electrolysis Problems

Most older subsurface systems used two conductor/fully insulated power supplies, and none of the metalwork forming the guideway was included in the circuit. This resulted in complete immunity from electrolytic damage attributable to the system.

Construction of the modern system offers the same advantage. No special precautions would be required—even for certain soil conditions or vulnerable subsoil utility installations.

High Power Delivery Capabilities

Current collection at 750 volts DC by regular pantograph and trolley wire occurs across a surprisingly small contact area in overhead collection systems; in busy downtown areas where starting cycles are frequent, the limit of collecting ability is likely to be reached. Where a service is heavy, the high overall current demand must be met by a suitably proportioned overhead line structure with frequent feeding points.

In a subsurface system, the power-conveying elements are located in a right-of-way below ground. Thus, they can be made as substantial as necessary and fed at frequent points from the cables carried in the ducts without any visual or physical impact on the guideway surface.

Vehicle Identification and Location

Although there is no precedent in the systems that have been built, the subsurface collection system could be equipped to provide data to an electronic information system. The collector would act as the transmitter, perhaps carrying information on vehicle fleet or running number and even data on loading, while sensors located in the access channel at strategic points would convey the information to central control for analysis.

Formation of Criteria for the San Diego LRT Project

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Light rail is a flexible form of transit; for this reason, special attention must be given to the development of project design criteria. As bases of a project's specifications, these criteria must invite bids suitable to its financing and schedule. They must reflect the particular program, that is, they must be derived from the same plan and must project the same combination of ridership, service efficiency, and schedule speed.

The design criteria for the major subsystems on the San Diego Light Rail Transit Project were derived in this way. Specific criteria for vehicles, trackwork, signals, traction power, and fare collection were developed, and methods for design integration were explored.

One of the characteristic features of light rail transit is its flexibility—its ability to operate within a wide range of conditions. Thus, a number of solutions may be used to meet goals, and the project design criteria for civil work and equipment may permit considerable scope.

Such criteria must be suitable to form the bases for plans and specifications that can be competitively bid in the public domain. In addition, the resulting civil work and equipment design must fit immediately into a practical operation.

The development of practical LRT project criteria therefore takes place in two steps. First, criteria must be developed that clearly reflect the transportation requirements on which the project was conceived. Second, the subsystem designs are combined so that criteria can be consolidated as much as possible.

DERIVATION OF PROJECT CRITERIA

Project criteria are derived from the initial transportation plan on which the decision was made to select light rail transit for the project. The transportation plan is based on the lowest level of service that will sustain the necessary patronage and revenue. Thus, the result of the first part of criteria formation is that the light rail system must produce the commercial speed and service frequency required to meet passenger demand, and do so cost-effectively.

This first part of criteria formation also requires development of an operating plan, which eventually becomes the basis for determining the details of the project criteria. The operating plan is a basic strategy—rather than a schedule—for evaluating the physical requirements for station sites, the track plan, vehicle configuration and fleet size, power loads, signaling capabilities, and fare collection schemes.

The second part of criteria formation is the consolidation of various subsystem designs to serve common functions. Light rail transit projects have a low economic tolerance for "on project" experimentation. Accordingly, the consolidated designs for most projects are similar. Due to this similarity, projects can use generally practiced construction and operations methods and standard "off-the-shelf" equipment. Thus, the criteria are formed to identify those design combinations that are particular to the project.

DEVELOPMENT OF CRITERIA

The San Diego Light Rail Transit Project, conceived in 1978 and put in revenue service 3 years later, was derived from project criteria formed by the two major steps outlined above.

Operating Plan

The operating plan for San Diego had its inception when the San Diego Metropolitan Transit Development Board (MTDB) selected the San Diego and Arizona Eastern (SD&AE) Railway corridor between downtown San Diego and the international border (United States/Mexico) for light rail transit operations. This selection was made, in part, as a result of a study and findings by Wyer Dick and Co., presented to the MTDB in May 1978¹. The report and transportation plan described specific methods for operating the low-volume SD&AE freight traffic and light rail transit traffic jointly on the same facility. The transportation plan was based on a modest growth of SD&AE traffic, and projections showed that freight trains could traverse the transit corridor without service disruption whenever the transit headway was at least 30 minutes.

This joint operation was based on the use of a single track line with passing sidings for transit meets every 7.5 minutes. For through freight trains, i.e., those running directly between San Diego and points east of the transit terminal at the international border, space would be given in the transit pattern from a vacant run in the 15-minute service. For the local freight service, the train would use switching leads to serve a collection of spurs in the same general area. The local would then run between switching leads in a vacant transit slot to serve the intermediate spur.

The initial transit patronage would come from passengers diverted from a parallel local bus line, and the service was expected to attract additional patronage. The base transit service was projected to be 1500 passengers per hour in the peak direction; thus a 15-minute headway was stipulated for both peak and base periods.

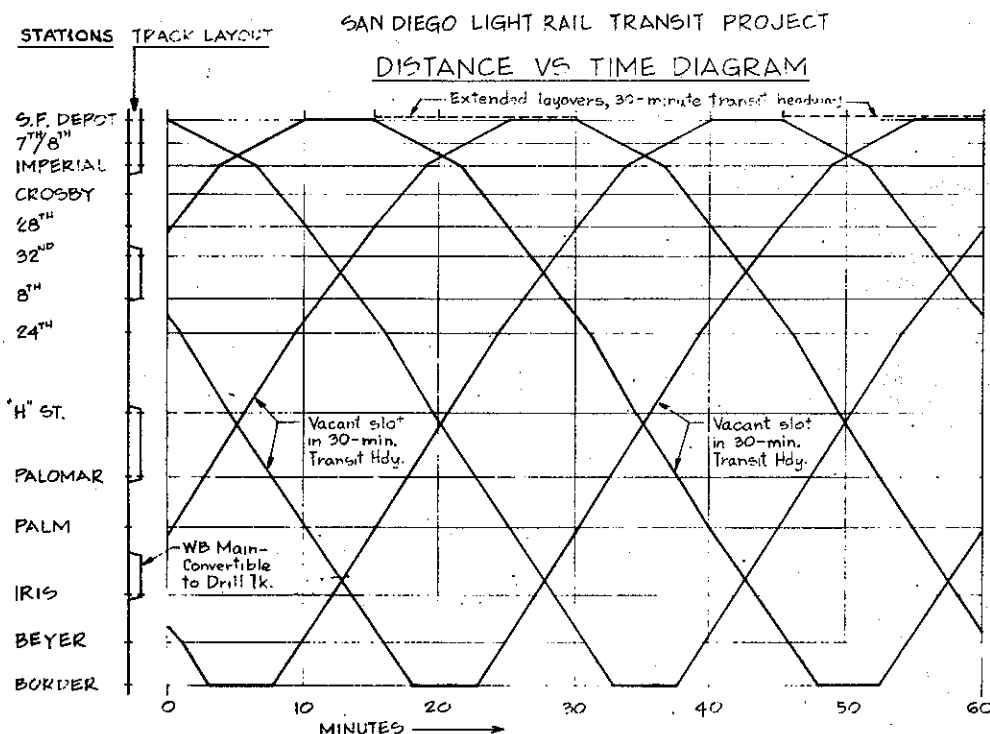
Because fast travel times mean a small fleet size, reduced labor requirements, and lower operating costs, the theme of the operating plan was to minimize circuit time (i.e., the time for one round trip, including two layover times). Accordingly, the operating plan was developed by using a significantly higher commercial speed—almost twice the 13-mph average for buses—to compute practical run times. The circuit time was calculated to be 75 minutes, and this became the principal criterion for vehicle performance.

From the project viewpoint, base functions of the transit car were for the first iteration of the operating plan. The approximate size of the vehicle was determined by the 1500 maximum hourly load point patronage. With the stipulated 15-minute service, the maximum design train load would be 375 passengers. It appeared that the market would offer a 64-seat car. Thus, with a fairly large percentage of standing riders during peak patronage periods and a vehicle with approximately 64 seats and room for 2 standees per seated passenger, peak service trains would have 2 cars each.

Route data were also needed for the first iteration of the operating plan and were also derived from the transportation plan. The principal route of the transit system was the SD&AE track. However, the main transit terminal was in Centre City and would require construction of tracks in streets. This part of the plan was the subject of considerable civic and political interest. At the time of the first iteration of the operating plan, the Centre City terminal was at C Street and Twelfth Avenue, and the border terminal was near the former SD&AE depot. In addition, 10 intermediate stations were indicated on the SD&AE corridor.

As the operating plan was developed, the project criteria began to form. Stipulated data were confirmed or

Figure 1. Operating plan.



altered, and the project functions were clarified.

On Figure 1, the operating plan is conveyed in graphical form $x(t)$, i.e., distance versus time. The graph shows a 1-hour module of peak period operations. The plots are loci of points traced by each train movement indicated.

The operating plan is interpreted largely through this graph. Each trace indicates the position and timing of each train movement with regard to other train movements. Through study of this graph, particular operating problems can be seen and possible alternatives examined. Practical consequences of train delays or changes of schedule or the effect of a remedial strategy to recover from an off-normal condition can readily be seen. In addition, the requirements for fleet distribution, utilization, and staffing can be derived from a study of this graph.

The graph is the basis for criteria in three major functional areas of the plan.

First, the operating plan graph indicates the basic single-line track plan. It locates the meets and the effects of variation in meets. Where crossovers or freight train yard entries or pullouts are made, the graph indicates the tolerance and workability of conflicting moves on whatever schedule is under study. Terminal operations, particularly those in Centre City, are clearly described so that the effects of alternative routing for utility repairs, on-line storage, or short turns for fire or accident can be readily understood.

Second, the whole graph is the basis for traction power design criteria. Individual vehicle propulsion is the initial data, but the operating plan exhibits the sum effect. The traction power load varies for each train generally as a function of place. Because any function of place on this plan is also a function of time, these data produce the traction power design criteria and requirements for installed capacity and the distribution of substations.

Third, the operating plan graph produces signaling criteria. These criteria indicate where block limits may be located without interfering with train spacing for trains operating either on allowable headways or on reduced headways during pattern recovery. The graph does not provide highway grade crossing protection criteria, but it does provide the base data for traffic light coordination

when trains operate on city streets.

Functional Consolidations

In the development of project criteria, the full criteria were developed for each of the major subsystems and then consolidated. Some important functional combinations that led to consolidated subsystem criteria on the San Diego Project are discussed below.

Signals and Power

The operation on a single track provided opportunities for consolidation of signaling and traction power criteria. The economy of the design and operation provided no intermediate meet locations, and all meet tolerance was provided on double-track sections used as long sidings. This required a tight pattern in 15-minute headway operation, i.e., trains could not get out of pattern without risking some difficult recovery problems. After the system opened, the pattern was loosened to a 20-minute headway. There are a number of slow orders due to present parallel construction of track, and the Centre City traffic coordination is not yet complete. At some future time, a tight pattern with 15-minute headways may be reinstituted.

Because of the project's basic commitment to economic light rail transit operation, it was decided early that signals would be designed for normal operating conditions only. The transit operator would have to develop operating procedures and rules for handling off-normal problems. Thus, the block signaling became absolute, and the criteria relied on there being no normal following moves within individual signal blocks.

With no following, the signal design was simplified, and the amount of traction power that could be drawn from the catenary and nearby substations was limited. A freight train doing switching "owns" the block so that it can drill with a little more flexibility than it might otherwise. In addition, transit cars may turn back anywhere in a single-track section merely by changing ends.

Circuit Time

As the operating plan emphasized the importance of circuit time, every aspect of the project that could protect and conserve the operating circuit time was included in the criteria.

In the operating plan, it quickly developed that running meets would provide the best margin to protect circuit time, particularly if the double-track sections had one or more stations to draw out the run time. So that the double-track sections would not be overextended, the criteria limited doubling to avoid major civil work, e.g., bridges, cuts, and fills. Thus, the meet locations and the track plan were juggled to optimize the operating plan and maximize the margin for circuit time disruption.

Also consolidated in the criteria were the requirements for fare collection procedures and vehicle door use to protect the circuit time against the effects of loading large numbers of passengers.

Vehicles and Tracks

Consolidation of track plan and the vehicle criteria involved a trade-off between double-ended versus single-ended vehicles and the track plan. It appeared that there would be physical difficulties if loops or wyes were allowed at the terminals. It also developed that there were advantages favoring single-sided stations in single-track sections. These points favored the double-ended, double-sided vehicle with sufficient passenger capacity.

Due to the requirements for joint freight/transit operation, it was inevitable that the track plan would include some criteria governed by the railroad but with an effect on transit. The net consequence of joint operation for design was that the average speeds of a freight and transit train had to be roughly the same. As transit equipment is capable of relatively high performance and a freight train is not, it was proposed that the freight train be brought up to speed and kept there by minimizing any need for speed reduction. This means that freight trains must be able to move on and off double-track sections at or near their average speed. To meet this objective, long-point No. 20 turnouts at the ends of double track were adopted as project criteria.

Because freight service has been perpetuated, the project has generated some on-line industrial development. One of these is located in the vicinity of Iris Avenue station. A switching lead for the projected switching services was provided for in the original criteria. After it was noted that joint operations would occur when the transit service headway was 30 minutes or more, criteria were developed to vacate the transit slots meeting at Iris Avenue. The signal criteria therefore provided for the conversion of the westward main at Iris to a switching lead when not used as a double track.

Under the general orders of the California Public Utilities Commission,² even with allowance for partial relief for cause, the minimum contact wire height above top-of-rail is 22 feet. This is beyond the reach of the standard pantograph of some light rail transit vehicles. For others, it is close to the maximum effective range. The criteria were developed to avoid long trolley poles and shoes, roof platforms, and heavy locomotive pantographs. However, the narrowness of the pantograph operating

range and the effects of sag in fixed-registry catenary virtually mandated the constant-tension catenary scheme that was subsequently designed and installed.

Because the line must continue to carry railroad interchange equipment, the design criteria provided for railroad-type trackwork. There is no flange bearing special work throughout the system. This necessitates a wide-tread, deep-flange railroad wheel with which the transit car is equipped.

The side clearance profile of freight train equipment is wider than that for transit equipment. Consequently, the transit system platforms cannot project above top-of-rail. Therefore, the criteria require transit cars to accommodate passenger loading at street level throughout the system.

Future Expansion

From the outset, because of limited funding, the design criteria prohibited hard design for possible future expansion. However, the developed criteria did allow design that could be expanded.

Expansion of system capacity is possible through double tracking. This solution was not available in the original project criteria due to funding, but because it was feared that patronage might soon increase to double the project feasibility level, this quick remedy was accepted to increase the passenger-carrying capacity.

The possibility of an increase in freight service was considered, but was not deemed as likely as the doubling of transit patronage. If freight train movements were increased to a pair of daytime through trains, one in each direction, transit service headways would have to be reduced to 30 minutes to accommodate the move.

Under such expansion, train lengths would double to four cars and the installed traction power capacity would be increased proportionally. The basis of this expansion is both expressed and implicit in the developed project criteria, which provide for multiple unit vehicle capability and prefabricated portable substations. Thus, substations can be relocated and added to serve the increased train size and prevent an unacceptable drop in line voltage.

CONCLUSION

Design criteria can be derived from the original project plan for corridor, patronage, and service speed. The resulting base specifications give form to the otherwise flexible possibilities that are characteristic of light rail transit.

The design criteria on the San Diego Light Rail Transit Project were derived in this way. The specifications based on these criteria invited suitable bids and materially contributed to the project's coming in under budget and on schedule.

REFERENCES

1. Wyer Dick and Co. A Report and Operation Plan of San Diego and Arizona Eastern Railway. Prepared for MTDB, May 1978.
2. General Order 95, Rules for Overhead Electric Line Construction. California Public Utilities Commission.

Decisions on Physical Configuration for Light Rail Vehicles

Robert J. Landgraf, Greater Cleveland Regional Transit Authority

This paper examines the physical configuration of light rail vehicles (LRV) from the standpoint of the individual car and how it relates to the transportation system. The major decision to be made for double-end bidirectional operation or single-end with turning loops is explored. The advantages and disadvantages of each concept are also reviewed. Whether to specify articulation is evaluated in light of its relationship to fleet size and economic trade-offs as well as the operational benefits and problems that may result from its use. Results of three major LRV procurements that treated articulation as an option are explained. Selection of the patterns for door openings, the interface between doors and platforms, whether to use folding steps, and types of door action available are described. The relationship of seating to aisle needs, door openings, car width capability, and passenger flow is considered. Multiple-unit operation is analyzed as an option, with a review of its effects on throughput capacity and labor productivity. The question of whether to run new cars in trains with an existing fleet is explored. The conclusion is developed that selection of car options must be a result of system design. The LRV should not be allowed to dictate the system and car-wayside interfaces, whether the fleet be for a new line or for replacement. Goals of equipment standardization should not inhibit choices of configuration that will be best suited to the particular light rail operation.

The major factors to consider in selecting a configuration for a light rail vehicle (LRV) are determined by the characteristics of the transportation system itself—physical constraints, distance and volume of trips (average and extremes), desired average speed, dwell time, throughput volumes, station spacing, and upper and lower limits of station loadings. Compatibility with an existing fleet of earlier LRVs must also be considered because of the question of whether the entire fleet is to be replaced in one purchase. The light rail system should dictate the LRV configuration; the existence of an off-the-shelf car configuration designed for some other system should not be allowed to place unnecessary restraints on the choice. Several examples could be cited of light rail operations that have not realized their full potential because an inadequate and unduly restrictive vehicle, such as the "standardized" PCC streetcar, was used. Cleveland and Newark would have benefited from larger, higher-performance cars.

Five fundamental decisions that must be made in the selection of the configuration of a new LRV are as follows:

- Should the car be double-end or single-end?
- Should articulation be used, and, if so, how many sections?
- Where should the doors be located and where should they be in relation to seating patterns?
- What are the platform height options? Should loading be single level or variable height?
- Should multiple-unit operation be used? Should new LRVs be run in trains with older cars?

DOUBLE-END OR SINGLE-END

Perhaps the most fundamental of all LRV choices is that of single- or double-end cars. A vehicle with a cab at each end is more versatile in all operating situations—normal and emergency. Double-end cars can reverse direction easily anywhere in the network. Any station can thus serve as a short-turn point; a crossover on a double-track line is all that is needed. A system with all double-end LRVs has

no need for turning loops or wyes at terminals, reducing the need for real estate at what are likely to be costly locations. Double-end cars have further advantages in that special track for turning single-end cars is frequently the locale of the most restrictive wayside clearances. Von Rohr points out that the use of city-center tunnels for light rail in Europe dictates the choice of double-end to avoid high-cost excavations for loops.¹

In emergencies double-end cars can reverse direction and proceed to the nearest crossover to avoid a blockage. Furthermore, a double-end car while going in the non-normal direction through an emergency single-track operation has a set of doors on the off-side to match the boarding areas at stations. Single-end cars characteristically have fewer doors and, in most models, on one side only. (The resulting added seating capacity is a great advantage of single-end cars.) When single-tracking in the off-direction, such cars must load and unload in the space between tracks. This is not significant in street running or other situations where track is paved to the top of the rail, but it is quite important where track is in ballast and platforms are provided. Many light rail systems depend on low platforms of approximately curb height.

Double-end cars have certain advantages because they do not need a small turning radius in many light rail systems, particularly where there is no tight street running. With no need for loops, such cars need only the minimum radius the route imposes. A large minimum radius permits the use of wider-diameter articulation units, with the interior passage reaching nearly the full interior width of the car, thus giving a feeling of spaciousness and blending the body sections better. Furthermore, the greater the turning radius, the longer the truck center that can be used without excessive overhang. This provides opportunity to utilize longer cars, with their greater economies and passenger capacity. The large turning radius makes some contribution to greater minimum car width, although wayside clearances usually govern that characteristic. Flexibility of track alignment must be balanced with this desire to maximize the radius.

With all these advantages to a double-end LRV, one may wonder why single-end cars are ever selected. The obvious factor in two recent decisions for single-end LRVs—i.e., Philadelphia and Toronto—is the need to phase new equipment into existing systems that employ single-end streetcars. However, the reason for the past single-end choice is still valid. Von Rohr notes that many early streetcar systems used double-end cars, although single-end clearly won out in the latter days of street railways.¹ Only a small number of the thousands of PCC cars were provided in the double-end design.

Single-end cars came to be preferred in cities with many lines because a track network with lines joining and crossing provided ample opportunities for loops and wyes using the street pattern. The two major surviving streetcar systems use single-end PCCs, and there is no valid reason now to prefer double-end cars in Philadelphia and Toronto. (An exception in the Philadelphia situation is the purchase of 29 double-end cars for two suburban light rail lines that have no turning loops or wyes at the outer ends.)

The biggest advantage to a single-end LRV, other than the obvious lower first cost, is the greater seating capacity available in a given body size. Space that would have been consumed by a cab at one end and the offside door openings (and stepwells if low-platform) can be used for additional seating. Each door opening not needed adds four seats, while elimination of the second cab adds another four. Maximum seating in a wide-bodied PCC of the standard length is 60, while a double-end PCC the same size with a

normal component of doors seats a maximum of 48. Gray explains that, when the objective is to carry maximum capacity, single-end cars have lower costs for the initial fleet purchase and for operation and maintenance that can be traded off against the cost of turnback loops.² The Boeing LRV has maximum seating of 68, and a single-end version was proposed to seat 84. This range of about one-fourth gain in seating capacity will hold true for most single-end LRV designs except where doors are provided on the offside.

A related advantage of single-end cars is that most or all seats can face forward. This capability can only be acquired in double-end rolling stock by using flipover seats, which require somewhat greater spacing because each "back" is padded. Furthermore, a car with all seats facing one direction can usually be laid out to have an extra row of seats compared with a car where some face each direction.

The higher seating capacity available in a single-end LRV becomes important when the trip characteristics are somewhat like a commuter railroad. In such a line, the average trip would be fairly long, 6.2 miles or more. There would not be a lot of "local" on-off traffic, so aisle spacing and door openings would not be as important as in high-density city cars. There is no new or recently re-equipped light rail system in North America that has those "commuter" characteristics to the extent that the other advantages of double-end cars were overruled.

An advantage of single-end cars that may no longer be important is the ability to tow trailers without the need to run around and recouple to the other end. As will be explained later, the use of articulation tends to make trailers obsolete.

It is interesting to note that the single-end articulated LRVs being provided for Rio de Janeiro have the door pattern and seating arrangement of a typical double-end car.³ Elimination of the second cab adds 5 seats in its place and undoubtedly lowers the initial cost. In the rear section, all other seats face the rear end of the car. There is a semi-permanent drawbar instead of the normal coupler at the back end. It appears that this car is not intended to be used singly as a normal rule but will operate in trains with an even number of cars. This approach is an economical way to achieve the advantage of double-end cars on a high-density light rail system when it is known that minimum passenger loads will justify more than one car per train.

It is likely that nearly all future LRVs in North America, except for some 4-axle cars used in cities with surviving street railway networks, will be double-end. In Europe, where operation with trailers is still used, new single-end cars may continue to be built. Any single-end car being built now should have a "hostler" control in the back, to permit operating at low speed from the rear of the car, a necessary feature for satisfactory yard handling.

ARTICULATED VERSUS RIGID

The second major component of LRV configuration is the choice between an articulated car and a rigid one. If articulation is selected, then the question is how many "joints" to provide in the total car. LRVs with two articulations are the exception, but they are not unusual in Europe.¹ Articulation ideally should lead to a higher number of seats or other unit of capacity per truck, as was the case with early modern passenger trains, but that is often not the case, as has been observed by Gray.² Considerations other than linear capacity usually govern in selecting articulation.

The most common reason for introducing articulation is the attempt to achieve greater labor productivity within the physical constraints of the system governing the distance between truck centers. It is believed that one crew member can handle an articulated car regardless of its length, especially where prepaid or honor fare systems are used.¹ This was not the case with the motor car and trailer

car combination widely used in Europe.

Articulated cars do not pose difficulties in passing between the sections, in contrast to end doors in trains. Because so many light rail systems have small curve radii and uneven track, LRVs with end doors have always been a rarity. Use of such doors was considered inherently unsafe.

In trains of LRVs, the inability to pass between cars promotes uneven passenger loading. Articulation helps to minimize this problem by making each "envelope" larger. Lengthening the design of a rigid car soon runs into two system constraints: horizontal clearances on curves and maximum axle loads allowable for the track structure. Articulation gets around this problem by enabling cars to "bend in the middle" and by usually distributing the weight of body and passengers among more axles. However, there have been conversions to articulation that decreased tare weight of trains and incidentally increased axle loads. An example is the 1929 reconstruction of pairs of 4-axle Milwaukee suburban cars to 6-axle articulateds.

As mentioned in the discussion of double-end versus single-end cars, a larger turning radius permits a broader articulation section, providing more of an integration between the car bodies. In fact, some recent articulation sections that are nearly full width contain 4 single passenger seats.

Articulated cars bear several fundamental disadvantages that must be weighed against the gains in labor productivity and passenger flow.⁵ It is often more difficult to rerail an articulated car, particularly when the truck under the articulation is involved. The articulation section can be easily damaged in such a derailment. Articulated cars can have adhesion problems when the truck under an articulation is unpowered, as is usually the case. Very good slip-slide control becomes essential to keep from lifting the center section off in turnouts and sharp curves. Furthermore, having some unpowered trucks in the vehicle compels the motors to be especially large if performance is not to suffer.

Articulated cars are more difficult to lift in the shops. It is not possible simply to lift one end, roll the truck out, and roll another in; the entire car must be elevated evenly. Because cars have to be positioned exactly for lifting, shop design becomes a limiting factor.

A major disadvantage of the extra-large articulated car is that the unit could well be much too large for economical use at slack times.^{4,5} Extra energy is consumed, and excess wear occurs in hauling around a big car. One solution is to have a small fleet of 4-axle cars for low-volume periods. Often in an existing system this fleet would be the best of some older cars from the days before articulation became widely adopted.

This approach of having some smaller cars opens up the possibility of using 8-axle vehicles with two articulations for the busy periods. The system's acceleration requirements and maximum uphill grades must not be high, or every truck will have to be powered. Such a car can attain a favorable ratio of passengers to axles and a moderate cost per seat. Labor productivity in double-articulated cars is very high with an honor fare system.

The decision whether to adopt articulation can be looked on as an economic trade-off, and therefore bids might be taken allowing a range of choices. There is a risk here in that the car selected might be very different from the optimum for the system. The Cleveland LRV procurement was historic in being very open-ended; merely specifying that 4000 seats were required within a range of 47 to 68 double-end cars, having 3 doors per side if seating capacity exceeded 60.⁶ All seating had to be transverse, with minimum pitch of 737 mm, and no seats were allowed in the articulation.

Bids were received from 10 manufacturers covering rigid cars and 6-axle articulated cars with seating capacities all the way from 60 to 84. Table 1 lists these bids with costs and key dimensions. The winner, a 48-car order with 84 seats, was the highest-capacity conforming unit offered. These numbers matched one other bid, with the

Table 1. Bids on light rail vehicles for Greater Cleveland Regional Transit Authority, May 1977.

Car Builder	Total Cost (dollars)	Cost Per Car (dollars)	Number of Cars	Seats Per Car	Car Length (mm)	Car Width (mm)	Truck Centers (mm)	Articulated
Breda	30 960 000	645 000	48	84	24 354	2821	8 229	Yes
U.T.D.C. ^a	32 764 700	712 561	53	76	19 202	2743	11 201	No
Pullman-Standard	34 353 989	582 271	59	68	19 202	2819	10 973	No
Kawasaki ^a	34 452 810	546 870	63	64	18 085	2699	10 719	No
U.T.D.C.	34 740 026	588 814	59	68	19 202	2743	11 201	No
M.T.S.-DuWag ^b	34 953 210	776 738	45	90	26 900	2700	9 820	Yes
Kawasaki	25 278 320	629 970	56	72	22 555	2699	7 468	Yes
Kawasaki	35 546 850	530 550	67	60	18 085	2699	10 719	No
Hawker-Siddeley ^c	37 265 088	665 448	56	72	19 609	n.a.	n.a.	No
Brugéoise et Nivelles	37 580 280	782 921	48	84	25 178	2700	8 401	Yes
Brugéoise et Nivelles	37 744 210	639 732	59	68	19 040	2700	10 665	No
Hawker-Siddeley	40 226 790	681 810	59	68	19 609	n.a.	n.a.	No
Bombardier-DuWag	45 013 760	818 432	55	74	24 295	2692	7 722	Yes
Boeing Vertol	51 330 000	870 000	59	68	21 641	2699	7 010	Yes

Note: Bids are ranked from lowest to highest; reference numbers describe disqualifying features.

^aNonconforming bid provided only 2 doors per side. Cars having more than 60 seats were required to have 3 doors per side.

^bNonconforming bid contained fewer than minimum number of 47 cars.

^cFront door pattern was nonconforming, with only 1 lane.

Two manufacturers, Brugéoise et Nivelles and Boeing-Vertol, each submitted two additional bids lower than those listed, containing disqualifying manufacturer-suggested cost reductions that did not affect car configuration.

parameters dictated by the total seating required and range in the quantity of cars allowed.⁶ Surprisingly, the rather close second-lowest bid was for 59 four-axle rigid cars seating 68 each. There also were 3 matching cars bid by other manufacturers. Again, the mathematics of the specifications dictated those numbers.

The bid was awarded without regard to articulation but on the basis of total price. In retrospect, this was a hazardous approach because the runner-up would not have had the most suitable configuration. There are many situations in which the larger car will permit a reduced train length. The savings in direct labor will more than offset any net additional life-cycle costs incurred resulting from the fleet's having 144 trucks and 48 articulations, instead of 118 trucks without articulation.

The Philadelphia procurement of single-end LRVs for the trolley subway and double-enders for the suburban light rail lines also allowed articulation as an option, but the required number of cars of each type was specified. There were 8 bids from 6 manufacturers. The articulated cars came in third, sixth, and eighth, and the award went to the lowest-bid 4-axle cars (Table 2). Note that the total bids for articulated cars from the same manufacturers were lower than for their 4-axle versions.

In a similar manner, the specifications for Buffalo's new LRV allowed the articulation option. Two bids were received for 33 four-axle cars and three bids for 25 to 27 six-axle articulated cars. Again the 4-axle car won on the basis of price. Here the articulated cars came in high (Table 3). The Buffalo process was unusual in that the evaluation of bids included add-on amounts estimated for spare parts and some life-cycle costs of maintenance plus travel for on-site inspection. These add-ons are not shown in the table. Consideration was not given to any greater labor productivity to be achieved by cars with more seats, since the operation calls for a train crew of one person regardless of train length.

These three examples show how the articulation decision was not made in advance, a conforming vehicle being selected on the basis of low bid. In Cleveland, a vehicle

far more suitable to the system's capabilities than the PCCs being retired was made possible by modifications to terminal layouts.

In Philadelphia, it could be argued that conservatism won out and that the opportunity for improved labor productivity was passed up by not selecting articulation. However, the new cars phase in well with their predecessors. A consideration is that Philadelphia's new LRVs normally will not run in trains except on the 2 suburban lines. A large articulated car could be wasteful on a surface-subway system with 5 branches, none of which alone justifies trains. Furthermore, the car selected is also usable on a separate network of surface streetcar lines, although that is not planned at present.

In conclusion, the decision on articulation must be made with full awareness of the gains to be achieved and the restrictions that will be imposed. Articulation has certainly been popular in recent years, and there is no indication that the trend will change. However, each light rail system must be considered with its own characteristics, not simply accepting an articulated configuration because that is popular or in production. There may still be some potential light rail applications that could make use of a rigid 4-axle car at lower total life-cycle costs and with fewer problems than would be experienced with 6-axle articulated units.

LOCATIONS OF DOOR OPENINGS

There is always a trade-off in an enclosed rail passenger vehicle between door openings and seating capacity. Every lane of opening eliminates at least 2 potential seats. The extreme form of maximized seating was the early "open end" car so often used on elevated railways. This evolved into the typical railroad car with enclosed end vestibules. Such door locations are totally unsuited to either light rail or rapid transit applications.

A few double-end light rail cars are in use that have doors only near the ends of the bodies. They are used on light-duty suburban feeder applications, namely Media and

Table 2. Bids on light rail vehicles for Southeastern Pennsylvania Transportation Authority, December 1978.

Car Builder	Total Cost (dollars)	Cost per Car (dollars)	Number of Cars	Cabs	Articulated
Kawasaki	46 291 400	413 316	112	1	No
	11 447 750	394 750	29	2	No
U.T.D.C.	48 115 636	429 604	112	1	No
	13 383 500	461 500	29	2	No
Breda	50 384 400	622 030	81	1	Yes
	14 396 800	654 400	22	2	Yes
Breda	53 691 400	479 388	112	1	No
	14 769 700	509 300	29	2	No
Hawker-Siddeley	61 407 806	548 284	112	1	No
	15 961 948	550 412	29	2	No
Brugéoise et Nivelles	61 719 015	761 963	81	1	Yes
	16 228 256	737 648	22	2	Yes
Brugéoise et Nivelles	64 623 936	576 999	112	1	No
	16 637 387	573 703	29	2	No
Budd Company	64 250 310	793 214	81	1	Yes
	19 797 690	899 895	22	2	Yes

Note: The bids for single-end cars include a quantity add-on option as follows: 112 four-axle cars include 18 add-on; 81 six-axle cars include 12 add-on. The lowest bid cars have these dimensions (in millimeters):

	Single-end	Double-end
Length	15 240	16 160
Width	2 592	2 692
Truck centers	7 620	8 400

Table 3. Bids on light rail vehicles for Niagara Frontier Transportation Authority, November 1980.

Car Builder	Total Cost (dollars)	Cost per Car (dollars)	Number of Cars	Articulated
Tokyu Car	21 833 567	661 623	33	No
U.T.D.C.	22 882 864	693 420	33	No
Siemens/DuWag	25 251 044	935 224	27	Yes
Bombardier	26 438 965	1 057 559	25	Yes
Hawker-Siddeley	30 369 008	1 214 760	25	Yes

Note: The lowest bid car has these key dimensions (in millimeters): length, 20 371; width, 2590; truck centers, 11 024. Costs do not include purchaser's bid evaluation add-ons, which were in a narrow spread from \$12 568 100 to \$12 946 950. These add-ons provided comparisons of life-cycle maintenance and repair costs and inspector travel expenses.

Sharon Hill lines west of Philadelphia and the Mattapan-Ashmont line outside Boston. The great majority of LRVs has at least one set of double doors somewhere in the mid-area.

The proportion of door openings to total car length depends on trip characteristics and load factors. Where the average trip is short and/or where a considerable part of the outer portion of a system is traveled with the cars lightly loaded, then doors could be maximized. This keeps dwell time short and does not eliminate seats that would otherwise receive long occupancy. Where most patrons travel on the greater part of the line and where stations are spread relatively far apart, doors can be kept to a

minimum. However, excessive dwell times must be avoided.

The methods of fare collection dictate whether doors should be located near the operator, who can do double duty as a fare collector. Putting doors up front as well as in the center was a great productivity improvement of the 1920s, permitting "one-man" cars that also had relatively fast loading. The double door across from the operator on a PCC was intended to provide 2-way flow with a pay-enter aisle on the right and departure on the left. For applications that are collective-distributive, with one heavily used central station, a single door opening near the operator will suffice, with double-door openings further back.

If cars are double-end, it is usual to provide symmetry of door openings. This cannot be done at the ends with an offset operator's position, and in some cases a narrow one-lane door is provided back of the operator. Without this door, loading from the offside with operator fare collection is inhibited. For example, having a door on the right only across from the operator (with on-board fare collection) compels right-hand running on double track with outside boarding areas and/or left-hand running on double track with boarding areas between the tracks. Because a narrow door behind the operator "costs" only 2 seats, it should be considered for all double-end cars unless all fares will always be collected off-train. Furthermore, such a door near the end on the offside will help loading and unloading at terminals where everyone has paid or will pay later.

The general North American rule in laying out transverse seats in a double-end rail car is that they should face the nearest door. This practice is not followed in Europe, where pairs of seats facing each other are widely used. Defining the nearest door becomes a problem where loading takes place on both sides, so the rule is often set aside for LRVs by having seats face the nearest cab. In this way, at times of light travel, riders can sit nearer the operator while facing forward. The back half of a 6-axle car can even be closed off at such times to reduce vandalism in a lightly occupied area.

"Excessive" door openings make it more difficult to collect all fares on board without loss. This problem has encouraged the application of prepaid or honor fare systems, removing the inhibitions on doors. A prepaid or postpaid fare system combined with ample doors on both sides and double platforms at terminals permits very fast unloading and reloading. A case can be made for providing doors on the offside on a very busy LRT system with single-end cars, as in the PCCs for Boston's Green Line. These doors are used only in the underground portion where everyone exiting or entering has already paid.

Mexico City uses single-end PCCs modified with door openings on the left side to achieve flexibility of loading areas. In some situations, boarding is from center medians of boulevards with right-hand running. The refitted car is an example of how even old LRVs can be made versatile to fit the system rather than making the system conform to the available car.

A lesson to be learned from experience with various patterns of door openings in the long history of light rail is that seldom will decisionmakers be criticized later for providing too many doors. There was formerly a tendency to provide too few, resulting in "pockets" of slow unloading. A prime example was the back end of certain single-end PCCs that had the center doors exactly amidships to provide a symmetrical body structure for double-end option. This layout resulted in 32 seats being to the rear of these doors. Later models with the center door moved more to the rear have faster unloading at the ends of the line.

SELECTION OF BOARDING LEVEL AND STEPS

Light rail vehicles can be designed to fit any desired level of passenger boarding, from the extremes of pavement at the top of rail up to platforms that match the car floor. It is sometimes believed that a system with high-platform loading is not really light rail, but the definition as applied in recent years is broad enough to include all platform heights.

Versatility of LRVs to adapt to different loading levels is shown by the car in common use at Edmonton, Calgary, and San Diego. The first two are high-platform lines, and the last one has paved platforms at rail top. Steps in the LRV for San Diego are external to the car body, while no steps are needed in the Canadian cities.

Decisions regarding platform height(s) should thus be made on the basis of what works best for the system and should not be dictated by what particular car to buy. It is not within the scope of a paper such as this, concentrating

on vehicle configuration, to deal at length with the advantages of various options in platform heights. In brief, a case can be made for keeping steps in the station instead of the vehicle when possible. A system without any stops during street running is certainly a good candidate for high platforms throughout.

Within the same system it is theoretically possible to have 3 different platform heights: a lowest either at rail top or at curb height, an intermediate platform height one step below the car floor or, alternatively, at a level even with a bottom car step, and the highest at car floor level.

Unless steps are suspended on the outside of the car body, a stepwell and the relationship to platforms will inhibit the choice of door action. An outward-folding door is manifestly not suitable to high platforms. An inward-folding door or a blinker door will require cutouts in stepwells. Sliding doors and "plug" doors will adapt to any loading level, but they have drawbacks of their own, such as air-actuated operation.¹

Outward-folding doors with electric drive have a long record of reliability and are therefore preferred where the system is all low-platform and expected to remain that way indefinitely. Internal steps are safer in cold climates; San Diego's approach to loading with the exposed steps might not work in a snowy city like Rochester, New York. The highly workable foolproof blinker doors once so popular on streetcars and on Chicago's elevated make the doorway lanes very narrow.

Several mechanisms are available for changing the height of one or more steps. External steps can be folded out of the way for high-platform operation, or can fit under a properly cantilevered platform, while internal stepwells can rise to make the well area flush with the remainder of the floor. Von Rohr observes that such devices add complications and therefore maintenance costs.¹ Capability to vary steps and thus utilize 2 platform heights that have more than 1 step height difference must therefore be selected with full awareness that a basic complication has been added to the car. The gain is maximum flexibility for the vehicle to fit any type of station.

The conclusion to be drawn concerning boarding level is that the system, present and future, can dictate the step selection in the vehicle with nearly complete freedom. It must be recognized that the high-platform choice restricts the door action to sliding or plug types but also gives greater freedom of door location with respect to trucks.⁴ Platform height selection will have far greater impact on station design and right-of-way appearance than it will have on the vehicle.

A strong point has been made over a period of many years that low-platform lines in major metropolitan areas should be constructed to be convertible later to full-size high-platform lines, and some stations and cars—e.g., Brussels—have been designed accordingly. The conversion may never take place, however. So-called pre-metro customarily stays in that state permanently.⁷

A misunderstanding of just what light rail is can bring forth strange ideas. One urban high-platform line with overhead power and no grade crossings is to undergo rebuilding of the platforms as part of a major station rehabilitation project. It was seriously suggested that the platforms be removed and replaced with low ones at curb height so that the facility would then be a light rail line!

CAPABILITY TO RUN IN TRAINS

One decision for LRV configuration that is nearly a matter of pure economics is whether the cars should be capable of running in trains—i.e., at least 2 cars coupled. Although many streetcars did not have couplers, it almost seems a truism now that if there is no need to operate at least 2-1 car trains in the rush periods, then perhaps a light rail line is not justified at all. The only disadvantages of provision for couplers other than higher initial cost are the slight increase in weight, thus using more energy, and a greater

tendency for the car to yaw and pitch because of the added weight beyond the car ends. These differences are noticeable in two groups of otherwise identical PCC cars acquired by Cleveland, 13 with couplers and 7 in their original state.

Coupling ability increases throughput capacity for peak times, since coupled cars are operating at the equivalent of zero headway. This ability is especially important where there is a bottleneck in the system such as single track. A prime example is the Pittsburgh line on the east bank of Saw Mill Run Valley, where a large fleet of PCCs undergoes rush-hour delays because the cars cannot couple and there is a long stretch of single track, with 4 passing sidings. Serious consideration was given several years ago to converting the best of the fleet to multiple units in order to relieve this problem.

Recovery from a delay can be faster with cars that couple because the single cars in the normal operation can be joined into trains during the delay. This will enable the entire group of cars that were held up to move off faster once the problem has been cleared. Furthermore, a disabled car can be towed or pushed by a car with a mating coupler far more readily than if a towbar must be attached. Even where electrical compatibility is not possible because of different control systems and/or very different weights of two types of vehicles, the capability to couple mechanically should be considered.

Once the decision is made to couple (as will usually be the case), the maximum useful train length should be selected. Control wiring can lose its capability as more and more connections between cars are added. Moreover, the difficulty of isolating a problem to a particular car also goes up rapidly with each added coupler. Where there is street running or crossing in a congested area, long trains can interfere too much with other traffic. Abnormal train length is sometimes a symptom of headways that have been made too long in order to reduce labor costs or for other operating considerations. It must be kept in mind that the objective of a light rail line is to move people, not vehicles. The rail car is only a means to this end. Long headways with correspondingly long trains do a disservice to the rider who cannot easily adapt to an infrequent schedule.

Another factor governing train length is the maximum distance gap expected to occur in the power supply. This is a normal concern on systems that have third-rail power pickup, especially where there are street crossings at grade. Usually a line with overhead wire, as is nearly always the case with light rail, has only minute power gaps to divide the power supply into sections. However, LRVs in trains can be very useful for passing under a break in the wire by virtue of having 2 power pickups on the same train spaced 2 or more car lengths apart.

Where platforms are used, their length should be coordinated with the maximum distance between doors on the longest revenue train, allowing a little extra for inaccurate stopping. It may be desirable to move longer trains in yards, but this has no effect on platform length.

Providing the capability for train operation brings with it the need to decide on an existing system whether new equipment should be operable in trains with older equipment or possibly with unpowered trailers. It is a general practice in the transit industry that newer equipment gets used first, the oldest units being brought into service only for peak times. Similarly, trailers are generally employed only at the busiest periods.

The condition and expected remaining life of older equipment must be considered along with the projected need to use these older cars. Restrictions imposed on newer cars by train-line operation with older cars must be weighed. The following are some of these restrictions:

- Power-to-weight ratios cannot be substantially different.
- Control methods must be compatible.
- Braking characteristics have to be well matched.

- Adhesion characteristics have to be similar.
- Acceleration curves and top speed must be reasonably matched.

It can be seen that these restrictions could inhibit the technology used in a new car order. An aging fleet that will be retired before many years should not compel the selection of options that will make new cars obsolete while they are still fairly young. An extreme example of the lengths taken to avoid this pitfall is the new fleet for the Shaker Heights line: double-end, articulated, high-performance. It will be used concurrently with the slower single-end PCC cars gradually being phased out.

If it is necessary to add peak capacity very economically, then the idea of converting some older cars to unpowered trailers might be worth exploring. This approach is particularly applicable in systems where congestion will not allow full use of high-performance LRVs.

CONCLUSION

This paper has reviewed five major considerations in developing the physical configuration for a new light rail vehicle: choice of one cab or two, whether the car shall be articulated, the pattern of doors and seating arrangement, relationship of car floor and steps to loading areas, and single- or multiple-unit operations. There are no "best" answers, although trends show that certain choices are becoming widely accepted—note, for example, the selection of double-end cars with a single articulation for all new North American light rail lines.

A lesson derived from experience is that a current vehicle specification must consider future requirements as well as present conditions. There can be a trap that later compels that extensions be equipped in an ill-suited way just to fit the restrictions of an existing car fleet. The configuration options available for LRVs are so varied that a custom vehicle need not be considered a luxury. The car ought to bring out the optimum capabilities of the system.

A great deal of effort has been expended in recent years to make one standardized car fit different light rail systems; this has proved largely futile. Two re-equipping projects received a car with only a few different features, while three new North American LRT systems ordered another more or less standard "off-the-shelf" car that has little in common with the first "standard" car except some gross configuration features. A pattern may have been set where new LRVs do not achieve the maximum dimensional and performance potentials of some systems.⁴ It is encouraging to note that the next likely new light rail system will use a still different vehicle considered best suited to its needs and adapted from a recent design.

REFERENCES

1. Joachim von Rohr. Foreign Light Rail Vehicle Development. Light Rail Transit, Proceedings of National Conference, Philadelphia, 1975. TRB Special Report 161, 1975, pp. 99-109.
2. A. Ross Gray. Application of Light Rail Transit Vehicles. Light Rail Transit: Planning and Technology, Proceedings of National Conference, Boston, 1977. TRB Special Report 182, 1978, pp. 137-139.
3. Articulated Light Rail Vehicle (operated by the Rio de Janeiro Pre-Metro). Brochure by Bombardier Inc., Mass Transit Division, Boucherville, Quebec, Canada, February 1981, 4 pp.
4. E.S. Diamant et al. Light Rail Vehicles. In Light Rail Transit: State of the Art Review, Chapter 5. U.S. Department of Transportation, Washington, D.C., Spring 1976, pp. 117-127 and 156.

5. Robert J. Landgraf. Preliminary Specifications for New Rapid Transit Cars. Shaker Heights, Ohio, Department of Transportation, General Revision No. 2, March 1972, p. 2B.
6. Specifications for Light Rail Vehicle. Greater Cleveland Regional Transit Authority, Final Edition

Amended to May 24, 1977, pp. 2-1 through 2-6, 3-1 through 3-4, and Terms and Conditions Paragraph 21.

7. Robert J. Landgraf. Pre-Metro: Conversion Now or Never. Light Rail Transit: Planning and Technology, Proceedings of National Conference, Boston, 1977. TRB Special Report 182, 1978, pp. 62-67.

Practical Considerations in Vehicle Procurement for San Diego LRT

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On the San Diego Light Rail Transit Project, time considerations required procurement of a standard car with project-necessitated modifications. Selection of the standard car and the resultant modifications are discussed.

For the San Diego Light Rail Transit Project, the product of the design criteria and the operating strategies defined the vehicle and sized the fleet. However, as vehicle procurement was on the project critical path, it became urgent to purchase a standard car, and thereby eliminate time for resolving custom design items.

The project, nonetheless, had some features requiring modifications to the standard car. These modifications were project oriented and were practical considerations in procurement of the vehicle.

THE STANDARD CAR

Among the four standard-car offers received, not one was satisfactory to the project without some modification. As standard cars of their respective manufacturers, all essentially conformed to the California Public Utilities Commission General Order 143 (Rules for the Design, Construction, and Operation of Light Rail Transit Systems Including Streetcar Operations), all could make the round trip within 75 minutes, all provided adequate natural ventilation, all could be multiplied up to four cars, and all could be equipped with an acoustically damped railroad wheel.

One of the four car types did not have sufficient passenger-carrying capacity and was of a new and unproven design; it would have been difficult to increase the capacity by another 20 standees (full load, not crush) through a straightforward design modification.

Of the remaining three, two required the use of platforms above top-of-rail, and of these two, one was a single-ended, single-sided car. Neither of the two high-platform cars could be certified by an operator as standard cars for 50 car-years, but the manufacturers were willing to build and demonstrate prototypes configured with proven modules. However, the manufacturer of the single-ended car indicated that the high passenger-carrying capability was essential to its standard car concept and was unwilling to consider the modifications required by the project.

As a result, two candidate cars were available and suited the criteria. On one car, the lowest step to street level could be modified, and the maintainability of the other could be demonstrated by the building of a prototype. The remaining technical considerations were the minimum turning radius and estimated energy consumption.

The car with a high platform could negotiate the 60-foot radius curve; the other car could not. However,

both cars could be structurally modified. In the end, the 60-foot minimum radius was relieved, and the criterion for minimum lowest step was changed from 12 inches to 10 inches. This meant that car floor and door design changes would be necessary to both standard cars in the final selection. An off-the-shelf version, without modifications, was not available.

The estimated propulsion energy consumption at empty car weight for the two standard cars in the final selection was 5.2 kWh per car mile and 4.7 kWh per car mile, respectively, in the Centre City portion of the run, and 3.6 kWh per car mile and 2.8 kWh per car mile in the high-speed and wide-station spacing portion of the run. The estimates were compared on equivalent conditions and appeared quite plausible. They approximated the engineer's calculation, and they were within the range for other electric traction transit projects with similar service and equipment.

The slightly higher energy consumption of one of the cars was the consequence of its larger size and higher performance capability. The car was wider and could carry about 12 more full-load passengers. It was capable of higher speeds and was chopper-controlled, which contributed to its weight and higher performance, especially at low speeds.

Thus, among the finalists, two were near-standard cars that reasonably fitted the project requirements. One exceeded the requirements more than the other, and as that difference had commercial significance, the decision was made to award the contract for the Siemens-Duwig U-2 car.

MODIFICATIONS

Once the car was selected, the actual purchase order was prepared to provide for certain modifications necessitated by the project. Actually, it soon became apparent that there was not a standard U-2. The manufacturer evolved the design from the Frankfurt U-2 via Edmonton and then Calgary so that San Diego would have its own model (MTDB-1). These evolutions were included in the standard car, whereas the project-necessitated modifications were not.

The seven project-necessitated modifications were as follows:

1. A swing-out footboard was ordered to meet the reduced requirement for the maximum step riser. In this modification, the car builder divided the car floor elevation, just over 38 inches above the top-of-rail, into four equal rises. Two of these are in the door well where structural modifications were minimal. The other two are

provided by a stepboard, which retracts under the car when not in use. The footboard and the door are interlocked so that the door will not open until it is swung out, nor will the door close and lock unless the footboard is fully retracted.

2. The California Public Utilities Commission, following provisions of General Order 143, decided that because service would operate with numerous highway grade crossings, the cars should be equipped with collision posts. The Frankfurt U-2 does not have collision posts, but a rams-horn type was developed for Calgary, and this modification was used on the San Diego model.

3. The standard U-2 provides the operator with an entirely enclosed cabin. As the San Diego project developed, it became apparent that the operator, who was expected to provide passenger assistance when possible, should not be sealed off. This requirement called for a modification to provide a window in the rear wall and a dutch door cabin entrance.

4. The San Diego project called for chair lift access for elderly and handicapped passengers. Because there was no standard lift equipment, a development subproject was required. The car builder engaged a subsupplier, and the purchase order was amended in three ways. The first amendment provided for engineering and installation of one lift at the car builder's factory. The lift manufacturer and the car builder would then refine the design before proceeding further. The second amendment, a consequence of the first, called for modifying one end of each of 13 cars in preparation for later installation of the lifts in San Diego. The third amendment provided for lift installation on the cars in San Diego. Unfortunately, the operating experience with the lifts has been unsatisfactory.

5. The radio equipment was furnished separately from the car. The radio units are portable, but are located in a cradle/charger when on board, and are connected to a low-profile antenna on the car roof when the portable unit is encradled. The car builder prepared the necessary wiring harness, terminations, backboard, and roof plate so

that the equipment could be installed after car delivery.

6. The fare collection system had not been resolved at the time of the car purchase order. It was thought then that there might be a requirement for onboard ticket cancellation. To prepare for that possibility, an amendment was prepared requiring the car builder to install wiring (six-line circuit) in stanchions near two doorways on each car and in the trainline. The wiring would provide battery energy and controls from the operator's console. These cars are so equipped, but the feature is not required and will remain unused.

7. Under the provisions of the California Public Utilities Commission General Order 143, light rail vehicles that operate on streets must have front, rear, and side markers and turn signals in accordance with the California Motor Vehicle Code. (It is interesting to note that the code does not itself require these markers.) The purchase order was amended to include the specific requirements of the motor vehicle code.

These seven amendments added about 6 percent to the base fleet price for the cars. In addition to the provisions of these amendments, the purchase order provided for spare parts, a maintenance contract for 1 year, which began in January 1981, and major shop equipment required to perform major maintenance on these cars.

CONCLUSIONS

Although the project criteria called for standard equipment and discouraged custom requirements, the San Diego light rail vehicle is not strictly an off-the-shelf standard nor was it unmodified. It is a standard design as evolved by the manufacturer from past projects and modified according to the particular requirements of this project. However, these modifications can be seen as contributions to the basic design of the car, and in this sense, the San Diego light rail vehicle is a standard car.

Optimizing the Light Rail Vehicle Pre-Procurement Effort

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Over the past 18 years, great technological advancements have been made in the development of rail transit systems. In conjunction with these developments, vehicle systems, related equipment, and operating techniques have become more complex and costly. These factors result primarily from the requirements of accommodating overall system configuration, increased sophistication, Buy-America constraints, vehicle improvements and standardization impacts, initial capital cost versus life-cycle cost considerations, critical vehicle options, and many other factors that tend to complicate the procurement process.

The objective of optimizing the light rail vehicle pre-procurement effort—to satisfy all functional, operational, safety, and site-specific requirements within predictable and reasonably acceptable cost and time constraints—can only be accomplished through a systematic and practical approach. The approach must have sufficient flexibility to permit tailoring the pre-procurement process to the site-specific requirements and must consider the various financial and technical compromises and constraints that may be imposed on the procurement.

Over the past 18 years, great technological advancements have been made in the development of rail transit systems. In conjunction with these developments, vehicle systems,

related equipment, and operating techniques have become more complex and costly. These factors result primarily from the requirements of accommodating overall system configuration, increased sophistication, Buy-America constraints, vehicle improvements and standardization impacts, initial capital cost versus life-cycle cost considerations, critical vehicle options, and many other factors that tend to complicate the procurement process. Periodic changes in employment, residential locations, and travel patterns also have a direct bearing on the selection of the most suitable and cost-effective transit system for a particular area.

Whether a new system is developed or an existing system rehabilitated, contractor assistance is frequently required. If government funds are used, the contractor must be selected through a bid process that allows two or more qualified candidates to bid on each system element to be acquired. The only control the transit authority has is to award the contract to the lowest responsible, responsive bidder that is in compliance with the bid documents for the particular system element. For transit authorities who are not dependent on funding from the government agencies bidding requirements are less rigid. If permitted by state or local law, they may negotiate a purchase order and an agreement with the preferred contractor, and thus avoid

having to prepare a specification. The savings in time and money can be considerable.

Regardless of which procurement is used, the transit system should give serious consideration to the system element to be procured. The contract documents should have two objectives: (a) to provide a legal contract that can be established and executed, and (b) to define the general and detailed requirements for acquiring the vehicles that will result in efficient, reliable, safe, and maintainable operation.

These objectives can only be met within cost and time constraints through a systematic approach to pre-procurement. The effort must have sufficient flexibility to permit tailoring the pre-procurement process to the site-specific requirements and to accommodate the various financial and technical compromises and constraints that may be imposed.

SYSTEM CONFIGURATION

Light rail vehicle (LRV) requirements are contingent on the overall transit system configuration. When a new transit system is being developed, determining the LRV configuration may not be too difficult. The new track alignment and fixed structures, although dependent on site-specific constraints, may have flexibility to accommodate a preferred LRV. However, if an existing transit system is to be rehabilitated, the track alignment and fixed structures usually cannot be altered. Such constraints will have an effect on the LRV configuration.

INCREASED SOPHISTICATION

Increased sophistication of any system element may be desirable. However, added cost, increased equipment and interface complexity, and possible reduced initial reliability are usually associated with increased sophistication.

Because the sole purpose of the LRV is to transport the public, the vehicle and all of the major subsystems involved must ensure safe and reliable operation at the lowest possible cost. Serious consideration should be given to using service-proven vehicles and equipment, even if site-specific requirements necessitate certain modifications. The cost, in all probability, will be lower than with a vehicle that is more sophisticated, but untried.

BUY-AMERICA CONSTRAINTS

There are no American-owned LRV manufacturers at the present time. Although the existing Buy-America constraints ensure that most of the major subsystems will be available in the United States, some feel that the Buy-America constraints impose undesirable restrictions on foreign manufacturers. Buy-America constraints may hamper the vehicle supplier and at times even the transit system; they may add to procurement costs and time. Major impacts on LRV procurement are described below.

Design Changes

When procuring service-proven (off-the-shelf) vehicles, the manufacturer may be required to modify an existing vehicle system to satisfy site-specific requirements. As a result, different subsystem suppliers may be used, who may require changes on assembly and component drawings, possibly on as many as 4000 drawings, depending on the system involved. At a nominal cost of \$400 per drawing, the cost could be \$1.6 million. An added cost of this magnitude could increase the bid price.

Assembly Line

The general policy of foreign manufacturers is to intersperse several vehicle procurements in the same assembly facility. They not be able to do this if the Buy-America constraints are too severe. If procurements are required to

be segregated, the manufacturer may not be able to maintain continuity of effort. The end result may be increased costs and schedule delays.

Shipment of Equipment

To comply with the Buy-America provisions, foreign manufacturers must transport some major subsystems and components from America to their overseas facility for final assembly. The equipment must then be shipped back to the transit system. Such extra shipments incur added costs.

Testing Program

Incorporating American-manufactured equipment into a previously service-proven vehicle may result in system interface conflicts that require additional tests to verify that the total vehicle is acceptable. The requirement for such added tests will obviously increase overall procurement costs.

VEHICLE IMPROVEMENTS AND STANDARDIZATION

Recently procured LRVs have been varied. Vehicle operational performance of some transit systems have had minor problems requiring minimal modifications; others have been extremely dissatisfied with delivery and subsequent pre-revenue performance and have required extensive retrofits before satisfactory operations were achieved. Vehicles may be unacceptable because they are highly sophisticated, because the vehicle or subsystem design is new, or because there are conflicts in the interface of major subsystems. Some of the problems might have been avoided through the procurement of service-proven vehicles or equipment.

An advantage of standardization includes lower costs and inventory storage requirements; however, these must be taken into consideration during the pre-procurement effort. There are two basic approaches to standardization when applied to vehicle procurement; total vehicle system standardization and subsystem and component standardization. Standardization of the total vehicle system may be achieved through cooperation and joint procurement of two or more transit systems (see Appendix A). Rarely will the identical vehicle satisfy the site-specific requirements of more than one system. However, in some cases, a joint pre-procurement effort could define a basic vehicle that, with a few alterations, would be satisfactory for more than one system. Subsystem and component standardization, to the extent possible without sacrificing total vehicle performance and safety requirements, is a more achievable goal.

ESTABLISHMENT OF THE AUTHORITY'S CONFERENCE COMMITTEE

About 3 years ago, the Port Authority of Allegheny County (PAT), under the leadership of Robert Sedlock, Manager of Systems Technology, began its LRV pre-procurement effort. Meetings were held with the various candidate vehicle manufacturers to inform them of the PAT site-specific requirements (as well as those of other systems) and to determine if the manufacturers had service-proven vehicle manufacturing capability. The manufacturers were also asked if the PAT-desired and essential requirements were considered achievable and reasonable. Other transit systems were invited to these meetings. On completion of the presentations by the manufacturers, the transit systems discussed each of their specific constraints and site-specific requirements.

The main objectives of these meetings were to determine the current status of service-proven vehicles and associated equipment and the feasibility of achieving standardization of LRVs among the various transit systems. Most systems agreed that the meetings were beneficial. Since this effort somewhat resembled that of the

President's Conference Committee (PCC), which resulted in the development and manufacture of the PCC car, all participants involved expressed the desire to continue and to identify themselves as the Authority's Conference Committee. UMTA has recognized that the positive results achieved so far should eventually provide advantages to the industry. Several systems indicated strong interest in the possibility of joint procurement. However, they agreed that, due to site-specific requirements, complete standardization of a total vehicle system was not feasible.

INITIAL CAPITAL COST VERSUS LIFE-CYCLE CONSIDERATIONS

Life-cycle costs are anticipated costs of initial procurement, the present value of implementation and training, and the value of the initial inventory of replacement parts and associated storage requirements. These various costs can be categorized as the costs of purchasing, operating, or maintaining a fleet of LRVs. To calculate life-cycle costs during the pre-procurement effort, sufficient data must be obtained to permit preparation of the bid documents and meaningful evaluation of the bids.

Life-cycle cost analysis is an effective tool for selection of specific major subsystems and components. It should, however, be considered an alternative to, rather than a replacement for, low initial price evaluation. As such, it can be employed as an adjunct to the pre-procurement effort.

Initially, a transit system should consider the merits of various types of LRVs that may satisfy the total system requirements. Then, the anticipated costs, directly influenced by each vehicle design, can be evaluated.

Purchase Price

The purchase price of LRVs depends on the quantity, type, and size of vehicle to be specified, the degree of sophistication involved in the vehicle design, the extent of standardization specified, and the impacts imposed on the bidders by the Buy-America constraints. Site-specific requirements must first be considered, as these will determine the vehicle configuration and performance requirements and the quantity required. The degree of sophistication and quantity of vehicles will depend on the funds available for procurement and the operational needs to satisfy the anticipated patronage.

Other important factors that will affect the purchase price include contract terms and conditions, inflation rate, potential for add-on orders from the transit system, the possibility of joint procurement with other systems, and general business conditions of interested bidders. The clarity and thoroughness of the bid documents and specifications are also important factors in minimizing contractor claims during the procurement.

Operating Cost

Operating costs involve recurring and nonrecurring costs. Recurring costs include operator cost, energy consumption, and maintenance; nonrecurring costs initially include training and scheduling and implementation of revenue service. These factors depend on the type of LRV procured.

For instance, based on an evaluation performed for the Pittsburgh LRV program, it was determined that a nonarticulated vehicle fleet would require 133 operators, whereas an articulated fleet would require only 88. It was also determined that the use of regenerative dynamic braking could reduce total system energy consumption. Con-

sidering all associated recurring costs involved, the use of articulated bi-directional LRVs would save \$1 400 000 each year.

Energy consumption has been determined to be directly proportional to the vehicle weight, assuming that the performance and profile are kept constant.

Maintenance Costs

Maintenance costs include replacement parts inventory and maintenance operations. Initially, replacement parts inventory requirements may be greater due to the introduction of new vehicles. However, these requirements may be reduced through standardization of components and use, where possible, of the components equivalent to those used in the existing fleet (e.g., automotive-type tempered safety glass, standard bus seats, head and taillights, floor covering, windshield wipers, rear view mirrors).

Maintenance operations include both scheduled and unscheduled maintenance. Maintenance activities on a new fleet of LRVs may initially be higher, depending on the extent of new design and sophistication involved. Routine and repetitive maintenance should reduce significantly once the maintenance personnel become familiar with the new vehicles and the "bugs" are removed. Unscheduled maintenance is normally directly related to the reliability of equipment. By specifying the requirement for service-proven equipment in the LRV procurement, reliability values can be acquired to permit the transit system to determine which equipment is acceptable. This obviously cannot be achieved on new designs of equipment.

CRITICAL VEHICLE OPTIONS

Critical subsystems must be selected with care. Criticality of subsystems should be determined by the impact a specific major subsystem has on operational availability, total system interface, overall vehicle system reliability, associated maintenance, and passenger safety. Arbitrary selection of major subsystems or components may jeopardize overall system effectiveness and user safety.

A method used by some transit systems for selection of critical vehicle options during the pre-procurement stage, is step 1 of the two-step procurement process. Step 1 is basically bidders qualification. During this period, interested bidders submit proposed designs to the buyer for review and approval. Before it reviews the submitted proposals, the transit system should identify those elements considered critical and to what extent options would be permissible. Another approach employs a modified two-step procurement. Under step 1 interested bidders would submit pre-bid data, to verify their experience as vehicle manufacturers and the experience of their proposed major subsystems suppliers, with sufficient data to prove that their product is service-proven.

CONCLUSIONS

The procurement of a new LRV fleet is a major effort and, depending on the number of vehicles involved, may constitute the largest expenditure for a system element in the total system cost. Bid documents must be prepared properly to ensure (a) that a legal contract that can be executed without litigation is established, and (b) that all specific requirements of the vehicle have been defined to provide proper interface with the total system and efficient, reliable, safe, and maintainable operation.

By using a systematic pre-procurement effort the procurement of a new LRV fleet may be accomplished in a timely and cost-effective manner.

Technical Aspects of the Two-Step Procurement of Light Rail Vehicles

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The two-step procurement process is described in general terms. In the first step of this process, the important elements are the request for technical proposals, submitted without cost data, and the conduct of technical negotiations based on the buyer's requirements and the car builder's proposals. This paper deals with how these elements can be carried out to ensure that the buyer's interests are properly served and, at the same time, deal with the legitimate concerns of several proposers with diverse products in an equitable manner.

In recent years, there has been a strong interest in improving methods of procuring rail cars for mass transit systems. In a 1980 Department of Transportation study of procurement processes,¹ it was recommended that UMTA grantees should be encouraged to utilize two-step formal advertising and that experienced procurement techniques, among them product standardization and life-cycle costing, should be used to strengthen the procurement process. The report further pointed out that the two-step procedure combines the best features of negotiation (competitive sealed proposals) and conventional formal advertising (competitive sealed bids).

The two-step procedure, or more accurately two-step formal advertising, was developed by the U.S. Department of Defense. It was first used in 1965 by the U.S. Navy for the acquisition of a quantity of Talos missiles. The federal government has issued directives consisting of formal guidelines, rules, and recommendations on when and how to use the procedure.² In 1979, the Niagara Frontier Transportation Authority (NFTA) of Buffalo, New York, reviewed these directives and decided to use the procedure in the procurement of light rail vehicles for its 6.4-mile system now under construction.

Briefly, the two-step procedure consists of

- Step 1—in which no-price technical proposals are solicited and evaluated for acceptability by the buyer (the word "authority" will be used hereafter). During step 1, the authority can conduct technical negotiations with each proposal respondent in order to arrive at a product definition that meets authority requirements with a minimum of modification to the products proposed by the respondents. The final product agreed on is defined by issuing addenda both to the technical proposals and to the authority's request for technical proposal (RFTP).
- Step 2—in which those respondents whose revised technical proposals were declared acceptable by the authority in step 1 are invited to submit sealed fixed-price bids. The lowest responsive and responsible bidder can then be awarded a contract.

THE NFTA EXPERIENCE

The main feature of the two-step process that NFTA found attractive was the flexibility in offerings it permitted the rail car industry. The authority achieved this flexibility, in part, by writing an RFTP that was not a detailed performance and hardware requirements document. It was thought that such an RFTP would result in offerings for existing rail cars and carry with it the advantages of increased competitiveness and reduced cost. Accordingly, the NFTA established a plan to implement the two-step process.^{3,4}

The major phases in step 1 of this plan were to

- Establish requirements and write and issue the RFTP,
- Evaluate the technical proposals,
- Conduct technical negotiation meetings, and
- Announce a closing date for final proposals and prepare for step 2—the solicitation of price bids.

Request for Technical Proposals

NFTA based its RFTP on a previously written detailed technical specification, which was then condensed to only those performance and hardware requirements essential to the Buffalo system. The task was not an easy one. If too much detail were specified (i.e., if requirements were mandated rather than left open), car builders with proven products that deviated in too many respects from the requirements would be discouraged. If not enough details were given, the RFTP would result in widely disparate proposed car designs.

This level of detail is a matter that each authority must deal with in terms of its own needs. The UMTA Light Rail Transit Car Specification Guide⁵ addresses indirectly the question of level of detail: It specifies a baseline vehicle, but allows the possibility of selecting options on requirements "to provide additional operational flexibility and capabilities . . ."

Several points should be considered when preparing an RFTP:

- The RFTP is the beginning of a series of events and, therefore, should be structured to be consistent with the proposal evaluation process, the technical negotiations, and the declarations of acceptability that will follow. Thus, the preparers should have some idea of the evaluation criteria and how the technical negotiation sessions are going to be run. For example, subsections of the Portland RFTP⁶ contained lists of questions to give potential respondents an indication of areas that would be of particular interest to the authority in the technical negotiation sessions.
- The specification of such detail as number of seats in a car, standee floor area, train makeup, or car length (or range of length allowed) should be considered carefully. The sensitivity of fleet size is greater to some of these parameters than others. The aim of the RFTP should be to specify them in such a way as to satisfy the operational requirements of the authority while minimizing any advantage that one car builder might have over another.
- If alternative subsystems may be proposed, the RFTP should make it clear to what depth each alternative (for any one subsystem) must be described and documented and to what extent interfacing and integration problems should be treated in the proposal.
- It is now common practice to require the offering of service-proven major subsystems in step 1 proposals. If this is to be done, the RFTP should make it clear that service histories, including data on reliability and maintainability, must be included in the initial proposal submitted; other-

wise, this information must be discussed in the technical negotiation meetings and documented in addenda to the car builder's proposals.

- The RFTP should require that all proposals be organized in the same way—down to the last ranking subparagraph. If this is done, comparisons between proposals can be made quickly.

Proposal Evaluation

In this phase of the step 1 process, all proposals received in response to the authority's RFTP are evaluated for acceptability. Except for blatant violations of RFTP requirements, it is rare that a proposal is declared unacceptable—the whole point of step 1 is to negotiate differences (which is the next phase). On the other hand, it is equally rare that a proposal is declared entirely acceptable at this point, that it is so well matched to the requirements that no technical negotiations are needed. Incidentally, if at any time a proposal is declared unacceptable, the two-step guidelines indicate that the RFTP respondent must be given an explanation.²

The manner in which technical proposals are evaluated depends on the evaluation staff's concept of the process. If the process is to be in the best interest of both the respondent and the purchasing authority, it must be well organized.

NFTA divided the evaluation process into two parts. The first part consisted of an evaluation of general acceptability in which such factors were considered as experience and background of the offering firm, its organization and plan to carry out a procurement program, and the ability of its proposed vehicle to meet the broadest general requirements. If the respondent passed this first test, the second part, the technical evaluation, was to be carried out.

NFTA received nine proposals in response to the RFTP; all passed the first test. Invitations were sent to the respondents for technical discussions.

The details of the technical evaluation procedure depend on the evaluation staff—primarily its experience with rail car procurement. In the NFTA case, a simple check-off list was prepared, and the paragraphs in the proposal (which had been numbered to correspond to the paragraphs in the RFTP) were checked off under the following column headings:

- Information not provided
- Meets requirements
- Deviations indicated
- Remarks
- Reviewer identification

All of the nine proposals received by NFTA were given checks in the "discussion needed" column. Hence, a schedule was set up, and invitations were sent out to all respondents to meet with NFTA and its consultants to carry out technical discussions. Each invitation also contained a brief discussion of NFTA's concern over the most important technical issues needing resolution in each proposal. By the time this phase ended (or, in two cases, shortly after) and the next phase began, there remained six proposers with whom detailed technical negotiations had to be carried out.

Technical Negotiation Meetings

This phase of step 1 is the most important and the most difficult to carry out in a way that meets the theoretical ideal for the process—namely, to arrive at a final set of proposed vehicles that meet the needs of the purchasing authority and to do so in a way that puts the proposed suppliers on an equal "selling" basis.

Two factors make the ideal hard to achieve: (a) the proposed rail cars are different products, and too much effort to make them technically equal violates the most

important tenet in the two-step process—i.e., to require minimum modifications to existing rail cars so that, other things being equal, costs are minimized; and (b) differences among vehicles make proper specification of parameters that influence the required fleet size difficult.

The NFTA experience with technical negotiations provides insight into ways this phase can be carried out expeditiously.

Agenda

A detailed agenda should be prepared before each meeting at the conference table; if possible, the agenda should be given to the RFTP respondent before the scheduled meeting.

Policy Statements

Authority policy should be established early in the negotiations; this will involve clarification or, if necessary, repetition of policy positions made in the RFTP but perhaps "missed" by some respondents. Policy statements may include methods of incorporating agreements reached during meetings into the procurement documents (the best way is by addenda to the technical proposals and to the RFTP), methods of handling subsystem suppliers (especially treatment of alternative subsystem listings), and life-cycle costing considerations, and, most importantly, the way the "size" of the intended purchase will be determined. In principal, all of these policy matters are made clear in the RFTP but, inevitably, issues will be raised with each respondent that may make it necessary to modify earlier positions.

Recordkeeping

The choice of a recordkeeping method should be up to the authority negotiation team. In the NFTA case, recording meetings on tape was considered but, for several reasons, not used. The sheer volume of tape expected was prohibitive—not in terms of cost but in terms of usefulness. As it turned out, more than 150 hours of meetings were held with six respondents. In addition, tape transcriptions of meetings with a number of people are often unintelligible.

It was finally decided that all the authority's negotiation team members (which ranged from four to six people at any given meeting) would take notes. The proposer's teams also took notes.

Changes in RFTP Requirements

This is the most vexing of the issues that can come up during the technical negotiations—especially if, as in the NFTA case, there was no formal industry review phase before the RFTP was issued (the schedule did not permit it) and both four-axle and six-axle articulated cars were allowed.

Some of the decisions facing any authority negotiation team are as follows:

- Which performance and hardware requirements are necessary and should be held firm—even at the risk of having an otherwise attractive proposal withdrawn.
- Which requirements are worth relaxing in order to keep as many of the respondents in the competition. Obviously, the relaxation of a requirement has to be weighed against its impact on meeting the operational needs of the system. The less detail in the RFTP, the more likely issues like this will arise.
- Which proposed features are desirable but not necessary. These are usually features that are not spelled out in detail in the RFTP and are associated with existing proposed vehicles. After

Table 1. NFTA light rail bid price comparison.

Bidder	Fleet Size, Cars	Car Type	Percent Deviation From Low Bid ^a
A	33	4-axle	0
B	33	4-axle	+4%
C	27	6-axle	+16%
D	25	6-axle	+21%
E	25	6-axle	+38%

^aBased on railcar costs, not including spares, software, and cost offsets (travel and maintenance costs) used as the basis for award.

the authority negotiating team has made it clear that a feature is desirable but not necessary, it is up to the respondent to decide whether he will keep it or remove it.

Clarifications and Additional Data

Given that proposals are responsive, the need for clarification and additional data from respondents will be in inverse proportion to the amount of detail in the RFTP. During the course of technical negotiations, it may become evident that more information is needed from some respondents. The obligation of the negotiation team is to make every effort to equalize the resulting effort required. Someone should keep careful track of who has been asked to do what. In the end, all respondents should have been asked to respond in essentially the same depth, with their proposals and additional data, on all issues.

Proposal Closing Date

During the course of the technical discussion meetings, agreements are reached and addenda issued, both to each respondent's proposal and to the authority's RFTP. At the end of the sessions, the authority's final addendum is issued (NFTA issued five addenda), and a closing date is announced for the receipt of all final proposals.

The essence of the step 1 negotiation process is reflected in the final RFTP; it will probably have been changed from its original version, though in no major respects, to encompass a number of different rail cars—all of which meet the needs of the purchasing authority. In the NFTA case, the proposed vehicles, of which there were six, ranged from a 67-foot, 4-axle car to a 98-foot, 6-axle articulated car.

Five of the proposal respondents submitted price bids in step 2. As shown in Table 1, the total spread in the bid price per car compared favorably with recent similar procurements.⁴ Thus, two of the aims of the two-step procedure—to attract a good number of bidders and to receive reasonably competitive price bids—were accomplished.

REFERENCES

1. U.S. Department of Transportation. Procurement Study: An Evaluation of the Procurement Process Used to Purchase Rolling Stock and Technical Equipment for Mass Transit, March 1980.
2. M.A. Wood. Two Step Formal Advertising. Government Contracts Monograph No. 12, The George Washington University Government Contracts Program, 1979.
3. T.D. Beck. NFTA Bid Evaluation and Award. Paper presented at APTA 1981 Rapid Transit Conference, Philadelphia, PA, June 8-11, 1981.
4. E.T. Ireton. "Transit Car Procurement: Breakthrough in Buffalo," Railway Age, January 12, 1981.
5. C. Elms, et al. Light Rail Transit Car Specification Guide, UMTA-MA-06-0025-81-4, December 1981.
6. Tri-County Metropolitan District of Oregon. Light Rail Vehicle Procurement Document, Portland, OR, April 1981.

A Study of Transit Rail Car Guarantee Warranty and Reliability Contractual Provisions

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Purchasers of light rail vehicles, concerned with the risks of developing new technology, have applied contractual remedies independently of one another. Members of the manufacturing and supply industry have complained that standardized guarantee/warranty/reliability (GWR) pro-

visions in contracts for the procurement of transit rail cars were becoming too restrictive and could have adverse financial effects on the industry.

Analysis of recent rail car contracts and discussions with transit operators and equipment suppliers support this

claim. More importantly, operators and suppliers have generally not worked together in developing and drafting GWR terms and conditions. They have felt that because of the variations in rail cars being purchased (new versus existing designs) and differences in local/state laws and regulations, standardized GWR provisions were neither workable nor applicable. This report presents the results of a study of the need to develop standardized contract provisions.

The need to establish a cooperative spirit between operator and seller developed as a key consensus of the study. To encourage cooperation, a rail transit car contract warranty model and a screen for preparing rail transit car warranty/reliability contract provisions were developed. The screen is used in preparing the specific clauses of the model.

The screen and model presented in this paper are for guidance only; they are not recommended for direct use in a contract. They summarize the ideas of the operators, suppliers, and engineers interviewed in this study and should be presented to the rail transit industry for further refinement. Ultimately they should be reviewed and modified by competent legal counsel for consistency with local laws and regulators.

Light rail vehicle (LRV) procurement is one of the important issues in the implementation of a light rail system. A large proportion of the cost of the system goes toward vehicle purchase. From the design through specification and manufacturing, there is a concern that this investment be made carefully, that the LRVs purchased be safe, reliable, and easily maintained. The system operator has sought this objective by asking for guarantees and warranties and by specifying a level of reliability for the rail car.

LRV technology in the United States had been stalled for 30 years between the last order of PCC cars and the development of the standard LRV for Boston and San Francisco. This gap meant that there was no slow iterative application of new technology to the LRV and that the recent rapid advances in technology, although necessary, brought some risk of failure. The guarantee, warranty, and reliability (GWR) clauses added to contracts were intended to reduce these risks.

The initial objective of this study was to assess the suitability of developing standardized GRW contract clauses for rail car procurement. Support for such a study dates from mid-1975, when the Railway Progress Institute (RPI) complained to the U.S. Secretary of Transportation and the administrator of the Urban Mass Transportation Administration (UMTA) about the contract terms and conditions used by transit authorities in rail transit equipment purchases. RPI claimed that these provisions were having severe financial effects on rail transit car manufacturers and their suppliers.

Because UMTA helps finance most rail transit equipment purchases, RPI sought federal assistance in monitoring such contracts for fairness. With the participation of RPI and the American Public Transit Association (APTA), UMTA assembled a review group to investigate the validity of the RPI claims and recommend contract terms and conditions. As a result, on March 1, 1978, the UMTA administrator issued 16 special guidelines for rail transit equipment purchases.

Because of the variety of local circumstances influencing rail transit car procurements and because consensus from all parties could not be achieved, UMTA was not able to issue guidelines covering all aspects of rail transit car contract terms and conditions. In January, 1980, N.D. Lea and Associates, Inc. (LEA), was asked by UMTA to study the feasibility of developing standard guarantee, warranty, and reliability specification clauses.

REVIEW AND ANALYSIS OF CURRENT GWR CONTRACT PROVISIONS

Is There a Problem?

Trends in the last decade of U.S. rail transit car purchases support the claim that a once-stable domestic rail transit industry has seriously deteriorated. Awards for 8 of the 14 most recent UMTA-funded rail transit car purchases, representing 29 percent of the rail cars purchased in the past decade, have gone to foreign manufacturers.

Foreign bid participation is most active in light rail purchases, which have tended toward existing designs purchased with a two-step negotiated procurement. The lack of a U.S. manufacturer with a proven light rail car design experience has essentially forced this result.

Both domestic and foreign car builders have had trouble with rapid rail car procurements. These cars have typically been purchased with detailed design specifications and in a sealed-bid selection process. The designs have required the introduction of sophisticated and unproven equipment, which has led buyers to include more stringent GWR requirements to ensure a reliable vehicle.

These contract provisions, while protecting the buyer, appear to have placed greater risks on the manufacturers. They have had to warrant designs and materials over which they have had little control. As a result, two U.S. car builders have announced that they would no longer bid on transit procurements because their resources could be invested in other markets at less risk.

Recent problems with vehicles delivered to BART, NYCTA, MARTA, MBTA, and SF MUNI and the withdrawal of St. Louis Car, Rohr, Pullman-Standard, Boeing, and General Electric from the car-building industry strongly indicate that the concerns and claims of both the rail transit operators and the manufacturers are legitimate.

Assessment of GWR Contract Provisions

The U.S. General Accounting Office (GAO) documented several examples of the failure of operators to administer rail transit car warranties. The GAO findings identified the need for complete and precise guarantee and remedy provisions in the rail transit car contract warranty. Just as warranty periods in excess of the custom for new rail transit equipment can be labeled inappropriately stringent, loose or ambiguous remedies can also lead to an inequitable assignment of contract responsibility and liability. On this basis, the LEA assessment of rail transit car GWR contract provisions was carried out.

The assessment of GWR contract provisions followed the structural outline shown in Figure 1. This outline, which classifies rail transit car warranty and guarantee provisions by function, was used to evaluate the completeness and precision of each warranty reviewed. It was also used in the development of the Proposed Rail Transit Car Contract Warranty Model presented at the end of this paper.

One objective of the assessment was to investigate the trends toward increased stringency in GWR contract provisions. Several functional groups of GWR provisions were identified and charted to establish their behavior over the past decade. The examination first focused on the length of the warranty periods—the basic warranty on all parts of the car and the extended warranties on specific subsystems or elements (see Figure 2). Warranty periods of typical subsystems and elements were then examined and charted. Results for car body structure and truck frame, propulsion motor, and propulsion gear unit warranty periods were not conclusive; it was difficult to document trends of increasing stringency for these examples even though there were variances in the length of warranty periods.

Although not as common as the functional groups discussed above, warranty of reliability has been applied to recent rail transit car contracts. As typically applied, warranty of reliability is accomplished through "fleet de-

fect" or "fleet failure rate" provisions. Such provisions state that if the failure rate of any warranted subsystem exceeds a contractually established threshold over a given period of time, the entire population of that subsystem shall be considered as failed, and remedies shall be set forth. To examine these provisions for trends of increased stringency, the threshold levels of several reliability warranties were charted in conjunction with the basic warranty periods and a lower threshold failure rate level. Figure 3 shows the behavior of these warranties for 12 rail transit car contracts let in the past 10 years. Although here again it is difficult to define any clear trends, the inclusion of a reliability warranty is in itself a definable trend during the past decade.

Figure 1. Rail transit car warranty structural outline

- I. Initiation of warranty period
- II. Period of warranty protection
 - A. Basic warranty—All parts of the car
 - B. Extended warranty—Specific subsystems and elements
- III. Definition of "failure"
- IV. Records and documentation
 - A. Maintenance records
 - B. Failure documentation and reporting
 1. Notification to seller
 2. Failure analysis
- V. Corrective action
 - A. Responsibility for corrective action
 1. Buyer
 2. Seller
 - B. Repair/replacement option
 - C. Approval of corrective action
 - D. Warranty corrective action costs liability
- VI. Reliability guarantees
 - A. Fleet defect provisions
 1. Failure rate trigger levels
 2. Corrective action provisions
 - B. Allowable failure rate provisions
 1. Application to extended warranties
 2. Allowable failure rate levels
 3. Corrective action provisions

Other Measures to Ensure Reliability

Non-rail-transit organizations and other large-volume equipment users permit the following alternative approaches, which may be applied in specifying rail car reliability:

- No reliability specifications are given; the warranty handles reliable performance by means of fleet defect clauses.
- No reliability specifications are given; the warranty handles reliable performance by means of fleet defect clauses and fleet availability requirements.
- Reliability goals are given, which the builder is expected to meet; however, some specifications use these goals as requirements that the builder must meet.
- Reliability specifications are given that the builder must meet through demonstration.
- Reliability specifications are given; however, the builder must propose reliability specifications according to a given format and must meet these through demonstration.

It has been claimed that rail transit car procurements before the 1970s emphasized use of the contract warranty and close working relationships between buyer and seller. This differs significantly from the approach used during the

Figure 2. Length of warranty coverage on all parts of car.

BASIC WARRANTY PERIOD INCREASINGLY STRINGENT	3-5 YEARS	○ SEPTA: GE COMMUTER RAILCARS (1974) ● MARTA: FRANCO BELGE RAPID RAIL (1976)	● PHILADELPHIA BROAD ST: NISSHO-IWAI (1979) ○ MUNI: BOEING SLRV (1973) ● CTA: BUDD (1978)
	1-2 YEARS	○ PATCO: BUDD RAPID RAIL (1966) ○ PCC CARS (1947-52) ○ BART: ROHR RAPID RAIL (1969) ○ RPI SUGGESTION TO UMTA (1975) ● PROCUREMENT AFTER 1975	● GCRTA: BRED A LRV'S (1977) ○ NYCTA: PULLMAN RAPID RAIL (1972) ○ PATH: HAWKER SIDDELEY RAPID RAIL (1970) ● PORTLAND: LRV'S (DRAFT SPEC. 1980) ○ MBTA: BOEING SLRV'S (1973) ● AMTRAK: GM LOCOMOTIVES (1980) ● SEPTA: KAWASAKI LRV'S (1979) ● NFTA: TOKYU CAR (1980) ● MBTA: HAWKER SIDDELEY RAPID RAIL (1976) ● WMATA: BRED A RAPID RAIL (1979) ○ CTA: BOEING RAPID RAIL (1974) ● BALTIMORE/MIAMI: BUDD RAPID RAIL (1978)
		5-15 YEARS	
		EXTENDED WARRANTY INCREASINGLY STRINGENT	

Figure 3. Length of warranty coverage and failure rate.

BASIC WARRANTY PERIOD ↑ INCREASINGLY STRINGENT	3-5 YEARS	• SAN FRANCISCO MUNI: BOEING SLRV'S (1973) • SEPTA: GE COMMUTER RAIL CARS (1974)	• MARTA: FRANCO BELGE RAPID RAIL (1976) • PHILADELPHIA: NISSHO-IWAI RRV'S (1980)
	1-2 YEARS	• WMATA: BRED A RAPID RAIL (1979) • SEPTA: NISSHO-IWAI LRV'S (1979) • AMTRAK: GM LOCOMOTIVES (1980) • TRI-MET: LRV'S (1980 DRAFT SPEC.)	• BALTIMORE/MIAMI: BUDD RAPID RAIL (1979) • CTA: BOEING-VERTOL RAPID RAIL (1974) • NFTA: TOKYU CAR LRV (1981) • CTA: BUDD RAPID RAIL (1978)
		>15%	≤15%
		FLEET FAILURE RATE	
		← INCREASINGLY STRINGENT →	

past decade in which reliability requirements such as those used in the aerospace industry have been included. However, neither buyer satisfaction nor rail car reliability has improved.

Costs

The costs of GWR requirements are difficult to estimate. They encompass the cost for warranty provisions and the associated risks, the direct costs of engineering and implementation of reliability requirements, and the costs associated with reconfiguration, redesign, or replacement of components that may be affected by GWR requirements.

In a cost study of the standard light rail vehicle specification performed by LEA for UMTA,¹ estimates for warranty and field service amount to 2.5 percent, and estimates for potential savings from simplifying reliability requirements amount to 1.8 percent. Thus, overall costs of GWR requirements amount to an estimated 4.3 percent of the purchase price.

Another report gave a conservatively estimated figure of 2 percent.² However, not all of these contractors were rail car builders, and the estimate does not necessarily include reliability requirements costs.

To substantiate these estimates, a quick telephone survey was taken of five car builders/system suppliers in May 1980. The estimates given were similar to those of LEA and GAO. Higher figures are quoted in the airline industry,³ where warranty costs range from 4 to 10 percent of the purchase cost per year of warranty.

There has also been concern that increased warranty periods have caused escalation in car prices. In July 1975, Pullman-Standard gave UMTA a response to this hypothesis. It indicated that (a) longer warranty periods on the car structure are less significant (a ratio of approximately 1 to 15) than longer warranty periods on all parts of the car; and (b) impact (in 1981 dollars) of the warranty period on all parts of the car are as follows:

- 1 year—base price, no impact
- 3 years—\$24 000 extra per car
- 5 years—\$57 000 extra per car

It would appear that there are opportunities to reduce GWR costs.

EXCHANGES WITH THE TRANSIT INDUSTRY

The results of the review and analyses of recent rail car contract documents were reviewed with UMTA. While conclusions could not be drawn immediately, a number of questions were raised and possible directions for study

were identified. These were formulated into a discussion outline, and arrangements were made to meet with transit operators and suppliers to determine if a consensus could be reached. Two series of visits were carried out. The first series was used to focus the second.

The results of these discussions were eventually used for the development of a proposed rail transit car contract warranty model and a proposed screen for preparing rail transit car GWR contract provisions. During the visit with Pullman-Standard, it was suggested that a "screen" might be the most useful product of this effort. A GWR provision screen could be used as a guide for preparing contract terms and conditions in much the same way that the APTA and RPI Standardization Committee's screen is used to prepare technical rail car specification provisions.

A draft guarantee/warranty screen was then developed on the basis of previous reviews and analyses and the information obtained during these three visits. The discussion agenda was also refined, and a second set of visits was planned.

It was during these visits that the idea of the rail car contract warranty model was proposed. The screen could then serve as a set of instructions and guidelines for a transit authority to complete a guarantee/warranty from the model.

Note: The screen and model presented here are not in their final form and are not recommended for immediate and direct use in a contract. They are drafts based on discussions and correspondence with suppliers and transit operators. Because of variations in laws and regulations from state to state and locality to locality, any GWR clauses should be reviewed by legal counsel at each specific site and appropriately modified before they are used.

RECOMMENDATIONS

It was assumed originally that a standard set of guarantee/warranty/reliability contract provisions would be of value for the transit industry. The results of our analyses and discussions with transit operators and suppliers do not support such a conclusion. There are too many variations in procurement regulations and laws across the different state and local jurisdictions, and standard contract provisions would not always be applicable to equipment being purchased (a new design car versus an existing and service-proven design).

During the visits with transit operators and suppliers, it was proposed that a set of guidelines, agreed on by both purchasers and suppliers, might be the best standards to develop. Also, the idea of a GWR model was suggested. These two suggestions were then developed into the pro-

posed screen for preparing rail transit car GWR contract provisions and the proposed rail transit car contract warranty model, which are presented below. (It should be noted that the model references by item number the suggestions in the screen that apply to the development of specific terms and conditions.)

It was also recommended that some terms and conditions be negotiated with potential bidders before bids are taken. If this is to be done, the specific term or condition should be defined, but notations made that can be negotiated later on the basis of the screen. Such an approach could lead to the development of a guarantee/warranty that better fits the practices of both the seller and buyer and minimizes the risk costs to both parties. Such practices could serve to instill a more positive spirit and reduce past adversary positions.

PROPOSED SCREEN FOR PREPARING RAIL TRANSIT CAR GWR CONTRACT PROVISIONS

The following are proposed as guidelines for the preparation of GWR Contract Provisions for rail car equipment.

GUARANTEE/WARRANTY PROVISIONS

Preamble

In drafting a warranty it is important to understand that a warranty is the "promise" to meet contractual requirements. The warranty binds the contractor to meet performance and other technical requirements. Therefore, it is important to define what the warranty is intended to promise—performance, design, or hardware specifications.

Initiation of Warranty

1. Warranties/guarantees of the car and/or major subsystems shall commence upon final acceptance of the rail car by the Buyer, or initiation of the rail car into revenue service, whichever occurs first. The terms and conditions for final acceptance are to be defined elsewhere in the contract and referenced in the warranty.

Warranty of spare parts shall commence upon placement of the cars in service or a fixed period from delivery to the Buyer. Delivery shall be defined in the contract.

Period of Coverage

General Warranty (All Parts of the Car)

2. The period of General Warranty will be 1 year minimum, 2 years maximum, continuous from the date of initiation of warranty.

Specific Warranty (Specific Subsystems/Components)

3. The intent of any specific warranty should be to correct defects in subsystems or elements which inherently display such defects after periods of use longer than the general warranty.

4. Specific warranties on specific subsystems should be used only to protect the Buyer from such latent deficiencies and shall not be used to capitalize normal required maintenance.

5. Any specific warranty should be short in comparison to the expected useful lifetime of the affected subsystem or element, perhaps on the order of 25 percent but generally not longer than 5 years.

Note: See items 20, 21, and 22 for additional suggestions concerning specific warranties.

Records and Documentation

6. Maintenance and warranty records shall be required of the Buyer. Complete and accurate records will

be required for all serialized major components (e.g., propulsion, braking, etc.) as verification of compliance with prescribed maintenance procedures and disposition.

7. The maintenance documentation and failure reporting mechanisms must be defined in the contract and in place prior to delivery of the equipment.

Definition of Failure

8. A subsystem or element shall be defined to be failed under warranty if there exists a loss of function or degradation of that particular subsystem or element as specified in the technical specifications. This will include primary failures, and secondary failures when the primary failure mode is a warranty failure; however, secondary failures (i.e., occurring as a consequence of primary failures) shall not be included in the calculation of reliability performance. Failures resulting from improper use of improper maintenance practices will not be considered warranty failures.

Corrective Action

9. The mechanisms for the reporting and analysis of failures shall be contractual. The requirements will cover provisions for failure reporting, analysis, and initiation of corrective action.

10. "Replacement" of a component or subsystem shall mean the removal of any such defective or failed item from the car and replacement with a like component or subsystem. "Repair" of any component or subsystem is defined to be identification of failed or defective parts or subassemblies contained in the component or subsystem and replacement of such failed or defective items, thus restoring the component or subsystem to its designed function.

11. The Seller shall be liable for all costs of warranty repair. The Buyer may be held responsible for replacement labor costs. Separate agreements will be reached where the Buyer is to conduct warranty repair. If the Seller is to be required to pay labor costs for "replacement," then the Buyer shall have well-established maintenance procedures and an accurate accounting system. A time study will be an appropriate method of establishing replacement labor requirements. The warranty shall include a reference to where the exact formulas for labor costs or any other associated costs are specified in the contract. Details of all warranty and guarantee financial responsibilities of the Seller shall be clearly spelled out in the contract, independent of who is required to complete the repairs.

12. The decision to repair or to replace and the method to repair a defective or failed item under warranty must be mutually agreed to between Buyer and Seller.

Reliability Guarantees

Fleet Defect Provisions

13. In the event that the failure rate of any subsystem or element exceeds a level prescribed in the technical provisions during any 12-month period of the warranty, the entire fleet population of that subsystem or element shall be considered to be failed.

14. The failure rate specified as constituting a fleet failure for a particular element or component will protect the Buyer from catastrophic failure rates in those items covered. The rate will reflect the amount of exercise a subsystem is expected to receive and the number of cars in service. Determination of this rate (fleet defect triggering level) must consider the size of the order. For example, a rate of 10 percent for an order of 30 cars would result in a triggering level of 3 cars. Such a small number of failures could be a material or workmanship defect. The Buyer should define the basis for counting failures in calculating the triggering level, i.e., all failures of the given subsystem or failures of the same type for the subsystem.

15. A failure analysis and plan for corrective action shall be required of the Seller for any subsystem or element exceeding the triggering level.

16. Corrective action to be taken when fleet defect levels are reached shall be stated within the guarantees and warranties contained in the contract terms and conditions.

17. In the event of a fleet defect, the Seller shall supply materials, parts, and labor to effect repairs on all cars in the fleet still covered by warranty.

18. In the event of a fleet defect, the Seller shall supply only the materials and parts necessary for repair of all cars in the purchase on which the warranty on the subsystem or element concerned has expired and where the subsystem or element has not failed prior to the expiration of the warranty.

19. Whenever practical, fleet defect repairs shall be completed in conjunction with scheduled maintenance or overhaul operations.

Allowable Failure Rate Provisions

20. Allowable Failure Rate Provisions could be used in connection with the Specific Warranties on certain subsystems as a means for Buyer and Seller to share risks of future problems and reduce up-front risk costs. As such, these technical reliability provisions shall specify an acceptable level of failures from items still warranted after the General Warranty has expired. The Allowable Failure Rate can act as a "deductible" which is the Buyer's share of the risk. Failures in excess of the Allowable Failure Rate become the responsibility of the Seller. It is suggested that the inverse of the MTBF be the Allowable Failure Rate. The Allowable Failure Rate Provision may not be applicable to some subsystems, such as structural items.

21. The Allowable Failure Rate could be stated within the reliability requirements contained in the technical specification. The remedies for the Allowable Failure Rate type of specific warranties shall be included with guarantees and warranties contained in the contract terms and conditions.

22. The Seller shall supply repairs or free exchange for all failed subsystems or elements covered by the specific warranty that exceed the allowable failure rate.

RELIABILITY/AVAILABILITY PROVISIONS

Technical Requirements

23. Reliability/availability requirements are technical performance requirements and shall not be included with the contract terms and conditions as warranties or guarantees.

24. Current data are not sufficient to establish complete reliability baseline requirements. Reliability growth requirements are appropriate for new designs or new applications of equipment. Specific reliability requirements shall be consistent with available documentation that the requirements are achievable. Otherwise, it would be better not to quote reliability requirements.

25. The data collection and analysis mechanisms specified in the contract, which are to be used to determine compliance with the technical reliability/availability requirements, shall be in place prior to delivery of the contracted equipment.

26. All reliability/availability requirements, however statistically stated, shall be mathematically compatible.

Contract Requirements

27. All corrective action to be taken for equipment not meeting technical reliability/availability requirements shall be included only in the contract terms and conditions and not in the technical specification.

28. The contract terms and conditions will require the Seller to submit a plan for corrective action when equipment

falls below the contractual reliability/availability requirements.

29. The Seller shall supply all labor and materials necessary to demonstrate subsystem or element compliance with reliability/availability requirements. These costs are those above the costs the Buyer bears in normal operation and maintenance of the cars during the demonstration period.

30. Demonstration of all reliability/availability requirements for a subsystem or element shall be required before the end of the warranty period for that subsystem or element over a definite time period.

31. All corrective actions for noncompliance with the technical reliability/availability requirements shall be contained in the contract terms and conditions.

PROPOSED RAIL TRANSIT CAR CONTRACT WARRANTY MODEL*

The Seller guarantees to the Buyer that the rail transit cars purchased under this contract shall be free from defects in design, materials and workmanship, and will comply with the requirements of the contract documents. The General Warranty on all parts of each of the rail transit cars purchased under this contract shall commence upon final acceptance of each car by the Buyer or its initiation into revenue service, whichever occurs first. (1) Each car accepted or placed into revenue service will have a warranty initiation date assigned to it. This date will be used to calculate the warranty period for all affected subsystems and elements for each car. The period of the General Warranty for each car shall be (TBS) year(s). (2) continuous from the date of initiation. The period of guarantee for spare parts shall be (TBS) year(s) from the date of delivery of the parts or (TBS) year(s) after placement into service, whichever occurs first.

#####Option 1 (Special Subsystem)—Specific Warranties are provided for (TBS) subsystems or elements. (3,4) The period of the Specific Warranty for the (TBS) (subsystems or elements) shall be (TBS) years or (TBS) miles respectively, whichever occurs first, continuous from the date of initiation. (5)#####

#####Option 1.1 (Allowable Failure Rate Specific Warranty) (20)—The Specific Warranty guarantees that the Seller shall provide repair or free exchange materials for all failures of the (TBS) subsystems or elements exceeding (TBS) percent of the fleet population of that subsystem or element during any 12-month period of its Specific Warranty. (21,22) Failures less than this (TBS) percent are not covered by the Specific Warranty and are the responsibility of the Buyer.#####

If, within the above-specified warranty periods, any equipment purchased under this contract shall fail in accordance with the terms of this warranty and the failure definition contained in the technical contract requirements, the Buyer guarantees, upon discovery, to notify the Seller or his Representative of the failure in writing within (TBS) hours. (8,9) The Seller shall thereupon initiate corrective action within (TBS) hours of the notification of failure by (at its option) approving repair or free exchange for the failed subsystem or element. The General Warranty for the car shall not be affected by said repairs or parts replacement. *****The Buyer shall be responsible

* The model uses a number of symbols and notes:

- the numbers in parentheses correspond to the applicable GWR screen items presented in the previous section.
- TBS—to be specified by the buyer.
- Optional text has been indicated as it begins and ends by the symbols.#####
- Screen item #8 definitions will appear with the technical provisions.
- Text appearing between the two sets of symbols, *****, must be deleted if option 2 is applied.

for carrying out the replacement of warranted items; that is, the removal of the failed subsystem or element and installation of a new or repaired item supplied by the Seller. (11) The Seller shall guarantee free repair of any item failed under warranty; that is, identification and free exchange of any defective parts or subassemblies contained in the failed subsystems or elements, thus returning that item to compliance with the technical contract requirements. (10,11,12) The Seller shall be responsible for stocking and supplying warranty exchange parts. The Seller shall guarantee to promptly resupply, on a free exchange basis, replacement parts which the Buyer supplies from his maintenance spare parts stock for warranty repairs. Replacement of failed items with the Seller supplied or approved repair or exchange parts shall constitute continuation of the Seller's warranty for that item.*****

*****Option 2 (Buyer Completes all Warranty Work)—The Buyer shall be responsible for replacement and repair of all items failing under warranty. The Seller shall guarantee free exchange of all items needed by the Buyer for repair and/or replacement of failed warranty items, and actual labor costs for the repair of any failed warranty items. (10) Labor costs shall be computed as follows: (TBS). (11) The Seller shall be responsible for stocking and supplying warranty exchange parts. The Seller shall guarantee to promptly supply free exchange for warranty replacement parts which the Buyer supplies from his maintenance spare parts stock. Replacement of failed items with Seller supplied exchange or approved repair or exchange parts shall constitute continuation of the Seller's warranty for that item. (12)*****

*****Option 3 (Fleet Defect Warranty) (20)—A Fleet Defect Warranty shall be in effect for the entire warranty period of any subsystem or element of the rail car purchased under this contract. If the failure rate for (TBS) subsystems or elements exceeds (TBS) percent of that elements' or subsystems' fleet population during any 12-month period of its warranty, the entire fleet population of that subsystem or element shall be considered to be failed. (13,14) Whereupon the Buyer invokes the Fleet Defect Warranty, the Seller shall promptly provide the Buyer with a written Failure Analysis and Plan for Corrective Action including scheduling and scope of the fleet repair plan within (TBS) weeks. For those failed items which are still under warranty, the Seller shall provide FOB the Buyer's property or point of repair, parts and labor for (at its option) the repair or free exchange of failed items.

(15,16,17) For those items included in a fleet failure for which the warranty period has expired, the Seller shall guarantee to provide FOB the Buyer's property or point of repair, (at its option) repaired or free exchange parts to return the car to compliance with the technical requirements. (11,12,18) Whenever possible, Fleet Defect repairs and replacements will be completed in conjunction with scheduled maintenance or scheduled overhaul operations. (19)*****

During the periods of the foregoing warranties, the Buyer guarantees to operate, maintain, repair and overhaul the rail equipment purchased under this contract in accordance with the requirements procedures prescribed in the Technical Contract Requirements and the Seller's Operating and Maintenance Manuals. The Buyer shall be responsible for maintenance records for each car covered under warranty as verification of compliance with the technical maintenance requirement provisions. (6,7) The Seller's warranties shall not apply to equipment that has failed or been damaged due to improper use or improper maintenance. (8)

In any case in which a part, component or item of equipment shall fail after the end of its normal service life (considering the usage to be expected in Buyer's normal service), and such failure shall occur prior to the expiration of the applicable guarantee period, such part, component or item of equipment shall be deemed to be outside the coverage of the guarantee. (4)

The foregoing guarantee is exclusive and in lieu of all other guarantees or warranties, whether written, oral, implied or statutory (except as to title). In no event shall the Seller be liable for incidental or consequential damages.

REFERENCES

1. N.D. Lea and Associates, Inc. Cost Savings Potential of Modifications to the Standard Light Rail Vehicle Specification. UMTA-MA-06-0025-79-11, February 1979.
2. U.S. General Accounting Office. Transit Equipment Warranties Should Be Enforced. GAO Report No. PSAD-80-12, December 1979.
3. Review of Commercial Airline Acquisition Methodology.

Rationalization of the Light Rail Vehicle Specification Process for Cost-Effectiveness

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Light rail vehicle (LRV) requirements should reflect site-specific transportation service needs, performance requirements, and life-cycle costs. This paper examines the process of defining these requirements. It addresses both technical and nontechnical issues. Technical issues include the justification processes and attendant costs for critical vehicle options such as articulation, bi-directionality, doors on both sides, and propulsion system. Nontechnical issues include contractual requirements that might cause higher assigned risk costs.

The benefits of various LRV features and contract provisions are compared with the costs, both capital and

operations and maintenance, and perspectives are established. Such considerations enable the buyer to maximize the return on his vehicle budget commensurate with real needs.

The process of defining light rail vehicle (LRV) requirements should consider site-specific transportation service needs and performance objectives in a cost-effective manner. The process is intended to be used in conjunction with the new Guideline Specification for Procurement of Light Rail Vehicles,¹ which was developed with UMTA funding through the cooperation of transit agency and

supplier groups. It is currently being used by the Port Authority of Allegheny County in Pittsburgh for its forthcoming light rail procurement.

The guideline specification provides a means by which a transit agency can specify only those requirements actually needed for its own site-specific mission. The guideline document also provides a uniform specification format and language to facilitate interpretation by the supplier industry and to reduce problems caused by misinterpretation.

If procurement of a transit vehicle can be compared with buying a car, the baseline specifications represent a stripped-down model. For example, specifications for the baseline LRV are as follows:

BASILINE SPECIFICATIONS

Unidirectional operation
Nonarticulated vehicle
No coupling (tow bar for dead car retrieval)
Door on right side only
Low-level passenger loading only
600V DC power
No cab signals
Moderate acceleration (0-50 mph in 58 seconds)
No load compensation
Single-stage track brake
No slip-slide protection
No air conditioning
Trolley pole power collection
Switched-resistor propulsion control
No regenerative braking
No resilient wheels
No load leveling

The buyer may then specify optional provisions to suit his needs. Specifications for all optional provisions are an integral part of the guideline document; therefore, a compatible set of specifications to suit the needs of a particular application can be readily generated. Typical optional provisions include the following:

CONFIGURATION OPTIONS

Bidirectional operation
Articulated vehicle
Mechanical or fully automatic coupler
Doors on both sides
High-level passenger loading

POWER/PROPULSION/BRAKING OPTIONS

750V DC primary power
Pantograph power pick-up
Higher acceleration (0-50 mph in 37 seconds)
Load compensation
Slip-slide control
Chopper thyristor control
Regenerative braking
Ability to tow dead car
Full service capability without dynamic braking
High-performance track brake (articulated shoes, three-stage braking force)

PASSENGER AMENITIES

Air conditioning
Load leveling
Resilient wheels
Special seating layouts

EXTRA FEATURES

Fully enclosed operator's position
Battery box heater
Lighted passenger "stop request" signal

Automatic pantograph control
Remote-controlled destination signs
Double-glazed side windows
Rubrails
Advertising card holders

SIGNALING/COMMUNICATIONS

Cab signaling
Traffic signal preemption equipment
Full public address communications system

A complete table of options is provided at the front of the specification referenced to the appropriate sections of the guideline document. The specification thus provides a checklist to help the transit agency ensure that it buys only what it needs.

A new guideline specification thus encourages the purchase of cars with only those technical features appropriate to the mission they must perform. System trade-off studies can be performed to ensure that a cost-effective car is specified. This paper presents examples of how trade-offs can be considered for unidirectional versus bidirectional car, articulated versus nonarticulated car, resistor versus solid-state propulsion control, and cost of guarantee/warranty/reliability terms and conditions.

In performing cost trade-offs, the following assumptions have been used:

- Labor costs for assembly and installation were taken at 12 percent of the cost of the elements involved;
- The wage rate for labor used in manufacturing was estimated at \$14 to \$18 per hour;
- Engineering costs were estimated at \$33 per hour, or \$3200 per assembly drawing; and
- A vehicle order of 100 units was assumed in assigning nonrecurring costs on a per vehicle basis.

In assessing operational impacts, the following operating scenario was assumed:

- Fleet size of 70 cars,
- Interest rate 10 percent (constant dollars),
- Route length of 40 track miles,
- 20 curves with radius of less than 125 feet,
- Six switchbacks or turnbacks, including two at the ends of the route and four en route, and
- Cost of right-of-way, \$0 to \$50 per square foot.

The study from which these costs were taken was performed in 1979. The costs have not been adjusted for inflation since that time.²

UNIDIRECTIONAL CAR

One of the first determinations that must be made is whether the car should be unidirectional or bidirectional.

Many of the pre-PCC streetcars were double-ended to permit operation on simple track layouts with switchbacks. As streetcar systems evolved, single-direction operation became popular. Greater car reliability reduced the requirement for turnbacks, and maximizing seating became an important goal. However, where subway construction was involved, the bidirectional car remained preferable, since it could turn back at a simple crossover track.

Today the advantages and disadvantages of bidirectional operation remain much the same. The bidirectional car can turn back with a simple crossover, which requires less land than the loop or wye required by a single-ended car. In addition, the bidirectional car permits passenger loading from either island or side platforms.

Disadvantages of bidirectional operation include the requirement for doors on both sides of the vehicle; this

arrangement reduces the seating capacity and increases the cost for doors. In addition, vehicle reliability is decreased, since there are twice as many door mechanisms that experience shows are particularly failure prone. Another disadvantage is that two operator's consoles are required; this reduces passenger capacity and increases the cost and technical complexity of the car.³

Because of these disadvantages, it is important to examine the operational need for bidirectional vehicles carefully. The new Canadian LRVs being built for Toronto are single direction. Many PCC cars, including those used in Boston, are single-ended, as are LRVs now operating in Amsterdam (the LHB eight-axle tram), Antwerp (BN four-axle tram), Basel (Schindler Be 4/4 and Be 4/6), Bern, Braunschweig, Bremen, Göteborg (ASEA type M-28), Helsinki, Nuremberg, and the Hague.⁴

The tendency toward tunnel construction for light rail in German cities and the high cost of underground turn-arounds have caused a recent preference for bidirectional vehicles.⁵ However, where construction is above ground, costs may often favor the unidirectional vehicle.

Savings in Car Costs

The unidirectional vehicle requires an operator's cab at only one end, and saves the cost of the other operator's cab along with all driver equipment, controls, and amenities. Additional seating is provided in the space formerly oc-

cupied by the cab. The rear destination sign is also eliminated. (Since some transit agencies may still require doors on both sides to handle center platform stations, savings from elimination of doors will be considered separately.) Table 1 gives the savings in vehicle first cost, estimated for a typical 100-car order. A six-axle articulated vehicle similar to the Boeing light rail car has been used as the basis for these calculations. Savings amount to nearly \$20 000 per car.

It is common for unidirectional cars to have doors only on the right side of the car. Specifying doors on one side of a typical articulated LRV eliminates six door panels, actuators, and associated equipment, along with the door tracks and guides, stepwells, and electrical relays. Indirectly associated equipment that can be deleted includes special entry lighting, windscreens, destination signs on one side, and outside mirrors. Materials added include additional seating, windows, baseboard heaters, and additional car body materials and paneling.

Table 2 gives the savings in vehicle first cost. These savings amount to more than \$22 000 per car. (In preparing estimates, doors were assumed to be the more expensive plug type as used on the Boeing light rail vehicle.) Operation of unidirectional cars with doors on only one side would thus save a total of \$42 000 per car.

Table 1. Cost savings estimate: unidirectional car.

	Per Car (100 cars)
Nonrecurring Cost Savings	
Engineering design time	\$ 30 000
Manufacturing and tooling	30 000
Total	\$ 60 000
Recurring Cost Savings (Increase)	
Material saved from deleting one cab:	
Instrument panels and cab lighting	\$ 565
Cab heating, air conditioning, defroster wipers and washers	1 210
Replace cab glass, visors and mirrors with standard vehicle glass	1 090
Communications panel	600
Master controller	3 750
1 set head and tail lights	100
Destination and run signs	575
Motorman's seat and console furniture	1 460
Cab enclosure and support structure	4 950
Horn and gong	225
Glare curtains	175
Sand box and sander control	740
Associated wiring relays circuit breakers and miscellaneous	2 400
Total	\$ 17 840
Materials added:	
Additional seating	(500)
Lighting fixtures and wiring	(640)
Interior paneling and trim	(750)
Total	(1 890)
Labor saved:	
Labor for component installation	1 800
Wiring installation	1 630
Total	3 430
Net Cost Savings (Increase)	\$ 19 980

Table 2. Cost savings estimate: cars with doors on one side only.

	Per Car (100 cars)
Nonrecurring Cost Savings	
Engineering design time	(4400)
Manufacturing and tooling	6000
Total	\$ 1600
Recurring Cost Savings (Increase)	
Material saved from deleting half of doors:	
Switches, valves, and tubing	\$ 300
Door panels (6)	3 600
Actuators (6)	720
Locking actuators and cams (6)	4 320
Tracks, waist rails, and trolleys	5 400
Door relay panels	800
Stepwells and windscreen assemblies	900
Lighting fixtures	390
Articulated mirror	400
Side destination signs (2)	1 000
Hardware, trim panels, and wiring	4 500
Total	\$ 22 330
Materials added:	
Baseboard heaters	(50)
Car body side skin and structure	(600)
Windows and glazing	(450)
Added seating	(450)
Interior panels and flooring	(3,200)
Stanchion bars and fittings	(150)
Total	(4 900)
Labor saved:	
Door installation and testing	3 600
Wire bundle fabrication and installation	2 000
Total	5 600
Labor added:	
Cost of installing windows, interiors, and seats	(850)
Net Cost Savings (Increase)	\$ 22 196

Impact of Operational Factors on Savings

Unidirectional cars are limited in their operational flexibility. They cannot terminate routes at switchbacks, but must continue to the more lightly patronized end of the line to turn around. This limitation can be overcome by installing turnaround loops with switches at intermediate locations along the route, provided that right-of-way is available. In performing this cost analysis, it was assumed that double turnaround loops are installed every 4 miles

along the route and that the loops are interconnected by a double slip switch so that vehicles cannot only use the loops to turn around, but can also switch to the parallel track to bypass failed equipment or permit track repairs. These double loops are assumed to replace double crossover switches installed for the same purpose on a system with bidirectional vehicles.

The cost analysis performed considers the savings per car for unidirectional cars with doors on one side, compared with the cost of increased trackwork and right-of-

Table 3. Impact of operational factors on savings from unidirectional car with doors on one side.

<u>Effect of increased vehicle capacity on fleet size</u>		
Crush capacity is increased by 12 passengers due to removal of one cab. This increases crush capacity by 5.5 percent. For a 70-vehicle fleet, 3 fewer cars are needed.		
Savings at \$700 000 per car are		\$ 2 100 000
<u>Savings on per car cost for unidirectional car</u>		
Savings are (17 800 - 1890 + 3430)		
67 + 60 000 or		\$ 1 358 460
<u>Savings on per car cost for doors on only one side</u>		
Savings are (22 330 - 4900 + 5600-850)		
67 + 1600 or		\$ 1 487 660
<u>Addition of double loops with switches</u>		
Assume 4 double loops are added. Each has one double slip switch and 4 simple split switches. Cost for switches and interlockings is estimated at \$558 000.		
Cost for extra track assuming 422 feet per double loop at \$65.53/ft is \$27 654.		
Total added cost		\$(2 342 616)
<u>Addition of simple loops at ends of line</u>		
Two simple loops added, one at each end of line.		
Total of 80.8 feet of extra track per loop at \$65.53 per linear foot.		
Total for 2 loops		\$ (10 590)
<u>Elimination of double crossover switches</u>		
Eliminate 4 double crossovers, each costing \$372 800		
Total savings		\$ 1 491 200
<u>Right-of-way-costs</u>		
Added land for double loops		20 493 ft ² each
Added land for end loops		9211.5 ft ² each
Total extra land for 2 end loops and 4 double loops		100 395 ft ²
<u>Summary of savings</u>		
Reduced fleet size		\$ 2 100 000
Reduced cost - unidirectional car		1 358 460
Reduced cost - doors on one side		1 487 660
Cost of 4 double loops		(2 342 616)
Cost of 2 simple loops		(10 590)
Elimination of 4 double crossovers		1 491 200
Total savings excluding right-of-way		\$ 4 084 114
<u>Savings Versus Right-of-Way Cost</u>	<u>Total</u>	<u>Per Car</u>
		(70 cars)
Net savings - no ROW cost	\$ 4 084 114	\$ 58 344
Net savings - ROW \$10/ft ²	3 080 164	44 002
Net savings - ROW \$20/ft ²	2 076 214	29 660
Net savings - ROW \$30/ft ²	1 072 264	15 318
Net savings - ROW \$40/ft ²	68 314	976
Net savings - ROW \$50/ft ²	(935 636)	(13 366)

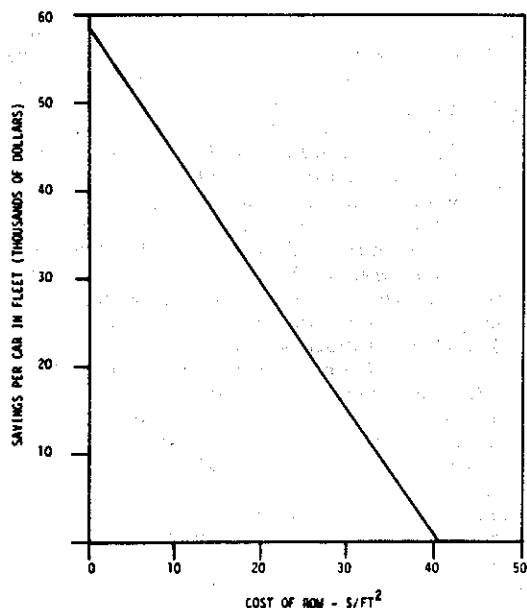
way need to provide these turnbacks. In addition, the analysis considers the reduction in fleet size made possible by the larger capacity of the unidirectional car, which is assumed to hold 12 additional passengers.

The analysis is conservative in estimating savings for the unidirectional car because it ignores the following

areas, both of which would be favorable to operation of unidirectional cars:

- It does not consider the operating cost savings that the larger vehicle capacity reflects in increased driver productivity; and
- It does not consider the reduced maintenance costs that should result from elimination of one set of vehicle controls and displays, with associated wiring and relays.

Figure 1. Net savings from unidirectional operation of cars with doors on one side, considering cost of added row.



The analysis assumes that the relative maintenance costs for the double loops and switchbacks are comparable. However, the tight curve radii for turnbacks increases wheel and track wear, thus favoring the bidirectional option.

The cost of right-of-way is a dominant factor in determining whether to purchase a bidirectional or unidirectional car. The estimate of potential savings from unidirectional operation given in this analysis is conservative. Table 3 gives the savings from a 70-vehicle fleet operating over a 40-track-mile system. Total savings exclusive of right-of-way costs are more than \$4 million, or nearly \$60 000 per car. Figure 1 shows the net savings per car as a function of the cost of right-of-way. Even with the right-of-way at \$30 per square foot, savings of more than \$1 million or \$15 000 per car appear possible.

From these savings, it would appear that localities should give serious consideration to unidirectional cars for aboveground operation.

DELETION OF ARTICULATION SECTION

Savings in Car Costs

This modification would permit cities where civil features such as curve radii are not limiting to eliminate the articulated section. Savings estimates are based on a six-axle articulated car similar to the Boeing LRV. Vehicle capacity is assumed to be the same, but the body is reconfigured to a four-axle design requiring a larger turn radius of about 125 feet. Savings would accrue from eliminating the center truck, its brake system, and the articulation assembly and associated shrouding.

Table 4 shows the savings, which amount to \$41 000 per car on a 100-car order.

Impact of Operational Factors

The minimum turn radius of a four-axle nonarticulated vehicle is 125 feet, as opposed to 42 feet for the present articulated design.

Although such cars may not be a viable option in many cases where right-of-way constraints make 125-foot turn radii impractical, an analysis was performed to get some idea of the trade-offs between land cost and vehicle savings. Vehicle capacity is assumed to be unaffected by the change. Savings from reduced maintenance associated with brakes, wheels, and articulation elements are estimated to 1.7¢ per vehicle-mile and the average vehicle mileage is estimated at 35 000 miles per year.

It is assumed that added right-of-way is required for 20 turns, formerly of 42-foot radius and now of 125-foot radius. Figure 2 shows the additional land required. The analysis assumes that all additional land required by the more gradual curve radius must be purchased, and that no credit is given for the land required by the 42-foot turn radius curve but no longer required by the wider turn.

A present-worth analysis was used to convert annual savings from reduced vehicle maintenance costs to an equivalent first cost. A 60-year period was used for the analysis, with the fleet renewed after 30 years. The total present worth of savings from vehicle costs and maintenance, but excluding costs for added right-of-way, were more than \$3.5 million, or more than \$50 000 per car (Table 5). Figure 3 shows the effect of right-of-way cost

Table 4. Cost savings estimate: articulation section deleted.

		Per Car (100 cars)
Nonrecurring Cost Savings		
Engineering design time	\$ 103 840	
Wiring design layout	16 800	
Qualification testing	134 000	
Manufacturing and tooling	100 000	
Total	\$ 354 640	\$ 3 546
Recurring Cost Savings (Increase)		
Material saved by deleting articulation section:		
Brakes		7 250
Center truck		6 346
Wheels and axles		6 000
Articulation assembly		7 304
Lighting		529
Side shrouds, wire, and miscellaneous		3 000
Total		30 429
Labor saved:		
Assembly and installation		3 411
Wiring labor		4 000
Total		7 411
Net Cost Savings (Increase)		\$ 41 386

Figure 2. Turn radius and right-of-way requirement.

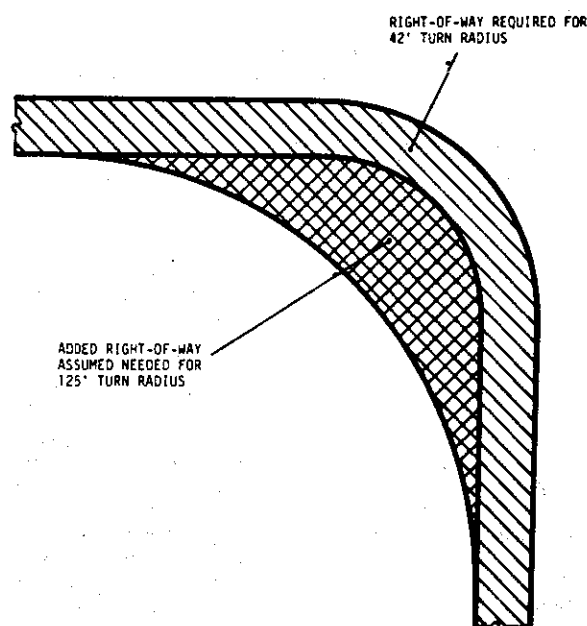


Table 5. Impact of operational factors on savings from elimination of articulation section.

<u>Savings per car from eliminating articulation unit</u>		
Savings are (30 429 + 7411) 70 + 354 640 or		\$3 003 440
<u>Savings from reduced vehicle maintenance</u>		
Assume savings of 1.7 cents per vehicle mile for 35 000 miles per year per vehicle in the fleet		
For 70 cars savings are		\$41 650/yr
<u>Added cost of right-of-way</u>		
Additional ROW for a 125 ft radius curve versus 42 ft radius curve is estimated at 2975 ft ²		
For 20 turns the row required is increased by		59 500 ft ²
<u>Present worth of savings</u>		
(Land at 60 years, vehicles at 30 years)		
Present worth of land	59 500 x (cost/ft ²)	
Present worth of maintenance (60 years at 10 percent)		\$415 134
Present worth of car savings		
First car order		\$3 003 440
Second car order		172 127
Total present worth less land		\$3 590 701
<u>Present worth of savings versus ROW cost</u>		
	<u>Present Worth of Savings</u>	
	<u>Total</u>	<u>Per Car (70 cars)</u>
No ROW cost	\$ 3 590 701	51 296
ROW \$10/ft ²	2 995 701	42 796
ROW \$20/ft ²	2 400 701	34 296
ROW \$30/ft ²	1 805 701	25 796
ROW \$40/ft ²	1 210 701	17 296
ROW \$50/ft ²	615 701	8 796

on the present worth of savings per vehicle in the fleet. With right-of-way at \$30 per square foot, savings of more than \$25 000 per car are possible. Even with right-of-way at \$50 per square foot, savings are more than \$8 500 per car.

In conclusion, it appears that serious consideration should be given, especially for new light rail installations, to designing the right-of-way to accept large, nonarticulated cars.

RESISTOR VERSUS SOLID STATE PROPULSION CONTROL

Chopper propulsion systems are currently more expensive than the traditional resistor controls, and the cost of the entire propulsion system can be from \$10 000 to \$30 000 more when chopper control is used. Energy consumption is not significantly better for the chopper if dynamic braking is used because the added weight of the chopper system compensates for its more efficient voltage control. For example, comparisons of weight differences for cam versus chopper control for the state-of-the-art car showed the chopper could increase car weight by almost 1000 pounds.

If regenerative braking is used, then the chopper controller can achieve a significant energy savings over resistor controls. Over typical urban routes, energy savings of 15 to 25 percent are possible.

Maintenance costs for chopper and resistor controllers can also be different because of differing failure modes and personnel skill levels. In addition, the different reliability of the two systems can mean that a different number of cars may be required to obtain the same number of cars available for service.

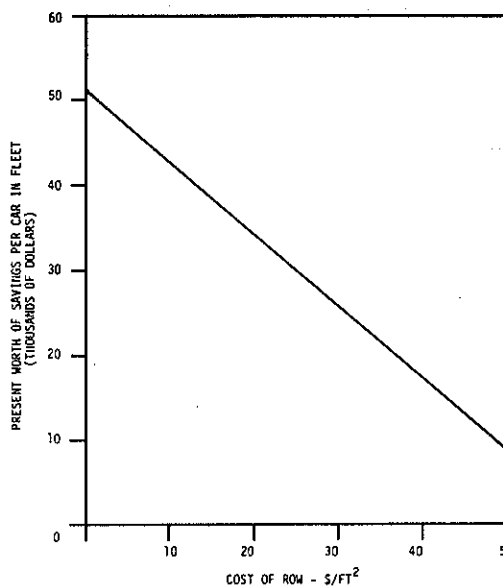
N.D. Lea and Associates (LEA) developed a life-cycle cost equation that can be used to determine whether to specify resistor or thyristor controllers. The life-cycle cost equation for life-cycle cost analysis of a rail car propulsion system is as follows:

$$PW_j = P_{O_j} + C_{S_j} + N_j P_j + A_{E_j}(d_E) + d(A_{PM_j} + A_{CM_j} + A_{RP_j}) \quad (1)$$

where:

PW_j = present worth of life-cycle costs from

Figure 3. Net savings from eliminating articulation joint, considering cost of added row.



propulsion system alternative j for the total number of vehicles in the purchase,

P_{O_j} = present worth of other costs and benefits associated with alternative j but not otherwise included in this equation,

N_j = total number of vehicles in purchase with propulsion alternative j ,

P_j = purchase price of propulsion system j ,

A_{E_j} = energy cost per vehicle per year for alternative j ,

A_{PM_j} = cost of preventive maintenance per vehicle per year for alternative j ,

A_{CM_j} = cost of corrective maintenance per vehicle per year for alternative j ,

A_{RP_j} = cost of replacement parts per vehicle per year for alternative j ,

C_{S_j} = cost of extra spare cars less the propulsion systems required for alternative j ,

d_E = present worth discount factor adjusted for energy price escalation, and

d = present worth discount factor for nonenergy recurring costs.

LEA also recommends language for specifying propulsion systems and evaluating bids, including both chopper and resistor-controlled propulsion equipment.⁶

GUARANTEE/WARRANTY/RELIABILITY

Members of the manufacturing and supply industry have complained that guarantee/warranty and reliability (GWR) clauses are becoming too restrictive and are having adverse financial effects on the supply industry.

Analysis of past rail car contracts and discussions with both transit operators and suppliers support the claim that GWR provisions have been made more restrictive than in the past. More importantly, both the buyers and suppliers have generally not participated in drafting GWR terms and conditions, and adversary roles have developed. The costs of GWR requirements are difficult to pinpoint, since they encompass not only the cost for warranty provisions and associated risks, the costs of engineering and implementation of reliability requirements, but also costs associated with reconfiguration, redesign, or replacements of components that may be affected by certain GWR requirements.

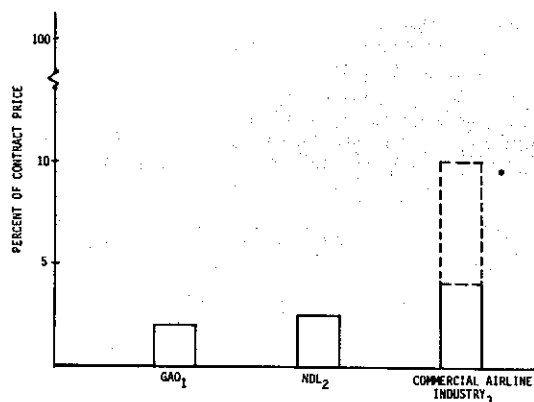
In a cost study performed by LEA for UMTA on the standard LRV specification² estimates for warranty and field service amount to 2.5 percent, and estimates for potential savings from simplifying reliability requirements (by deleting the 2-year demonstration and reliability analysis and substituting warranty provisions) amount to 1.8 percent. Thus overall costs of GWR requirements are estimated at 4.3 percent of the purchase.

In a report by the GAO,⁶ a conservatively estimated figure of 2 percent is mentioned based on a survey of 35 contractors by the Defense Contracts Audit Service in February 1979. It must be assumed that not all of these contractors were rail car builders and that the estimate does not necessarily include reliability requirement costs.

A quick telephone interview of five car builders/system suppliers in May 1980 provided estimates similar to those by LEA and GAO. Higher figures are quoted in the airline industry,⁷ where warranty costs range from 4 to 10 percent of purchase cost per year of warranty. These estimates are shown on Figure 4.

There has also been concern that increased warranty periods have caused escalation in car prices. In July 1975, Pullman-Standard gave UMTA the following response to this hypothesis: (a) Longer warranty periods on the car structure are less significant (by a ratio of approximately

Figure 4. Cost estimates of warranty contract terms.



*NOTE: AIRLINE INDUSTRY ESTIMATE IS A PERCENT OF CONTRACT COST PER YEAR.
SOURCE: REFERENCES 7, 8, 9

1 to 15) than longer warranty periods on all parts of the car; and (b) Impact (in 1975 dollars) of the warranty period on all parts of the car is as follows:

- 1 year—base price, no impact
- 3 years—\$15 000 extra per car
- 5 years—\$35 000 extra per car

By using the Consumer Price Index to convert a January 1981 (factor of 1.62 over 1975) dollars, the impacts would be:

- 1 year—base price, no impact
- 3 years—\$24 000 extra per car
- 5 years—\$57 000 extra per car

There apparently are opportunities to reduce GWR costs through careful preparation of terms and conditions. The transit authority should not buy more than it needs, whatever is bought must be paid for—and the result is a more expensive car.

APPLICATION TO AN ACTUAL CASE

In 1979, LEA was asked by UMTA to review the proposed Niagara Frontier Transportation Authority (NFTA) light rail specification to ensure that the level of complexity was compatible with the actual transportation requirement.

NFTA had required articulated vehicles because of their greater carrying capacity. However, articulated vehicles offer greater capacity only when compared with smaller cars. The LEA review indicated that a nonarticulated car with a similar carrying capacity would be practical. Front overhang on curves could be solved by tapering the front end of the car as is done on the Boeing LRV. The remaining problem was the chording on the inside of curves. Sketches showed that a 70-foot nonarticulated car would require only an additional 1.57 feet on the inside of a 100-foot radius curve. As there were relatively few tight radius turns on the route, NFTA decided to permit large nonarticulated cars to be bid to see if there would in fact be a cost savings. The low bidder was Tokyu Car Corporation, which bid \$21.8 million for 33 cars. The lowest bid for articulated cars was from Siemens, which bid \$25.2 million for 27 cars. (The nonarticulated cars were slightly smaller.) NFTA's savings amounted to \$3.4 million. It saved money by not buying what it did not need. Not only were the cars cheaper, but NFTA now has 60 fewer wheels to grind and 60 fewer brakes to overhaul for the life of the cars. Maintenance of 27 articulated joints has also been eliminated, and car traction has been enhanced on grades.

REFERENCES

1. N.D. Lea and Associates, Inc. A Guideline Specification for Procurement of Light Rail Vehicles. Washington, D.C., May 1981.
2. N.D. Lea and Associates, Inc. Cost Savings Potential of Modifications to the Standard Light Rail Vehicle Specification. UMTA-MA-06-0025-79-11, February 1979.
3. De Leuw Cather and Company. Light Rail Transit, A State of the Art Review. NTIS PB 256-821, 1976.
4. N.D. Lea Transportation Research Corporation. Lea Transit Compendium, Light Rail Transit, Vol. II, No. 5. Huntsville, Alabama, 1975.
5. N.D. Lea and Associates, Inc. Proposed Analysis Methodology for Railcar Propulsion System Selection. Washington, D.C., April 1980.
6. U.S. General Accounting Office. Transit Equipment Warranties Should be Enforced. GAO Report No. PSAD-80-12, December 1979.
7. Review of Commercial Airline Acquisition Methodology (CAAM).

Factors Affecting Rail Car Costs

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Five major factors affect light and rapid rail car prices: (a) inflation, (b) market conditions, (c) technical aspects, (d) procurement and contractual practices, and (e) financial condition of the supply industry. Except for general inflation, most of these factors, particularly in the technical and contractual areas, are controllable to some degree by agencies purchasing rail equipment.

Many people in the transit industry and government are concerned about the dramatic increase in rail car prices. The light or rapid rail car that cost \$150 000 to \$200 000 in 1970, for example, may now cost \$1 000 000. Two questions should be asked: (a) Have light and rapid rail car prices increased faster than the dramatic inflation of 1970-1981? and (b) Are rail car prices controllable? These questions are examined below.

INFLATION

Over the past decade, the transit industry, along with other sectors of the economy, has suffered from the effects of inflation. Figure 1 shows the escalation of rail transit car prices over the years. Inflation, as measured by the Consumer Price Index, has raised prices 250 percent since 1967. However, the General Rail Equipment Index shows rail car prices increasing more than 330 percent over this same period. Some of the increase in rail car prices may be attributable to general inflation, but almost half is clearly due to other factors.

In an inflationary period, where "time is money," a delay in any step of the procurement process has a negative effect (for the buyer) on bid prices. Costs of labor, materials, and overhead are rising constantly, and inflation will continue to take its toll on rail car costs.

MARKET CONDITIONS

Rail cars are largely custom designed for individual rail operators. Units are built in varying production runs, which have ranged in recent years from 14 units for the San Diego light rail to 754 units for the New York City Transit Authority rapid rail.

The market for light and rapid rail cars has been on the order of 300 to 400 cars per year. In terms of the domestic industry, where some items are produced in quantities of hundreds of thousands or millions, the rail car market is very small in quantity, but large in dollar cost per unit. The market has been characterized by a feast-or-

famine cycle, with orders coming in bunches during certain periods. This irregularity of demand is reflected in prices, since production facilities and a core staff of skilled people are usually maintained in an active status even in periods of low production.

In terms of traditional economic supply and demand curves, large orders should result in significant competition among bidders. However, competition for small light rail car orders has been great, while competition for rapid rail car orders has been considerably less (see Table 1). The large capital requirements, perceived technical and contractual risks, and long delivery times associated with large procurements may have contributed to the decline in competition for large orders. On the other hand, foreign-based winners of light rail procurements, such as DuWag, continually build small production runs of relatively standardized equipment. (Procurements affected by the domestic assembly requirement of the UMTA Buy-America regulation for UMTA-funded procurements are not included in this group.) These firms are geared up for orders of 20 to 50 units and are therefore able to bid competitively for small orders, if the specifications do not require a new design. Recent light rail car procurements in San Diego, Buffalo, and Portland were based on in-production models.

The sequencing of orders has an effect on car prices. Recently, there has been a remarkable clustering of orders. In Chicago, Cleveland, Philadelphia, Atlanta, San Diego, Miami, Baltimore, Buffalo, Portland, and New York, transit agencies have all called for bids or placed orders in the past several years. This bunching of orders for different cars gives prime bidders and subcontractors minimal time to review specifications, seek cost estimates from vendors, and make the detailed technical analyses necessary to respond to bid documents. The time compression leads to added insurance costs for unknown conditions or risks.

Most orders are for a limited number of cars. The lack of assurance that there will be follow-on orders for similar cars contributes to high car prices. (In the past, a few orders have carried large options, such as CTA's order in 1978 for 300 rapid transit cars, with an option for an additional 300 cars.)

Bid timing and funding assurance also affect car prices. In an inflationary period, delays in the grant and multistage procurement process escalate costs. Funding should be timed so that local, state, and federal shares are all available at the appropriate time, and prime bidders must be given assurance that procurement will occur in a timely manner.

Figure 1. Cost of railcars compared with various economic indices.

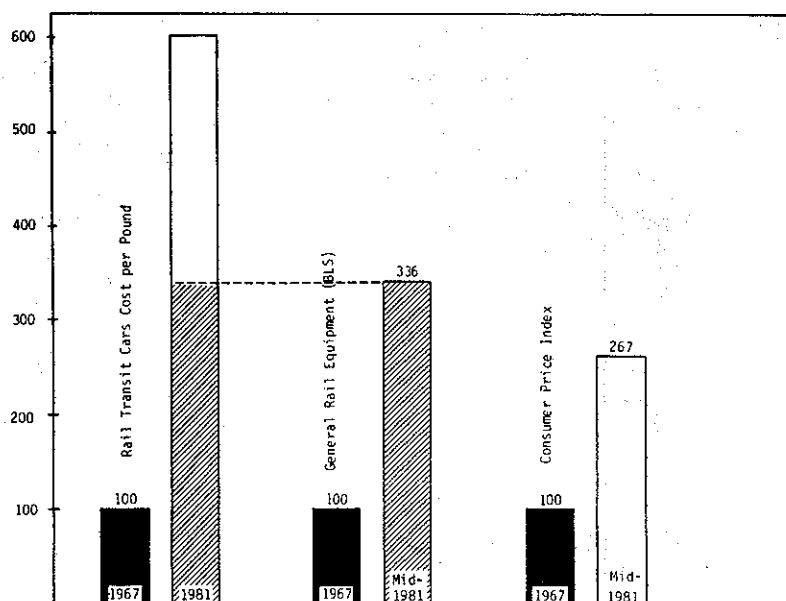


Table 1. Competitive rail car purchases.

Year	Authority	Number of Cars	Number of Bidders
Rapid Rail Cars:			
1970	PATH	46	3
1972	NYCTA	752	4
1972	WMATA	300	4
1974	CTA	100	2
1976	MARTA	100	2
1976	MBTA	190	2
1978	MDC/MTA	136/56	1
1978	CTA	300	3
1979	WMATA	94	3
1979	Philadelphia	125	4
Light Rail Cars:			
1973	MBTA/MUNI	230 ^a	5
1977	GCRTA	48 ^a	10
1979	SEPTA	141 ^a	6
1980	NFTA	30 ^a	9
1981	TRI-MET	26 ^a	2

^aOriginal order; not including option.

TECHNICAL ASPECTS

There is no single technical factor that determines car prices; rather, a number of factors, such as specification type (i.e., level of detail), car design, and degree of standardization, combine with the contractual terms and conditions to result in a final bid price.

Specification Type

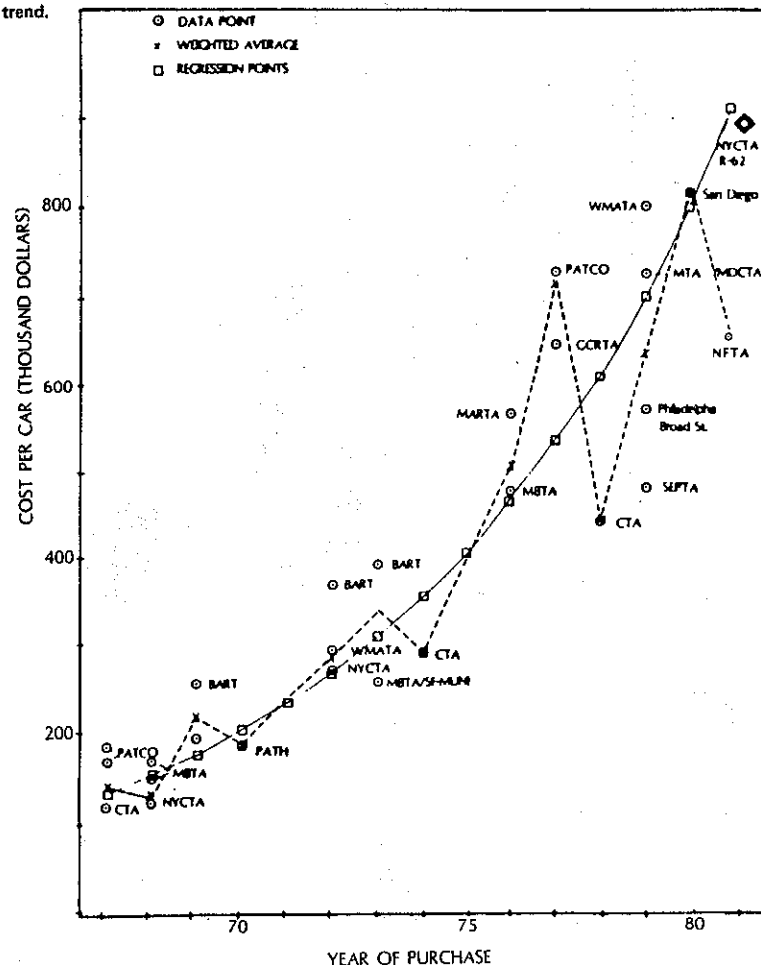
Figure 2 shows car purchase prices for various systems over time, with weighted average by quantity. The trend line is an average for the population of all cars. The more sophisticated cars with some degree of automation and/or electronic propulsion are above this trend line. All these

cars, except those for PATCO, were produced from performance-type specifications.

Figure 3 shows the escalation of car costs per pound for similar cars purchased by the same authority in different years. The lines on Figure 3 are remarkably parallel, which suggests that the car price escalation rates have been consistent over a large number of procurements.¹ This indicates that the factors causing price escalation are not specific to any one authority or any one car design, but have affected the whole industry uniformly.

Two specification types are used in rail car procurements: (a) performance and (b) detail or hardware. Performance specifications, the type preferred by car builders because of the greater design flexibility they allow, are generalized descriptions of the rail car to be purchased.

Figure 2. Rail transit car cost trend.



Sometimes performance specifications may be very short, providing only a minimal outline of a system's fixed facilities, to allow a car already in production to be offered. Performance specifications are frequently used for newer systems without lengthy operating experience. Detailed specifications, frequently used by older rapid rail systems, usually consist of specific hardware and component designs. They are most often used where new cars must be made compatible with existing cars.

Car Technical Details

In preparing technical specifications, a purchasing agency must make a number of trade-offs on technical features of the vehicle. Each of these technical features will have an impact on initial and operating costs. In a study of the Massachusetts Bay Transportation Authority/San Francisco Municipal Railway joint light rail car specifications, a number of technical and contractual changes were cited that could reduce the purchase price by approximately 10 percent on a potential 100-car order.² These changes included the following:

- Deleting plug doors and substituting folding doors,
- Simplifying the control system,
- Simplifying qualifications testing,
- Simplifying documentation requirements,
- Relaxing car body smoothness criteria, and
- Simplifying the articulation section.

Other technical details also have potential for affecting costs; cars could be designed with doors on one side

versus both sides, with one cab versus two operating cabs, or as an articulated or a rigid unit.

The articulation joint and extra truck may add \$100 000 to the initial car cost. However, articulated cars may provide significant operating savings if fewer articulated cars can provide the same seating capacity as nonarticulated cars. Such technical trade-off decisions made during the specification development process optimize system performance and influence both initial and operating rail car costs.

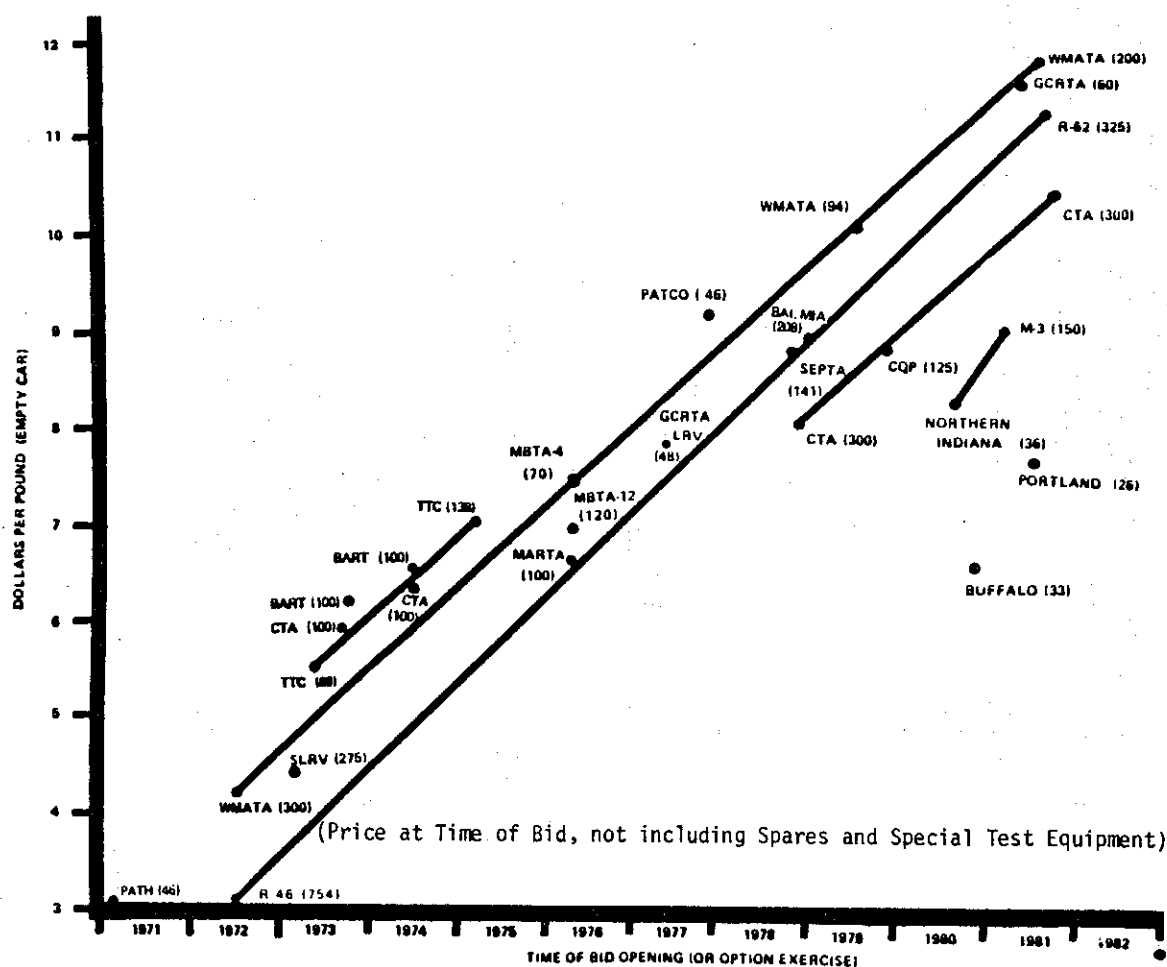
Standardization

Standardization is another important (and controversial) technical factor that has the potential to reduce car prices. However, in the past, light rail design has resisted standardization. As D.S. Hellewell concluded from an analysis of 16 light rail vehicle designs in 1977³,

It is remarkable . . . that in spite of attempts to lay down standards for new tramcars in several countries—notably West Germany—and the existence of so-called "standard" products from the small number of specialist tramcar builders, no true standard designs have emerged suitable for . . . light rail operation.

Certainly in the United States, no single design such as that for the PCC car of the 1930s has been adopted. However, it is increasingly clear from early light rail experience in Boston that equipment with proven reliability and operational experience is being specified by buyers of

Figure 3. Transit railcar procurements, 1971-1981.



light and rapid rail cars to ensure initial reliable operation.

Car prices reflect the degree of standardization at the subsystem, subsystem interface, and general performance levels. If standard products of several manufacturers can be used widely, not only will initial car order prices show benefits of price competition, but an assured market for replacement parts will benefit purchasers by making parts available at competitive prices. Standardization in the maintenance area will help stabilize or lower operating costs by reducing spare parts inventory, ordering lead times, and training time for maintenance personnel. Savings resulting from reduced inventory and lead time for parts reordering could be \$5.9 million per year.⁴ Unfortunately, with the exception of the Siemens-DuWag U-2 car used in San Diego, Calgary, and Edmonton, domestic light rail cars ordered recently (Portland, Buffalo, and Cleveland) are quite different in design and subsystem configuration. As a result, their unit prices vary widely: Cleveland, 48 LRVs (1977), \$645 000; Buffalo, 33 LRVs (1981) \$660 600; and Portland, 26 LRVs (1981), \$775 521. This amount does not include spare parts, special tools, and training, which, when included, add \$57 940 per car.

PROCUREMENT AND CONTRACTUAL PRACTICES

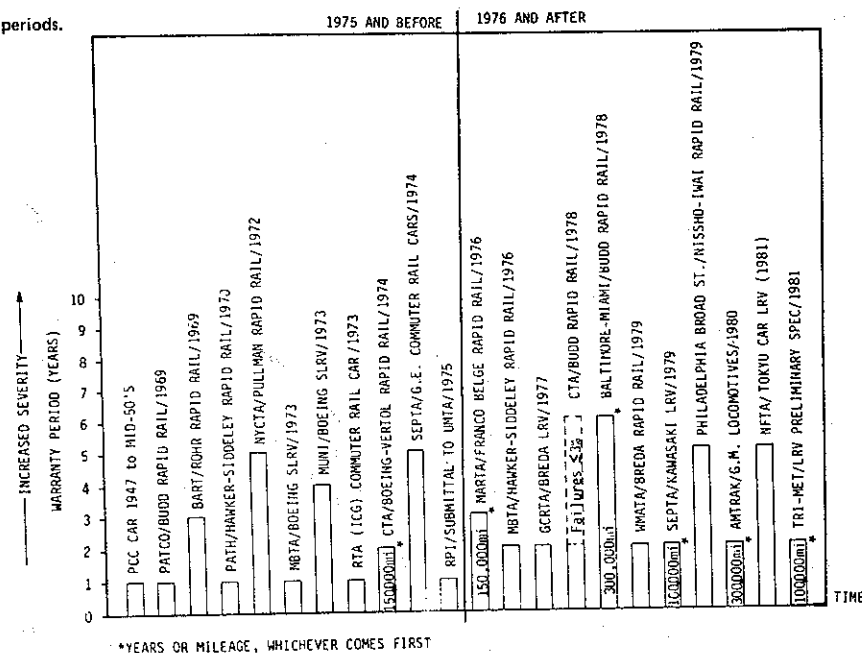
In the mid-1970s, the supply industry initiated a campaign against what were considered inequitable contractual terms and conditions offered on rail car bid documents. Suppliers believed that a number of clauses, notably those covering authority of the engineer, progress payments, escalation, guarantees, and indemnification, were weighted

unfairly in favor of buyers. A dialogue with operators and suppliers conducted by UMTA in response to supplier complaints resulted in issuance of the Special Guidelines for Rail Transit Equipment Procurements in 1978. These procurement guidelines were intended to clarify and improve some of the more commonly used clauses in rail car contracts. Guaranty and warranty clauses, however, were not included in the special guidelines because of the difficulty, complexity, and controversy surrounding this important contractual area. (The terms guaranty and warranty have different legal meanings, but are frequently used interchangeably in the transit industry.) A study of warranty clauses (see Figure 4) performed for UMTA⁵ shows that warranty periods for transit and locomotive motors differ dramatically in time and/or mileage. There has been a noticeable trend toward increasing warranty periods in rail car procurements—which has resulted in increased bid prices.

It has been estimated that 2.5 percent of the car purchase price is for warranty and field support and that reliability requirements add another 1.8 percent.² Thus, an estimated total of 4.5 percent of the car price is related to guaranty, warranty, and reliability contractual provisions. Such provisions are a necessary part of any equipment purchase, but careful structuring of these clauses may result in a modest cost reduction without a sacrifice in quality.

Clarity of items in contracts (such as definition of failure) has important cost implications. Unclear contractual language can lead to unproductive legal or administrative disputes and claims. Procurement practices

Figure 4. Propulsion motor warranty periods.



and contractual language are receiving increased attention in the transit industry as areas that directly affect car prices.

FINANCIAL CONDITIONS

Interest rates have a direct bearing on car costs. Although interest rates are not controllable, equitable progress payments can help builders meet interest payments. Timely payments are particularly important in the pre-production stages of a car order, when tooling is being ordered and parts stockpiled. Profit on previous orders is important to prime and subcontractors; a good experience on a past order will keep a company active and competitive in the future.

SUMMARY

There are five major factors that have an impact on car prices:

- Inflation,
- Market conditions,
- Technical aspects,
- Procurement and contractual practices, and
- Financial conditions.

Inflation and the financial condition of suppliers as it is affected by interest rates are the least controllable factors. But the other factors can be to some degree controlled. From Figure 1, it is clear that much of the escalation in rail transit car prices is not due to inflation, but rather to some combination of these other controllable factors. Figure 3 shows that price escalation is not a problem of only one authority or related to a single car design. The rise in cost is uniform: Every rail transit car purchase in the past 10 years has been affected to almost the same degree. If the factors driving noninflationary escalation are understood and controlled, significant cost savings can be realized on future rail car procurements.

Many persons with different professional expertise (attorneys, procurement specialists, engineers, operations specialists, maintenance directors, etc.), within and outside

of a transit authority, are involved in preparing rail car specifications. Therefore, optimization of car design depends to some extent on "who's in charge." The large number of technical and operational trade-offs necessary in specification development will shape the rail car design, performance, and maintenance characteristics and will ultimately be reflected in initial and operating costs. Decisions on contractual provisions, particularly the guaranty and reliability provisions, will reflect the degree of risk in the car design and will be reflected in bid price through built-in insurance costs. In some cases, transit authorities have capitalized maintenance costs by using extended (or special) warranties.

The million-dollar rail car is now a fact of life. The extent to which future bid prices will be above or below that figure will be determined by how effectively the specification writer approaches the complex factors described in this paper.

REFERENCES

1. Lawrence Colman. (Intransco). Letter to Jeffrey G. Mora, October 23, 1981.
2. T.J. McGean, C.P. Elms, F.A.F. Cooke, and W. Bamberg. Cost Savings Potential of Modifications to the Standard Light Rail Vehicle Specification. N.D. Lea and Associates, UMTA-MA-06-0025-79-11, February 1979.
3. D.S. Hellewell. Time to Standardize LRT Car Designs. Railway Gazette International, May 1977, Vol. 133, No. 5.
4. T.J. McGean, D.B. Eldredge, W.H. Frost. Benefits of Railcar Standardization. N.D. Lea and Associates, UMTA-IT-06-0229-82-2, 1982.
5. D.B. Eldredge and C.P. Elms. A Study of Transit Railcar Guaranty, Warranty, and Reliability Contractual Provisions. N.D. Lea and Associates, UMTA-IT-06-0229-81-1, 1982.

Part 4

Operating Strategies and Issues

Self-Service Fare Collection: Getting There from Here

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For many years, conventional wisdom in the transit industry has been that self-service fare collection (SSFC) may be fine in Europe, but "it won't work here." Meanwhile, SSFC has spread to the extent that it has become almost universal in western Europe (outside Britain). At the same time, the concept is being applied in increasingly diversified forms to meet the different requirements of individual transit agencies or to conform to the constraints of local social or legal requirements. This diversification is important because it reemphasizes that SSFC is a concept of fare collection rather than a system based on a particular type of equipment or operating configuration, which is particularly relevant when considering SSFC in the U.S. context. This paper describes how Tri-Met decided to switch to SSFC and will institute it on its 600-bus system in the fall of 1982.

During this same period, conditions in North American transit have changed. High-technology fare collection systems have proved costly and not particularly reliable, and there is a growing need to operate the new articulated buses and light rail vehicles more efficiently. There are problems with fare equity, revenue loss, and dollar bills clogging fareboxes. Intermodal transfers, the control of revenue loss, and the need to improve passenger convenience have become important transit goals. Together, these factors have begun to put pressure on North American transit agencies to search for better ways to collect fares and to reexamine ways to avoid the constraints imposed by traditional farebox and barrier-type systems. Tri-Met, the transit agency for Portland, Oregon, is no exception.

DEVELOPMENT OF THE SELF-SERVICE FARE COLLECTION PROGRAM

Selection of LRT

In August 1978 the Tri-Met Board adopted a plan to build Tri-Met's first light rail transit (LRT) line in the Banfield Corridor. Implicit in that decision was that the LRT would use self-service for fare collection. During the subsequent preliminary engineering, the advantages of SSFC were reaffirmed and documented. In particular, SSFC was estimated to save approximately \$1.1 million in system capital costs and some \$400 000 annually in operating costs, compared with the use of the traditional farebox collection system. Barrier fare collection is not practical on Tri-Met's LRT.

1979 Fare Policy Study

In 1979, as part of the preparation of a 5-year Transit Development Plan, Tri-Met staff performed a fare policy study to investigate future fare collection options. The main focus of that study was whether to proceed with the SSFC recommendation and, if so, when and how. Options examined included adoption of SSFC on the light rail only, adoption of SSFC systemwide, and continuation of the traditional system of fare collection without any SSFC. Particular effort was focused on problem areas, such as how to phase in a fare collection change on an existing transit system, enforcement, and the avoidance of undue legal or financial risk.

Among the main conclusions of the fare policy study were the following:

1. The present method of fare collection would increasingly impede smooth, efficient transit operations during the coming decade. There is no such thing as a perfect system of fare collection. The choice lies between a succession of palliative measures that can, at best, relieve the most pressing problems associated with today's fare collection or, alternatively, a bold move requiring substantial effort and perhaps some risk to reform the fare collection system to best match and exploit the changes that will be taking place in Tri-Met's operations by adopting self-service fare collection.

2. A phase-in plan can be devised for introducing SSFC a few lines at a time in such a way that legal and financial risks can be minimized. Incremental phase-in of SSFC is frequently used in Europe, particularly in France. Legal risk is minimized because the system could still revert to the present system of fare collection overnight in the event of a challenge, and financial risk is minimized because only a small percentage of the system is initially exposed to an increased risk of fare evasion.

3. Self-service fare collection can substantially improve existing bus operations, particularly on the new articulated buses; therefore, if it is to be implemented at all it should be implemented as soon as possible. Early implementation would also enable Tri-Met to thoroughly shake down the system and address problems before LRT construction was completed. The risk of designing LRT around SSFC was thereby eliminated.

4. UMTA was interested in supporting a demonstration of SSFC, and Tri-Met could become a leading candidate for demonstration funding.

On the basis of this study, self-service fare collection was incorporated into the 5-year Transit Development Plan, and applications for funding SSFC were initiated.

Organization

With the partial approval of project funding in September 1980, the project moved into the implementation phase. Because SSFC affects every facet of a transit agency, it was first necessary to establish an interdepartmental committee charged with overseeing all aspects of the work, representing the interests of each department, and making recommendations where appropriate on technical details of the project. Subcommittees were assigned to cover details in the following areas: fare structure; fare and schedule outlets; on-board equipment and retrofit of rear doors; legal concerns; fare inspection; records, billing and collection; operations; public information; and evaluation study.

This structure has provided a forum for the discussion and analysis aspects of the project affecting several departments and has enabled the work to proceed with a high degree of interdepartmental cooperation.

Preliminary Plan

The plan to introduce self-service envisaged a succession of phases. In the initial phase limited self-service (with drivers continuing to monitor fares and therefore requiring front door entry) would be used to minimize changes in passengers' habits and the risk of fare evasion. Once this system had become established, successive phases would provide a gradual transition to full self-service, under which entry and exit would be permitted through all doors of the vehicles. Both driver-monitored and full self-

service would have the following features:

- Passengers would be required by local ordinance to possess a valid ticket or pass when traveling on Tri-Met vehicles.
- Passengers traveling without a pass would complete their fare transaction immediately on boarding either by paying a cash fare and obtaining a receipt or by validating a multi-ride ticket.
- The farebox would be retained for fare payment since it exists and is fairly efficient, but the percentage of passengers using the farebox would be reduced in order to avoid issuance of excessive numbers of fare receipts. This would be achieved by selling discounted multi-ride tickets off the vehicle. These tickets require validation at the start of a trip.
- Fare collection would be enforced by fare inspectors who would check tickets on a random basis and collect surcharge fares from passengers traveling without a valid ticket or pass.

Final Implementation Plan

As the project implementation proceeded, Tri-Met management became increasingly comfortable with the concept of self-service fare collection and questioned whether the additional steps inherent in the phased approach were necessary. After extended debate, it was concluded that the greater simplicity of a single one-time switch to systemwide full self-service more than outweighed the benefits of the more cautious phased-in approach. Accordingly, the original plan was revised to provide for full systemwide conversion to self-service without interim phases. This change had no effect on the on-board equipment, which was required for either driver-monitored or full self-service, but it does require an additional outlay in fare inspection. On the other hand, the benefits anticipated for full SSFC will, accordingly, be realized sooner.

Fare Structure Revision

One consequence of self-service fare collection is the opportunity to revise the fare structure. Since the revision of a fare structure, particularly changing of fare zones, is a complex marketing undertaking, there are advantages in combining it with the change to SSFC. The two major issues were (a) how to structure the methods of payment to reduce farebox use, and (b) what zone adjustments, if any, should be made.

Reduction of farebox use is an essential feature of SSFC since reduction of boarding times cannot be achieved if too many passengers continue to use the farebox. Accordingly, two alternative methods of payment, both of which avoid driver interface, are offered: a 10-ride multi-ride ticket, good for an indefinite time period, which requires validation with date, time, and zone for each trip; and passes, similar to those in use now, which are good for an unlimited number of trips over a fixed time period. Tri-Met adopted a target of 15 percent farebox use, 30 percent multi-ride ticket use, and 55 percent pass use. To encourage a switch to this fare structure, the cash fare will be raised, thereby increasing the discounts for the alternative methods of payment.

Tri-Met at present operates a 3-zone fare system, charging 2 different zone fares. Some routes are more than 20 miles long, and the public at various hearings has repeatedly requested that Tri-Met introduce additional fare zones to avoid having short-distance riders subsidize the longer trips.

Because with SSFC the on-board fare collection equipment will provide an automatic record of the zone in which all passengers board the bus, the present restriction on the number of fare zones (delays to service and enforceability)

is removed. With no restriction on the number of fare zones, Tri-Met had to decide how many zones best met its policy and revenue needs. Alternative circumferential and cellular zone systems were studied, and it was concluded that, although the cellular system was the fairest, since all fares were closely related to distance, Tri-Met had insufficient crosstown ridership to justify the increased complexity. In addition, any fare benefits to crosstown riders arising from a circumferential fare zone system were supportive of the agency's goal of diverting trips from radial to crosstown trips wherever applicable. Accordingly, a 5-zone system with 3 zone fares was recommended.

Project Schedule and Status

As the project proceeded to implementation, the start-up date was postponed from March to September 1982 to better coordinate with service improvements. Start-up was scheduled for September 5, 1982.

As of March 1982 all of the on-board equipment (validators and ticket dispensers) had been ordered, and delivery, installation, and testing had begun. Work was also starting on the modification of bus rear doors to enable passengers to board through either door. The selection and training of fare inspectors was in progress, and the supporting fare ordinances had been drafted.

Plans have been developed for a major public information program including training for all Tri-Met staff and operating personnel, as well as the riding and non-riding public.

REASONS FOR SELF-SERVICE FARE COLLECTION

Much of the early impetus for the SSFC program came from the LRT project. However, as understanding of SSFC at Tri-Met increased, it became possible to develop projections for the economic impact of SSFC on both light rail and bus operations. A better appreciation of the pervasive and generally beneficial effect of SSFC throughout the system also began to emerge.

The kinds of benefits were identified—nonquantifiable benefits, such as increased passenger convenience, reduced driver stress and work load, or improved system security; and quantifiable benefits, such as savings in bus-hours or new revenue to which a dollar amount can be attached. Some of these benefits require additional action by Tri-Met beyond the implementation of self-service, such as the procurement of future buses with double doors, the re-scheduling of lines to capture time savings, and the deployment of high-capacity equipment on lines where this equipment is warranted. The principal benefits that Tri-Met expects to derive from SSFC are summarized below.

Speed-Up of Existing Bus Operations

Part of the SSFC program calls for retrofitting the rear doors of buses to permit passengers to enter through them. This will reduce the time required to load, particularly at busy stops such as transit centers and during the peak period. Retrofitting for rear boarding will provide 2-door streams on standard buses, enabling them to better match the loading speed of the 5-door-stream articulated buses.

Effective Operation of Articulated Buses

Self-service fare collection enables Tri-Met to derive the fullest benefit from its investment in articulated buses. For instance, on the Mall, the traffic signals operate on a progression. If a bus can load fast, it can travel down the Mall catching each of the traffic signals. However, if the loading time is more than about 15 seconds, the bus will miss each signal. Thus, a few seconds' increase in loading time is multiplied several times by the delay at each traffic signal. If the articulated buses are operated without self-service, they not only will accelerate slower,

a characteristic of these vehicles, but also will load slower. In doing so, they will also delay all other buses using the Mall, leading to a substantial loss in total system capacity. With self-service, however, the articulated buses will load faster than the standard buses, and Mall capacity will be preserved and probably increased.

In addition, self-service permits the effective deployment of articulated buses on the heaviest inner-city routes. Such routes, generally characterized by large numbers of passengers loading and unloading, are traditionally considered unsuited for articulated buses in the United States because they are used without SSFC. However, these routes are also those on which the improved productivity and greater schedule reliability can be deployed to the greatest economic benefit.

Improved Schedule Adherence and System Productivity

A bus running late will pick up an additional passenger load. This in turn will make the bus later still, thereby destabilizing service (bunching). With SSFC and boarding through all doors, late buses will not incur the same proportionate delay, and so there will be less tendency for buses to bunch. In addition, the greatest effect of faster operation of both articulated and standard buses will occur during the peak periods when present loading delays are most noticeable. If buses can be operated faster during peak periods, the capacity of the system is increased. Since the total fleet is sized for the peak hour, an increase in fleet capacity during the peak would permit the same passenger load to be carried by fewer vehicles, with a net capital and operating savings.

Effective Operation of LRT

The LRT plan is based on the use of trains of large (88-ft) vehicles, loading from the street. Each 2-car train has 16 door streams. Erecting fare barriers at on-street stations would be expensive and in any case unacceptable. Farebox fare collection would be so slow that each trip would take several minutes longer. Zone fares would be impractical. More cars would be required to maintain system capacity, and operators would be required on trailing cars for the sole purpose of collecting fares. Not surprisingly, SSFC has been adopted on the new LRT systems in Edmonton, Calgary, and San Diego, as well as on all LRT systems in Europe.

Expense of Farebox Replacement

When Tri-Met's zone 3 fare reaches \$1.00 later this year, the ability of fareboxes to accept dollar bills will become a major problem. Not only do Tri-Met's existing farebox vaults have a capacity of only about 60 dollar bills, but the bills have a tendency to jam the farebox. Torn bills are sometimes presented, resulting in lost revenue and increased money-room costs. Self-service fare collection, by reducing the percentage of fares paid into the farebox to less than one-third of their present volume, will enable the existing fareboxes to continue in service and the drivers to deal with the bill problem by requiring bills to be presented unfolded, if necessary, without significant delay to service. Recent experience by other properties that have replaced their fareboxes with electronic fareboxes capable of accommodating dollar bills has shown that the capital costs incurred by Tri-Met in switching to self-service are no greater than the costs other properties are incurring by replacing their fareboxes and vaults.

Increased Fare Equity

As fares increase, Tri-Met, like most properties operating over a large geographical area, is finding it desirable to make the fare more closely reflect the length of trip. This can only be achieved by use of a zonal fare system. In 1978 Tri-Met switched from a flat fare to a 2-fare zone

structure. However, under increasing fiscal pressure, this is not proving sufficient. Although the fare for the long-distance trips on the system is still less than it was 10 years ago, the fare for short trips is so high as to discourage ridership. This position can be rectified only by adding one or more additional fare zones. SSFC provides an effective way to control zones on a multi-zone system without resorting to a hat check system and the delays such a system cause to service. Moreover, by selectively increasing zone fares to what the market will bear, transit revenue can be increased with little loss of ridership.

Fare Evasion Control

The potential for fare evasion is widely quoted as a reason for not adopting SSFC. However, Tri-Met currently experiences forged passes as well as passengers who refuse to pay, who short-change the farebox, and who override the zones. Drivers can do little to control these abuses. Although opportunities for certain types of fare evasion are increased under SSFC, other types of fare evasion, particularly forged passes, short-changing, and zone overriding can be effectively controlled by fare inspectors. After 1 year of SSFC operation, Edmonton reports a fare evasion level of around 1 percent. Not only is SSFC expected to reduce revenue loss from fare evasion on Tri-Met, but some additional revenue will be generated from the surcharge paid by passengers found traveling without proof of payment. Moreover, the system is partly self-stabilizing, since the greater the revenue loss from fare evasion, the greater the potential revenue from surcharge fares.

Improved System Security

The presence of radio-equipped fare inspectors traveling at random on the system will provide a measure of visible and real support to drivers and will enhance passengers' perception of transit system security.

Convenience for Passengers

The new fare structure will open up new and more convenient ways to pay fares. The new multi-ride ticket, for up to 10 rides, will permit passengers to travel without needing the exact fare for each trip. Moreover, pass holders, who will make up more than 50 percent of Tri-Met's passengers, will no longer have to dig for their pass each time they board a transit vehicle. Except when requested by fare inspectors, pass holders will carry their passes just as automobile drivers currently carry their driver's license.

Reduced Cash-Handling Costs

The extensive adoption of prepayment of fares (targeted at 85 percent under SSFC) is expected to reduce money-room and cash-transfer costs and related security requirements.

Reduced Driver Risks

SSFC will provide clearer definition of the driver's role with regard to fare collection by reducing and redefining tasks and responsibilities. The driver will no longer be required to try to extract a fare from a reluctant passenger or to argue over cash or transfers. Fare disputes are the most common source of passenger and driver friction today.

Improved Passenger Comfort

Passenger comfort will be improved because multi-door loading will provide better passenger distribution on the vehicle. Passengers may enter and leave through any door, thereby being exposed to less bunching and jostling on the

vehicle. Overall, the passenger's perception of transit service is likely to be enhanced.

COSTS

An economic analysis was developed to estimate the costs and benefits of those aspects of SSFC for which such estimates can be made.¹ Estimates were developed for three different years—1983, 1985, and 1990—for a transit fleet expected to grow as follows:

	Number of Vehicles		
	1983	1985	1990
Standard bus	500	700	800
Articulated bus	87	125	250
Light rail vehicle	0	26	68

Operating Cost and Revenue Comparisons

The cost of operating SSFC can be determined with considerable accuracy since implementation is well advanced and all major expenditures are budgeted. By far the largest operating cost is fare inspection, for which 50 fare inspectors are budgeted. Other costs include transit police support, administration, marketing, and equipment maintenance.

Operating costs are not expected to increase in proportion to system ridership, since less inspection effort per passenger is anticipated as passengers get used to self-service. The major dollar benefit attributable to SSFC lies in the reduction in the number of vehicles required to provide an equivalent level of service capacity compared with operation without SSFC. These benefits will occur primarily on the most heavily used lines, and particularly during peak periods. Improvement in system efficiency during peak periods is particularly significant since the transit fleet is sized to provide the necessary peak capacity. Any vehicle savings occurring in the peak period are, therefore, potential savings in the total fleet size.

Operating cost savings on the light rail system are particularly dramatic and are expected to exceed the savings in bus operations by 1990. The reason for this lies with the nature of LRT operations. Specifically,

- Operation of LRT with the traditional system of fare collection would require a driver on the

trailing car of a 2-car train solely to collect fares.

- Operation of LRT with the traditional system of fare collection would increase dwell times at stations and thus require two additional train sets to maintain equivalent service capacity.
- This additional equipment would require additional maintenance personnel.

Along with most transit agencies, Tri-Met experiences considerable lost time and expense due to driver absenteeism. Tri-Met expects SSFC to be a factor in reducing driver job stress, and hence absenteeism.

SSFC is expected to generate some additional revenue. One source of anticipated additional revenue is the reduction of fare evasion because fare inspectors are present. In addition, increasing the number of fare zones enables Tri-Met to increase fare revenue without increasing the base fare. Thus, for any given base fare, a fare structure including multiple zones collected by self-service will have a higher level of revenue.

Passengers riding the transit system without a ticket will be charged a surcharge fare of \$20 by fare inspectors. Tri-Met expects to generate significant new revenue from this source, even after allowing for administrative expenses and uncollectable surcharge fares.

The net operating cost savings attributable to SSFC are summarized in Table 1. All estimates are in constant 1982 dollars.

Capital Cost Comparisons

The capital costs of introducing SSFC are accurately determinable since procurement of most of the capital equipment is in progress. Equipment requirements include the on-board equipment such as validators and ticket dispensers, the retrofitting of rear doors of buses to permit passengers to enter through either door, and the purchase of a small number of vending machines to sell tickets at key points on the transit system.

Just as SSFC will reduce the transit system operating costs by enabling fewer buses to provide the same amount of service capacity, so too will SSFC reduce Tri-Met's fleet requirement—both buses and light rail. In addition, the adoption of SSFC will enable Tri-Met to avoid replacing its existing fareboxes with new fareboxes able to accept dollar bills and count the large number of coins now required to make up a transit fare.

Table 1. Net systemwide operating cost savings from SSFC (\$ in thousands).

Source	Year		
	1983	1985	1990
Fare inspection	(1696)	(1846)	(1846)
Administration	(470)	(470)	(470)
Other	(75)	(100)	(150)
Subtotal, costs	(2241)	(2416)	(2466)
Bus operation	1000	1405	1789
LRT operation	--	910	2080
Absenteeism	375	400	500
Reduced fare evasion	180	240	290
Zone fare revenue increase	1800	2400	2900
Surcharge fares	1000	1100	1200
Total	2114	4039	6293

The balance of capital costs and savings attributable to SSFC are shown in Table 2.

EQUIPMENT

On-Board Equipment

The major capital expense incurred by Tri-Met's SSFC project is the requirement for equipment on every bus to provide passengers with accurate and readily verified proof-of-payment. To achieve this, each bus must have a set of equipment consisting of three electronically integrated units. Particular importance is attached to procuring state-of-the-art equipment similar to that used in other systems. The three units are shown in Figures 1 through 3 and are described below.

The bus driver will be provided with a controller attached to the dash (Figure 1). This unit consists of a small box that displays the time and enables the driver to insert the zone number in which the vehicle is traveling into the fare-collection equipment. The only requirement this equipment places on the driver is to ensure that the zone displayed on the controller is always the zone in which the vehicle is traveling. The controller also contains a built-in warning system to alert the driver to equipment malfunction. All bus-stop signs show their zone.

To enable multi-ride ticket users to validate their tickets, every bus will be equipped with a validator attached to the stanchion behind the driver's seat (Figure 2). This unit will identify multi-ride tickets and stamp the date, time, and zone on the ticket. This information is obtained by the validator from the controller. The driver may change the zone remotely through the controller. At the same moment a small piece of the ticket, representing one ride, is clipped off. Validators are a widely used device and found on almost all European surface transit systems. Articulated buses will have three validators, one at each door. Light rail vehicles will have four validators.

To provide passengers using the farebox with a receipt, a receipt dispenser will be installed on all buses adjacent to the farebox (Figure 3). This unit contains components identical to the validator and a paper ticket dispensing unit in addition. When a passenger pays a fare into the farebox, the driver provides a receipt for this fare by pressing a single button mounted on the controller. The dispenser then prints a ticket containing the date, time,

zone boarded, and fare paid—in effect, an electronically printed transfer.

In March 1981 Tri-Met awarded a contract to supply this equipment to a joint venture of CAMP of France and Vultron of Michigan. The contract provides for the supply and installation of 874 controllers, 1198 validators, and 904 dispensers. The design of this equipment is based on similar units supplied by CAMP to a number of European transit agencies, modified where necessary for use in the United States.

Following the testing of pre-production units and completion of pre-acceptance tests, the contractor will commence delivery and installation on all Tri-Met buses.

Vending Machines

The Tri-Met SSFC program also calls for the experimental introduction of machines to sell multi-ride tickets. These vending machines will supplement Tri-Met's extensive retail outlet network, which is currently the main method of ticket distribution. These machines are proposed to accept only credit cards and to print multi-ride tickets from blank paper stock. If such machines can be procured, they will have the advantage of containing neither money nor tickets, which will considerably simplify their servicing and security and remove the incentive for break-ins.

Further expansion of Tri-Met's ticket-vending system will be heavily dependent on the experience with the initial procurement.

Retrofit of Rear Doors

Since a major benefit of SSFC is all-door boarding, a further task is to retrofit about 560 of Tri-Met's existing buses to permit rear-door boarding. On retrofitted buses the rear doors will be directly controlled by drivers. All future buses will be purchased already equipped for all-door boarding.

Future Bus Procurement

In addition to the need for rear-door boarding, SSFC will also require increased door capacity if the full economic benefits are to be realized. A number of factors affect the desirable number of doors on U.S. transit buses used with self-service. These include the traffic-signal charac-

Table 2. Net saving in systemwide capital needs from SSFC (\$ in thousands).

Source	Period		
	1981-82	1983-85	1986-90
On-board equipment (validators, etc.)	(2950)	(900)	(1700)
Rear door modifications	(250)	--	--
Vending machines	--	(1030)	(800)
Subtotal, costs	(3200)	(1930)	(2500)
Bus fleet reduction	3000	1400	1500
LRT fleet reduction	--	4000	2000
Farebox replacement	2450	460	450
Subtotal, reduced capital requirements	5450	5860	3950
Net reduction in capital needs	2250	3930	1450

Figure 1. Controller.

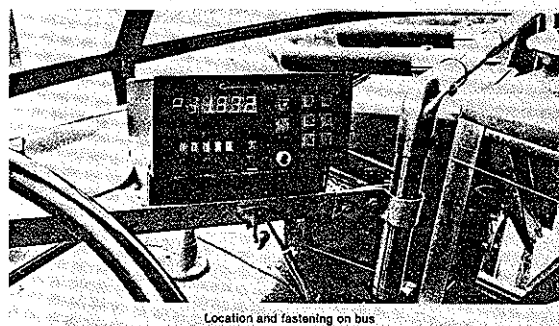
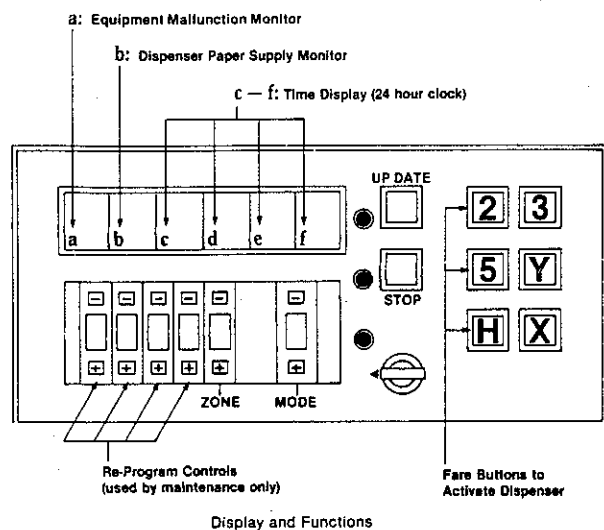
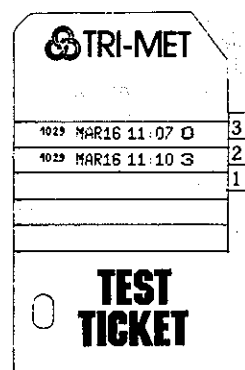
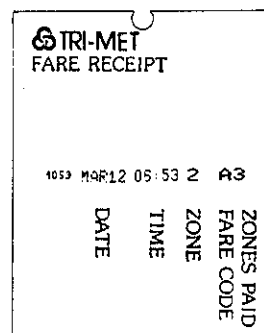


Figure 2. Validator.



Multi-Ride Ticket showing validation (Machine #, Date, Time, Zone Boarded)

Figure 3. Dispenser.



Ticket from Dispenser showing validation (Machine #, Date, Time, Zone Boarded, Fare Category, Zones Paid)

teristics in the city served, the line characteristics in terms of percentage of schedule time required for boarding passengers, and the type of vehicle mix used. To match the loading speed of a 60-ft, 3-double-door articulated bus, a 40-ft standard bus requires 2 double doors. It is anticipated that all future Tri-Met procurements for standard buses will require at least 2 double doors to match the triple double doors on articulated buses. Tri-Met's 88-ft-long light rail vehicles will be equipped with 4 double doors on each side.

DESCRIPTION OF OPERATION

This section provides an overview of the key features of the system that Tri-Met implements on September 5, 1982. From that date, a "proof-of-payment" ordinance requires all passengers using the transit system to have a valid ticket or pass and provides for the inspection of tickets and the charging of surcharge fares to passengers traveling without tickets. A second ordinance provides a new fare structure for concurrent implementation.

Proof-of-payment will normally consist of one of the following:

- A ticket printed on board by the dispenser in exchange for cash deposited in the farebox. The dispenser is activated by the driver and issues a ticket similar in concept to transfers, which will no longer be necessary and will be discontinued.
- A multi-ride ticket, a new method of payment requiring purchase of a 10-ride card ticket. To reduce farebox use the cost per ride on a multi-ride ticket will be less than the cash fare. Passengers using multi-ride tickets must validate the ticket at the beginning of each trip using the validator installed on all buses.
- Passes, which will continue to be used in much the same manner as today. Pass use will continue to be encouraged by maintaining or increasing the existing discount. Pass users will experience little change other than the increased convenience of not having to show their passes each time they board the bus.

As a result of the proof-of-payment ordinance and the new ticketing system, most passengers no longer need to deal with the driver and consequently may board through any door. Major operating improvements are expected during peak periods, particularly with articulated buses.

An extensive information and marketing effort includes not only the training of all agency employees but also an information program for schools, special groups, and the general public. All buses require new signing to provide information concerning fare collection, and modifications are required to all of Tri-Met's 7000 bus stops.

Some 50 full- and part-time fare inspectors will be hired to check tickets. Passengers traveling without proof of payment will be charged a \$20 surcharge fare. This may be collected by the fare inspector, in which case a receipt is issued that is valid as proof of payment, or it may be

paid later, in which case a "Notice to Pay" will be issued. The notice is also valid as proof of payment. Passengers who ignore the notice will incur late charges, and after a certain period unpaid notices will be turned over to a collection agency. Passengers who travel repeatedly without proof of payment may also be liable to prosecution for theft of service, an offense which in Oregon carries a fine of up to \$500. A computerized system of records, billing, and collection (RBC) is being set up to administer the fare inspection records.

Regional Transit Coordination

Tri-Met at present provides service linking Portland to Vancouver, Washington, where Columbia Transit (C-Tran) provides transit service. As part of the SSFC program, Tri-Met and C-Tran are integrating their fare structures with coordinated zones, and mutual acceptance of each other's tickets and passes. Passengers are thus able to travel on the transit systems in either state without concern as to who provides the service. An annual contract between the agencies enables any resulting inequity in fare revenue distribution to be corrected according to an agreed formula.

Light Rail

Tri-Met's light rail system was both the initial impetus behind the SSFC program and will be the ultimate beneficiary. It can be readily appreciated that if the SSFC system can be successfully deployed on the buses in 1982, its extension to LRT in 1984 or 1985 will present no major problems. Nonetheless, certain modifications are required to respond to the different operating environment of the LRT. Specifically,

- Cash fares will be collected only off the vehicle using vending machines. It is not practical to extend the farebox and dispenser system of cash fare collection to light rail because of the major increase in dwell time that would result.
- Each car will be equipped with a modified controller in each cab and four validators. The use of on-board validators will be consistent with the rest of the Tri-Met system and also provides an additional convenience incentive to passengers to use multi-ride tickets. Single-ride ticket-vending machines will be provided at all stations, and multi-ride vending machines will be provided at key stations. It is intended that, to the extent possible, all passengers will have access to a multi-ride ticket vending machine at one end of their trip.

All fare regulations, tickets, and fares will be freely interchangeable between the bus and LRT lines, and there will be no barriers or gates anywhere on the system.

REFERENCE

1. Economic Impact of Self-Service Fare Collection. Tri-Met, Portland, Oregon, January 1982.

Comparison of Fare Collection Methods for LRT

TOM PARKINSON, Consultant to the Urban Transit Authority of British Columbia Rapid Transit Project

Fare collection is an important aspect in the design of a light rail system because it has a greater impact on both capital and operating costs than on a conventional rapid transit system, where these costs can be distributed over larger passenger volumes. The aim in designing the LRT fare system is to (a) minimize the collection cost per passenger; (b) be compatible with the existing transit fare system (assumed to be typical exact cash fares, with or without passes); (c) permit transfers between modes without necessitating changes to bus collection or requiring machinery on buses; (d) be flexible to accommodate any future fare changes, including the introduction of zone or graduated fares, the use of passes (flash cards), other prepurchased measures such as carnets (multi-ride tickets), strip tickets, tokens, or single tickets; various forms of concession fares; and time-variable fares, such as reduced off-peak fares; and (e) permit the use of low-cost LRT stations.

Conventional barrier fare collection is used on all North American rapid transit systems. Stations and vehicles are designated as fare-paid areas, and access to and from stations is controlled by barriers. Fare payment takes place at turnstiles or manned booths at the barriers. Differing degrees of self-service are possible, ranging from coin- or token-operated turnstiles to elaborate magnetic ticket systems where single or multiple tickets are purchased in advance in banks, trust companies, newsstands, or other commission outlets or from coin- and bill-accepting machines in the stations. Because machinery and turnstiles cannot detect whether passengers are entitled to concession fares, children and senior citizens must usually pay at or pass a manned booth.

Unmanned stations are possible, but problems occur with adults using concession fares or with evaders jumping turnstiles. Considerable losses are experienced in some cities. Total control therefore requires such stations (or just the specific unmanned entrance) to have full-height turnstiles and to preclude concession fare users. Except in Montreal and Atlanta, where machine-readable bus transfers are issued, bus transfer passengers must also pass the manned booth. The manpower expense of such arrangements is considerable. PATCO in Philadelphia uses unmanned stations with remote closed-circuit television surveillance to deter turnstile jumpers. PATH also has some unstaffed stations with TB surveillance.

Barrier systems impose considerable design constraints and additional capital costs on stations. Barrier collection cannot be used on LRT systems with on-street tracks and stops. However, hybrid collection may be possible to permit front-door-only boarding and driver collection at these locations or by using the "pay entrance inbound, pay exit outbound" system (as in Pittsburgh or Seattle) where no fare collection takes place on the street in the downtown area. This provides in effect a free downtown zone, which can be desirable in attracting transit use or reducing internal CBD automobile trips.

In general, barrier systems are not appropriate for LRT systems, particularly if any on-street running is planned initially or in later phases.¹ Barrier collection costs are discussed later in this paper.

CONVENTIONAL LRT FARE COLLECTION IN NORTH AMERICA

Excluding the three new systems in San Diego, Calgary, and Edmonton, most North American LRT operations use motorman (or operator) manual fare collection. Thus, when multiple-unit trains are run, the operator in the front

unit both drives the train and collects fares (as in normal bus operation) while all cars to the rear must be manned by an operator paid at the same rate as the driver but who is only responsible for collecting fares and operating the doors. This extra manpower requirement may appear inefficient, but if it is used only in the peak period and if the alternative is to man each station or stop, then it becomes either essential (surface stops could not all be manned) or an acceptable option.

An interesting variant on certain lines in Philadelphia, Newark, Boston, San Francisco, and Cleveland is that major downtown stations have fare-paid platforms, thus permitting faster loading through use of all doors on each car. Operator collection is retained at other stops.

Conventional fare collection is simple to implement and administer. It is compatible with exact-cash fares, passes, multi-ride tickets, tokens, or concession fares. It permits issuance and acceptance of conventional manual transfers. Revenue collection and accounting involve the normal bus procedures with on-board farebox cash vaults. The operator on each car provides additional security and door operation safety as well as better availability of user information. In emergencies and when entering or leaving service, trains can be broken down into single units, each of which then has its own operator. However, conventional fare collection has disadvantages. Zone fares are inconvenient and cumbersome to collect manually (and possibly for this reason are rarely used on existing LRT systems). Station dwell times are lengthened by the need to board only the front door and file past the motorman, while the need for manual collection introduces high labor costs in manning the rear car(s) of multiple-unit trains.

This conventional form of fare collection has been retained despite its inefficiencies because of simplicity, compatibility, and union pressures against job reduction. Most LRT lines are operated as part of a bus system rather than as an entirely separate mode because they have historically evolved from earlier streetcar networks. They frequently use single-car trains, which impose no cost penalty for manual collection, and, in fact, where there are no headway capacity restraints, the need for an operator on each car removes any incentive for multiple-unit operation.

CONVENTIONAL LRT FARE COLLECTION IN EUROPE

Most LRT systems in Western Europe use a self-service barrier-free fare system, sometimes called a "proof-of-payment" system. Although there are many combinations and permutations in terms of fare purchase, ticket validation, and checking, the basic principle remains the same. There are no barriers such as turnstiles at stations or any fare payment necessary on boarding a vehicle. Each passenger must ensure that he is in possession of proof of valid fare paid when on the vehicle or in the section of a station designated as a fare-paid zone. Fare payment is typically by the purchase of passes (flash cards) or multi-ride or single-ride tickets from outlets or machines located on or off the transit property. These must be validated (i.e., cancelled) when entering a station or vehicle by inserting into a small machine that imprints the location or zone, time and date, and usually clips a portion of the ticket to prevent reuse (overprinting). This stamped ticket then serves as both proof of payment and as a transfer under whatever transfer rules the property specifies.

To control fare evasion, a system of checks is necessary. This usually involves roving transit personnel, either solely as ticket inspectors or with a supervisory role. The number of checks should be in proportion to the

determined evasion rate, which in Europe ranges from 1 percent to 5 percent. Thus from 1 in 50 to 1 in 20 passenger trips should be checked on an organized sample basis. As the sampling rate can be allowed to vary from hour to hour or day to day, the use of transit supervisors has advantages. Such staff can drop fare checks, without harm, to cope with emergencies or regulatory tasks, thus providing much better supervision than could normally be justified. Their presence can perform an important security role, particularly in late evenings or on unmanned cars.

When a passenger is found without a valid ticket or pass, penalties are usually applied. One of the most significant penalties is just the embarrassment of being detected and the resulting confrontation with a uniformed official. However, at the discretion of the checker, monetary penalties can be requested. These start with a request for correct fare payment, and the designated "cash" fare can be much higher than the "ticket" fare. Under common law, a passenger can typically refuse to pay or to provide identification and thus can only be asked to leave the vehicle at the next stop. Therefore, most Western European systems have obtained powers for their checkers similar to those of a traffic warden or parking officer. Identification can be requested and an "evasion notice" or "citation" issued. This carries a penalty of \$1 to \$10 (early 1970s data, presumably higher now)—ideally the fare multiplied by the check rate, e.g., times 20. Such citations can either be paid on the spot, taken to the transit office for payment or to be disputed, or very rarely, pursued into court.

Tickets or passes can be purchased in a variety of ways: by mail or in person from transit offices, at banks, savings and loan offices, stores (large or small), and from booths at major transit locations where a manned location can be justified for security or information purposes. Multi-ride tickets are often machine-vended in stations; and single-ticket machines may vend at individual stops or on each car. In the latter case, single-ticket machines usually precancel the ticket with the zone, time, and date imprint. Such vending machines are subject to vandalism, and thus curb locations are rare outside Switzerland and a few German cities. The track record on vandalism in Europe and North America is good but requires attention in machine design, location, and security practices. Closed-circuit television surveillance and remote vandalism alarms are often used. However, a simple internal alarm can be effective.

Several systems utilize the operator to accept cash fares or sell tickets to passengers boarding through the front door of a train. Charges are slightly higher than from other outlets, to deter frequent use of driver transactions and possible delays. This is of particular help to tourists or other people unfamiliar with the transit system.

The self-service barrier-free system is regarded in Europe as offering the greatest flexibility at the lowest cost. It is fully compatible with any fare system on connecting modes, since any transfers are subject to the fare inspections while the imprinted tickets serve as transfers to the other mode. The system is exceptionally flexible, accommodating flat or zone fares, various types of passes and concession fares, and fares that vary by time of day (since each ticket is time-stamped). Limited promotional fares are possible. For example, the central business area or an area within 1 mile of a shopping center can be designated as fare-free for a short or long time and no fare checks carried out in that area.

A self-service fare system should not be confused with the so-called "honor" system. Honor systems have been used in several eastern European countries but appear to be phased out. In an honor system, the passenger pays the fare into a box onboard the vehicle; no receipt or transfer is issued and no checks are imposed other than "each comrade watching the other." It does not work! This confusion with honor fare systems has tended to delay implementation of self-service fares in North America

because of unfounded attitudes that North Americans are less honest than their European counterparts.

In 1975 Atlanta examined self-service fares as part of a major fare study for its conventional rapid transit system, which includes complete grade separation and controlled-access station platforms.² The study could find no socioeconomic justification why North Americans would be any different with respect to self-service fares than West Germans. Fare evasion of some 100 transit systems in Europe ranges from 0.01 percent to 3 percent, with the higher value on commuter rail lines, which have higher fares, and in larger cities where people feel more "anonymous." The typical range was around 0.5 percent (see Table 1).

The percentage of passengers checked ranged from under 1 percent to 10 percent but typically is in the 1.5 to 3 percent range. Penalties (either a spot fine or supplementary ticket) range from \$1 to \$10 (1975), the most common being \$5 in West Germany and \$1 in Switzerland. There was little correlation between the penalty and the amount of evasion or the percentage checked, although evasion was lower on systems where a high proportion of passengers use passes and thus have little or no incentive to cheat. Where a cash transaction is required for every trip, each trip requires a decision, "Shall I pay or shall I evade?"

A reverse philosophy appears to apply where fare checks are frequent, inconvenient, or brusque, and penalties high, whereby the resentment created encourages people to try to beat the system. The largest disincentive to evading payment is not cash penalty but the social penalty from the embarrassment of being caught and admonished in public. This is particularly pronounced in small cities, on suburban buses, or on regular commuter runs where the evader perceives that someone he knows may see him being caught.

The Atlanta study looked at fraud in other areas of North American life. At self-service gasoline stations, driveaways are far less than 1 percent and about comparable with regular gasoline stations, despite the typical purchase value of \$6 to \$10. Telephone fraud by billing to other numbers or credit cards and by coded messages on person calls are estimated at less than 1 percent. Newspaper vendors (honor type) have losses below 0.5 percent.

Automatic highway tolls have a fraud rate of 1 percent to 2 percent when adjacent to manned lanes but 5 percent to 10 percent when entirely remote (usually 10 cents to 50 cents toll). About one-third of these higher levels appears to result from lack of correct change. Shoplifting on the average (study by National Retail Merchants Association) is 1-2 percent compared with 5-6 percent loss on gross revenue from employee theft and error. Fraud on existing exact-cash fare systems runs from 0.5 percent to 4 percent and encompasses counterfeit tickets or transfers and slugs. The bulk of this fraud is transfer abuse and relates to a system's caliber of driver training and supervision.

The net result is that, while most North Americans have few qualms at minor legal infractions—exceeding the speed limit, stealing pencils and pads from the office—a self-service fare system can expect fraud levels of 0.5-2 percent on the basis of European experience with enforcement, whereas with no minimum enforcement a rate between 0.5 percent and 6.5 percent is likely.³

Evasion rates on self-service barrier-free systems in Europe are given in Table 1. The data originate from a 1972 UITP survey of member properties. More recent information indicates that higher rates are being tolerated in certain German cities to reduce the cost of inspectors. There is a trade-off between inspection costs and revenue lost. Past tendencies were to reduce fraud at all costs, but now a more realistic attitude is appearing, with evasion rates allowed to climb if there is a net overall saving.

Table 1. European self-service barrier-free evasion rates (1971-72 data).

System	Percent of Detected Evasion	Percent of Passengers Checked	Amount of Fine \$US (1972)
<u>West Germany</u>			
Duisburg	0.41	2.2	3.1
Düsseldorf	0.48	2.2	6.2
Flensburg	0.21	3.0	3.1
Frankfurt	3.06	0.8	6.2
Hagen	0.5	3.0	4.6
Hannover	0.3	3.5	6.2
Kiel	0.3	2.8	
Köln	1.6	5.0	3.1
Stuttgart	1.03	3.6	3.1
<u>Switzerland</u>			
Basel	0.3	10.0	1.3
Geneva	0.75	2.3	7.7
Lausanne	0.35	5.0	1.3
Lucerne	0.27	1.2	1.3
Neuchâtel	0.2	5.0	2.6
St. Gallen	0.4	7.0	2.6
Winterthur	0.1	10.0	1.3
Zurich	0.48	9.0	1.3

LOSSES WITH CONVENTIONAL FARE COLLECTION

Other transit fare evasion rates are difficult to determine. Operators are reluctant to discuss or even admit to losses. However, it is generally accepted that the common exact-cash fare payment in North America has a 2-4 percent evasion rate from vehicle entry without payment (via the rear door or skipping past the driver at busy stops; short payment into fareboxes, many of which make it difficult, if not impossible, for the driver to determine the exact value of coins deposited; counterfeit bills, tickets, passes, coins, and tokens; fraudulent use of concession fares, particularly older students using high-school-only privileges; and transfer abuse (making two or more distinct trips on a transfer). Poor training and discipline of operating staff have contributed to increases in this last form of evasion.

Major fare increases in 1980 and 1981 to \$0.75-\$1.00 have compounded the problem of exact fare payment in nonregistering fareboxes. Dollar bills in these boxes are now common in many cities and involve significant handling difficulties and expenses, while multi-coin fares cannot be realistically checked by the operator. The result is a de facto honor system where any handful of coins can get a passenger on board. Attempts to introduce a 1 dollar coin in the United States have failed, although this will soon be a useful coin in both the transit and the automatic-vending industries.

NORTH AMERICAN EXPERIENCE WITH SELF-SERVICE FARE SYSTEMS

Vancouver

The first self-service fare system in North America started on June 17, 1977, on the Burrard Inlet Rapid Transit Ferry (Seabus) between downtown Vancouver and a cross-harbor suburb. Volumes of up to 22 000 passengers per day have been carried. Although many passengers transfer from buses, some 60 to 70 percent buy tickets from coin-operated European machines at either terminal. These are issued stamped with the location, date, and time and serve both as fare receipts and transfers to connecting buses. Inspection is by existing ferry personnel on a "time

available from other duties" basis; no extra staff was hired except for machine maintenance. There is no monetary penalty. Fare evaders are asked to return to the terminal fare machine to pay their correct fare; the intent was to prosecute for theft of transportation only if necessary and to implement a "citation" type of penalty only if existing legal means proved inadequate or evasion rates were too high. This has not been the case, and after 4 years of operation and more than 15 million passengers, no prosecution has taken place and ideas of penalties have been dropped.

The Vancouver Seabus data indicate that total detected evasion ranged from 0.9 percent to 1.8 percent, with a mean of 1.35 percent (the introduction of unrestricted time-value transfers in 1981 resulted in the mean evasion rate dropping to around 1 percent), but on weekdays, when the majority of riders is regular users, detected evasion ranged from 0.44 percent to 0.75 percent, with a mean of 0.62 percent. This is exceptionally good, better than some European rates and less than the probable evasion on the exact-cash fare buses. In round terms, \$80 000 of coin-operated ticket machinery is estimated to save \$300 000 per year in manpower (manual collection costs less machine maintenance costs) for a fare evasion loss of about \$10 000 per year. The net annual balance is a saving of \$280 000 per year, or a return on investment of 350 percent (1978 dollars).

The Seabus experience has shown two valuable lessons. First, evasion is significantly and consistently lower in the northbound direction, where the fare payment terminal is better located and more clearly signed. Passengers cannot get to this terminal without passing close to the brightly colored and lighted fare machines. Second, evasion is much higher on weekends and holidays when tourists and persons unfamiliar with transit and its need for exact-cash fares make up a significant number of riders. These people often cannot or do not read the fare payment signs, do not pay until asked, or do not pay because they have no change. Clear signing and availability of change are therefore important design objects.

Edmonton

The Edmonton LRT opened in 1979 with manned barrier collection. Costs of fare collection were so high that they exceeded all other transportation labor costs (operators and supervisors), and thus a self-service proof-of-payment system was introduced in 1980. The system is not barrier-free but uses turnstiles in conjunction with a fare receipt vending machine called a POP (proof-of-payment) machine. Free-wheeling turnstiles are provided for pass and transfer holders. Additional POP machines are located by the elevators for the handicapped.

Edmonton Transit "fare agents" in supervisors' uniforms have enforcement powers under a city by-law (ordinance) to issue fines (i.e., tickets) between \$25 and \$100, the higher amount for repeat offenders. Sixty tickets were issued in January 1982, indicating an evasion rate of about 1 percent. There were 4 complaints in that month, but generally the fare agents are positively received and are perceived in more of a supervisor, public information role than one of law enforcement.

Calgary

The Calgary LRT line opened in May 1981 with a self-service barrier-free system, using Xamax (Swiss) automatic ticket-vending machines that also validate 10-ride tickets. Security and fare checks on the "C-Train" are provided by "protective services officers" with powers of and a uniform similar to city "by-law enforcement officers."

By-laws (ordinances) 4M81 and 62M82 provide the following:

- It is unlawful to ride the C-Train without a valid pass, ticket, or transfer in your possession.
- Passengers must be prepared to produce proof of payment at any time during their ride. Proof of payment must be shown to a peace officer (a member of a police force, a special constable, or a by-law enforcement officer) of the City of Calgary upon request.
- Anyone failing to produce proof of payment upon request will be immediately issued a voluntary payment tag for \$25.
- Failure to pay to \$25 within the time specified on the tag could result in a fine not exceeding \$2500, and on default of payment of the fine to imprisonment for a term not exceeding 6 months, unless the fine is paid sooner.
- The transit platforms at Anderson, Southland, Heritage, Chinook, and Erlton Stations are restricted fare areas, and you must have a valid ticket, transfer, permit, or pass in your possession on the platform.

An evasion study was under way in March 1982. Early experience indicates an evasion rate of about 1 percent. As in Edmonton, the enforcement officers are seen positively as offering security and information.

San Diego⁴

San Diego initiated LRT service in July 1981 with a self-service barrier-free system using Autelca (Swiss) machines to vend validated tickets or to validate multi-ride tickets ("READY 10"). Uniformed ticket inspectors conduct random checks. The 6 bilingual officers plus a supervisor are each equipped with 2-way radios. State legislation permitted the MTD Board of Directors to adopt an ordinance that establishes \$20 bail and a mandatory court appearance on a third offense. MTDB receives 85 percent of any fine revenue for fare evasion.

The first 6 months of operation showed 2231 citations for evasion among the 829 000 riders checked. This represents 41 percent of the 2 001 000 total riders and an evasion rate of 0.27 percent. As in Vancouver, inspection

personnel have time to check a much greater number of passengers than is necessary to enforce payment and also play a major security and information role. San Diego MTDB feels that the inspectors have become ambassadors of the system. They are the only employees of the system exposed to passengers and offer an important public relations benefit. A firm yet positive attitude was stressed during staff training, and this has seemingly paid off with resulting positive attitudes from patrons.

San Diego feels that the system has met and exceeded expectations and demonstrated the cost-effectiveness of self-service barrier-free collection. Although data from other cities are not directly comparable, the performance of the ticket-vending machines in San Diego appears significantly better than elsewhere. The expected initial surge of malfunctions was experienced as the machines were "burnt-in" and maintenance staff and passengers became familiar with the equipment. However, the December 1981 rate of 6.7 percent service calls per machine per month was about half the initial rate and, while higher than the manufacturer's specifications, is still falling. (About 25 percent of these service calls were false reports, and 20 percent were validator jams, in part due to vandalism, in part due to incorrect paper stock, which has been corrected. However, vandalism and machine tampering have not been a major problem. This rate is equivalent to 1 service call per 1660 vends or validations.)

San Francisco

A self-service fare system has been introduced on the cable cars.

Portland

Tri-Met is progressing with the implementation of a systemwide self-service system that is the subject of a separate paper.⁴

ECONOMIC EVALUATION

Assumptions have been made for a hypothetical LRT line with two levels of patronage. Although many cost estimates may appear approximate and will require adjusting for system specific requirements, the comparative costs of different fare systems are regarded as realistic and revealing. The following general assumptions are made:

- A 10-mile LRT line with 10 stations.
- An average speed of 40 km/h (25 mph) with a round-trip time of 60 minutes.
- Peak loading of 165 passengers per car.
- Two passenger volumes:
 - A. 5000 pphd (passengers per peak hour duration) = 20 000/day = 6m/year.
 - B. 10 000 pphd = 40 000/day = 12m/year.
- Service in peak hours:
 - A. 2-car trains every 4 minutes = 15 trains/hour, total 30 cars and spares.
 - B. 3-car trains every 3 minutes = 20 trains/hour, total 60 cars and spares.
- Peak-hour configuration is retained for 13 hours, 6 a.m. to 7 p.m. Then 8 hours of service with A = 1 car/train, B = 2 cars/train. Daily train hours are then A = 450, B = 908.
- One-man train operation will be used.
- Revenue collection, off system sales, and ticket printing are assumed identical for all systems.

Estimates are in Canadian dollars (1982).

Barrier Collection

All stations will be equipped with an area of 60 m² (700 ft²) as a fare collection module containing a manned booth and 6 low-level turnstiles that are coin- or magnetic-ticket operated.

Capital costs for fare collection are as follows:

700 ft ² of building at \$100/ft ²	\$ 70 000
Land for above (at half of stations only)	10 000
6 turnstiles	25 000
1 booth equipped with telephone, PA, vault	20 000
Underpasses at half of stations, 50 percent of 60 000	30 000
Fencing for barrier control	10 000
Total per station	\$ 165 000
Total for 10 stations = \$1.65 million	
Equivalent annual amount (15 percent) =	250 000
Operation with 1 man per station, required staff of 50 at union rate with fringe benefit and overhead of \$35 000/year*	1 750 000
Turnstile and building maintenance, 2 men = 2 percent	100 000
Total annual cost	\$ 2 100 000
Cost per passenger, A = 35 cents B = 18 cents	

Self-Service Barrier-Free

Capital costs for 2 coin-operated ticket machines per car plus validators at \$30 000 and \$1000 each plus 10 percent spares:

A = 66 coin machines (this item could be replaced by 20 coin machines on station platforms)	\$ 1 980 000
132 validators	132 000
	\$ 2 112 000

Annualized = \$320 000

B = 132 coin machines	\$ 3 960 000
264 validators	264 000
	\$ 4 224 000

Annualized = \$640 000

Operating cost for a 5 percent check rate, assuming 60 checks per man-hour:

A = 3 man-years =	\$ 105 000
B = 6 man-years =	210 000

Additional control will use normal proportion of transit supervision. Inspectors will have 30 percent to 50 percent of their time free to deal with security and information needs.

Machine maintenance at 1 man-year per 30 coin machines and 1 man-year per 130 validators:

A = 3 man-years =	\$ 105 000
B = 6 man-years =	210 000

Total annual costs,

A =	\$ 530 000
B =	1 060 000

*Typical of large city rates, \$11.40 per hour + 35 percent benefits + 15 percent administrative overhead.

Cost per passenger,

A =	8.8 cents
B =	8.8 cents

Comparison

Cost per passenger in cents excluding common costs.

	A	B
	5000 ppphd (6m passengers/ year)	10 000 ppphd (12m passengers/ year)
Barrier (turnstile) collection	35 cents	18 cents
Driver collection	20 cents	30 cents
Self-service barrier fare	9 cents	9 cents

Other Factors

All three options have advantages and disadvantages beyond the simplistic economic evaluation above.

Barrier Collection

Only adult cash or coded tickets can be accepted by the turnstiles. Concession and transfer passengers must normally pay their fares to the collector. At busy stations or ones with many transfer passengers, line-ups will occur, or duplicate manning may be necessary.

Certain stations may demand a physical layout with more than one entrance. In this case, a separate manned fare collection module would be required. This would increase collection costs by approximately 10 percent per extra manned entrance.

Manned stations permit a high level of security and a higher quality of public information, provided the staff is properly trained and supervised.

Each station fare collection module requires either grade-separated or at-grade connection to the other platform where side platforms are used. This introduces costs and security problems. At-grade alternates compound the difficulty on surface lines of unauthorized and hazardous entries along the tracks.

Manual fare collection systems are subject to robbery, particularly at remote stations, even when drop safes are used to minimize cash on hand. Zone fares cannot be readily used on manual systems without exit checks. Machinery (exit turnstiles) can accomplish this as on BART and MARTA but at a high equipment cost and with high fraud potential if concession fares are available.

Driver Collection

Driver collection is by far the simplest to implement, with a significant advantage: Each car is manned, and security and public information are good. However, boarding is permitted at the front door of each car only. At busy stations this can delay service to the point that an extra train may have to be added at a significant cost, which is not included in the foregoing analysis.

Self-Service Barrier-Free Collection

SSBF offers by far the most flexible systems encompassing a wide range of tariff options. However, it requires a higher level of public education than other methods and involves more management effort. Penalties and ultimately court enforcement involve the time of lawyers and staff.

Unattended ticket vendors in vehicles (and possibly on stations) present targets for vandalism. However, roving

inspectors with a multiple role in security supervision and public information can provide a high perceived level of presence.

Other Costs

Common to all systems are certain additional costs: All options—in fact, any fare system—should offer the convenience of prepayment and the concomitant advantage of an advance cash flow (a float). Books of tickets or tokens have long been used and still are common in Canadian transit systems, less so in U.S. cities. Passes are now becoming common in North America and have been very successful on some systems. Prepayment in its various forms requires commission outlets—the more the better. This requires a sales organization and a distribution and accounting system. Depending on the commission (typically 1 to 3 percent), this will cost 1 to 8 cents per passenger at current fare levels, including ticket and pass printing. Forty percent more adult riders can be expected to use passes in a well-managed program. All forms of prepayment, tickets, tokens, and passes can exceed 80 percent of all fares, as in Toronto. In all three fare collection systems, this advantageously reduces the cash payment load on collectors, drivers, or coin ticket machines.

Revenue collection and management and supervision are the principal other costs. Self-service and driver collection can reduce these costs if all collection is aboard vehicles with farebox and fare-machine vaults pulled and emptied at a central location—the maintenance and storage depot—under easily secured conditions.

Barrier collection and the SSBF, when using station platform vending machines, require an armored car and armed crew to visit each station daily. In many cases this task can be handled by the existing bus garage revenue collection crew. If arrangements must be established without prior conditions, either a contract can be obtained with an armored car money service company or a 2-man crew can be established. This, together with sorting and counting, will cost 1 to 2 cents per passenger.

Sensitivity Analysis

All three options will vary with changes in the basic assumptions:

- Length of route will change the running time and hence the number of vehicles and operating staff. This is a disadvantage for the driver collection option with its onboard labor but has minimal impact on the other two options. Driver collection costs are almost proportional to round-trip time and hence route length.
- Number of stations affects driver and SSBF collection only slightly (other than where this changes running time). Barrier collection costs will change in direct proportion to the number of stations.
- Speed and hence travel time will have an almost inversely proportionate change in the costs of driver collection, with little effect on the other options.
- Passengers per car including different car sizes (4-axle versus articulated) will have an almost proportionate change in driver collection costs, with no impact on the other methods.
- Passenger volumes in cases A and B give different costs for different volumes. Barrier collection is independent of volume up to the point where volume at an individual station requires more than one manned collector's booth. In effect, costs fixed by the number of stations are shared by the applicable volume of passengers. Driver collection is proportionate to volume at higher volumes. However, where volume is so low that only single-car operation is required, no extra staff is needed

beyond the one operator per car. This favors driver collection at volumes below about 3000 pphd.

- Peak versus off-peak passenger ratio changes will reduce the cost of driver collection substantially if low off-peak ratios allow reduced train consists at these times. For example, in case A, multiple-unit operation only during the peak will reduce costs from 20 cents to about 12 cents per passenger.
- Unmanned barrier stations with automatic equipment (possibly with closed-circuit television surveillance from an adjacent manned station) will reduce costs in proportion to the number of manned stations plus some extra equipment costs. Evasion potential increases with the availability of concession fares. For example, with only 5 manned stations, costs would reduce to about 18 cents for case A and 19 cents for case B per passenger.
- Capital cost estimates are given at median 1981 prices. Reductions are possible by using the simpler designs—for example, if only 3 fares need be vended rather than multiple-tariff zone fares. This would reduce the capital cost component of SSBF collection. Costs for the barrier system station module are most subject to variation. More elaborate arrangements, with facilities such as washrooms, crash gates, and automatic vendors, could substantially increase the estimates. Provisions for handicapped passengers give highest costs for this form of collection.
- Annualization of capital costs in the simplistic approach used assigns 15 percent of total capital cost to each year. This is reasonable for such a comparative exercise. More precise methods would use discounted cash flow and allocate depreciation based on the estimated life of 10 years for machinery and 30 years for buildings.
- Labor costs constitute 88 percent of barrier cost estimates, 98 percent of driver collection cost estimates, and 40 percent of SSBF estimates. All are highly sensitive to labor costs. Although station collectors may be expected to have a lower hourly rate than drivers (operators), many properties use ex-drivers who have developed a physical disability as collectors, with comparable pay. Inspectors and supervisors in the SSBF system can expect to receive a premium rate, but neither variance will significantly affect the overall comparison.

Hybrid Alternatives

It is possible to use driver collection with certain heavy-volume stations equipped with manned barriers to save boarding time. Conversely, on a barrier system, certain low-volume stations can use driver collection via the front door of the first car. SSBF can use the driver to collect fares, reducing or even eliminating coin-operated ticket machines. (On bus systems with SSBF collection, drivers can be used to check tickets on a time-available basis at timing points and transfer points where there may be scheduled layover time.) Each of these situations is system-specific and requires a special economic analysis.

CONCLUSIONS

All fare systems will gain by maximizing fare prepayment. In the considered range of passenger volumes, self-service is by far the lowest cost. In all cases, SSBF collection costs less than half the cost per passenger of the other options. SSBF systems are fully compatible with other fare systems on connecting modes, provided proof of fare payments is given, such as when a transfer is issued.

The only negative aspects are the additional passenger effort needed with its information requirement and the

enforcement process. Early fears that Canadian and U.S. legal systems were not amenable to enforcement have been dispelled by successful systems in Vancouver, Edmonton, Calgary, and San Diego. Edmonton is particularly revealing in that it started with a barrier system but within 2 years converted to self-service as an economic measure. In all 4 SSBF systems, evasion is now at or below 1 percent and is well below anticipated levels. Machine maintenance varies from satisfactory to very good. Vandalism has been shown to be a minor problem. The legalities of ticket inspection and enforcement have proved workable under different jurisdictional and legal systems. The protected benefits of added security and information services offered by enforcement staff have exceeded all expectations.

Any city that can adequately control and administer parking meter enforcement should be able to handle self-service. The self-service, barrier-free, proof-of-payment system has often been labeled as an "honor system." In fact, increasing fraud or potential for fraud on conventional transit fare collection systems makes these more of an "honor system" than self-service. Not only is SSBF clearly the preferred option for new LRT systems in a wide range of passenger volumes, but it may also have merit for

use on the entire transit system. It now appears that Portland, Oregon, will be the first to implement this systemwide. The results could have a major impact on the entire future of transit fare collection in North America, which is still geared to concepts dating from when fares were a nickel and labor cost 15 cents an hour.

REFERENCES

1. T.E. Parkinson. Fare Collection. Chapter 7 in System and Vehicle Specifications, San Diego Metropolitan Transit Development Board, November 1977.
2. Manuel Padron and Richard Stanger. The MARTA Study of No-Barrier Fare Collection: Review and Discussion. TRB 56th Annual Meeting, January 1976.
3. Maurice M. Carter and Langley C. Powell. Self-Service Barrier-Free Collection: An Early Look at San Diego's Experience. Unpublished paper, March 1982.
4. Gerald F. Fox. Self-Service Fare Collection—Getting There From Here. Tri-Met, Portland, Oregon.

San Francisco Muni Metro: Operating Issues and Strategies

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The advent of a light rail vehicle system presented the San Francisco Municipal Railway (Muni) with new challenges associated with operating a high-speed subway system. The Metro, as the system is known, is a subway and surface operation on five existing streetcar lines in San Francisco. It carries about 120 000 passengers per day. Muni was able to run extensive tests with its new fleet of LRVs before starting revenue service to check operating characteristics, especially the ability to couple and run as a multi-car train. Muni's start-up strategy for a gradual phase-in of LRV service provided opportunities to learn about a far more complex operating environment than traditional streetcar operation. It became apparent in the early operational phases that a traditional schedule approach was unworkable. Before full-scale operation began, it was decided to abandon the usual schedules and use a "dynamic schedule." By headwaying the cars and providing a pool of fallback operators, it was hoped to maximize the use of the LRVs and help meet the ever-increasing demand of Metro passengers. This headway and fallback system was refined to help Metro break the turnaround bottleneck at the Embarcadero Station, which limited the system's capacity. In addition, a central trainmaster at Van Ness Station improved the consistency of service. The headway and fallback system's shortcomings include partially developed crew dispatching and trainmaster procedures and stacking of outbound trains caused by system saturation.

The five existing Muni streetcar lines are all that remain of an extensive network of electric street railways that once served most areas of San Francisco. Most of these lines were discontinued before or immediately after World War II. The 44 miles of double track in the five existing lines survived principally because of their exclusive rights-of-way, which were not, and are not, readily convertible to motor bus use.

Three of the five streetcar lines (K, L, and M) use the Twin Peaks Tunnel, which was completed in 1917. One of

the lines (N) uses the Sunset Tunnel, completed in 1928. The fifth line (J) partially uses an exclusive right-of-way parallel to Church Street. Before the completion of the subway, all five lines used the same tracks for more than 2 miles on Market Street. At Duboce and Church Streets, in the Upper Market area, two of the lines separate from the other three: The N Line proceeds west to the Sunset district; the J Line serves a portion of the Mission district; and the K, L, and M lines travel through the Twin Peaks Tunnel to serve, respectively, the Ingleside, Parkside, and Ocean View districts.

This is the surface portion of the existing Muni streetcar network that has been transformed into a light rail vehicle system called Muni Metro. The primary objective of this modernization was to provide significantly improved speed, capacity, comfort, reliability, and safety to the patrons of the existing streetcar system.

One of the major improvements provided by the Muni Metro has been the replacement of 2 miles of surface street operations on Market Street with nearly 5.5 miles of subway. This subway includes four stations in downtown San Francisco—shared by occupying the upper level of the BART subway—plus three new Muni Metro-only subway stations along Market Street. In addition, one subway station is to be remodeled in the Twin Peaks Tunnel, and one new station is at West Portal.

In addition to the subway improvements, the surface operations of Muni Metro were upgraded: The aging track and power distribution facilities were repaired or replaced; facilities were provided to aid the separation of rail traffic and vehicular traffic; and additional passenger-loading islands were constructed.

One hundred new U.S. standard light rail vehicles (SLRV) were procured for service on the Muni Metro. These vehicles were built by the Boeing-Vertol Company under a contract signed in 1973. The cars are capable of speeds up to 50 mph, are articulated to facilitate curves in streets, and have steps adjustable to high and low. High

steps accommodate the standard design of high platforms in the subway stations; low steps meet the pitch of standard traffic islands and street stops.

METRO TASK FORCE

Although it was in the works for a number of years, the pieces of the Metro System really began to come together with the creation of the Muni Metro Task Force, established in 1978. The Task Force consisted of a small number of staff members and a director, Farrel Schell, who had the responsibility for recommending and expediting the timely completion of actions necessary for the successful inauguration of Muni Metro service.

The Task Force worked with other members from all Muni departments, Public Utilities Commission Bureaus, and other city agencies that had direct line responsibility for various aspects of Metro implementation. This Task Force concept proved to be an effective management tool in coordinating and directing the efforts of so many different departments and agencies working to bring the Metro into operation.

COUPLING ISSUE

Could Muni couple LRVs safely? Because the system lacked experience in coupling cars, some safety-related concerns were raised, such as hazards inherent in coupling, the hazard of coupling on a grade at Duboce Portal, and the risk of "fall-on-board" types of accidents. These potential hazards were quickly dispelled after Muni acquired the LRVs and tested the coupling procedure during the test and acceptance program. Muni learned that it could couple LRVs without incident.

Muni Metro's system components were designed to allow coupling. As proposed, coupling would be accomplished at the two entrances to the subway. Three lines, K (Ingleside), L (Taraval), and M (Ocean View), would couple into trains at West Portal Station. Similarly, J (Church) and N (Judah) cars would couple at Duboce Portal and proceed into the subway as a train.

It was hoped that peak headways on individual lines would be about 4 minutes, with trains from the two subway trunks merged alternately at the subway junction. They would operate on a 2-minute combined peak headway to the Embarcadero Station terminal.

This operational strategy built high capacity around the use of multi-car trains despite a relatively long 2-minute headway. (Market Street surface streetcar operations ran on a 50-second headway.) In fact, the physical design of the Embarcadero Station Terminal facility effectively prevented turning trains around in less than 2 minutes. Thus, subway capacity was limited by the terminal capacity, not line capacity.

This type of scheduled operation has never been implemented. A number of factors contributed to its demise. A major factor was the operation of the LRVs on the surface: They proved to be much slower than expected. It quickly became evident that a 4-minute peak headway, given the number of LRVs Muni had purchased, would be impossible to obtain.

The reliability of such a schedule was based on the almost-perfect arrival of cars at the coupling locations, so trains could be dispatched at regular intervals. Delays at coupling locations were inevitable unless timely arrival of cars from outer terminals could be assured. With LRVs operating on the surface in mixed traffic, this became an impossible task. In addition, early service was plagued by numerous delays caused by car disablements on the street. These frequent disablements ruined any chance of regular arrivals for coupling. Once the coupling cycle was broken, "short trains" would be dispatched before all scheduled cars arrived. This caused haphazard outbound schedules, which then contributed directly to problems of scheduled coupling when these trains arrived back at the coupling point off schedule.

Although Muni chose not to use the "scheduled" coupling, it devised a method of coupling that was not tied to scheduled arrivals. The procedure of coupling and sequencing cars is discussed later in this paper.

TEST AND ACCEPTANCE PROGRAM

Before any of the new LRVs went into revenue service they had to prove themselves in the test and acceptance program. Each vehicle was required to provide well-documented proof that, under simulated revenue conditions, it was able to perform up to specifications.

Each vehicle had to show 30 "good" days of service. A "good" day meant that, if in revenue service, the vehicle would not have to be removed from revenue service due to mechanical problems. Areas that received extensive testing were braking rates (service and emergency), acceleration rates, and the propulsion system. This program used the combined efforts of Louis T. Klauder and Associates, a Muni engineering consultant, and the Muni operations and engineering departments.

In addition to testing the vehicles, Muni used the test and acceptance program to develop a new operator's training program that provided instruction in operating in a high-speed subway environment, knowledge of the signal system, troubleshooting vehicle problems, and emergency procedures.

The test and acceptance program allowed Muni to test the LRV's capability to sustain regular programmed in-service coupling, which was to be an important feature of Muni's operating strategy. All tests showed that in-service coupling could be accomplished safely and without damage to the LRV's couplers.

Projected operating schedules called for LRVs to operate on a 4-minute surface headway. However, tests of the LRV in surface operation showed that it was significantly slower than PCCs, due primarily to slow door cycles and a 3-second delay from the time power is called for and a brake release is achieved. Given the slower surface operating characteristics, it became apparent that Muni would not be able to operate on a 4-minute headway.

The test and acceptance program allowed Muni to "season" the cars before actual revenue service began. In addition, it provided the time and experience to develop new operating rules and procedures for the subway and to familiarize operators, supervisors, and maintenance personnel with the many new Metro features.

PHASE-IN STRATEGY

Metro service did not begin all at once on all five lines. Muni had decided on a phase-in strategy because subway operation was both new to Muni and far more operationally complex than Muni's traditional mode of streetcar operation. The phase-in strategy provided hands-on experience and opportunities to learn. Phasing was also a response to the fact that various components—new track and electrification facilities, station fare equipment, etc.—were not all available at the same early date as a single line could be placed into service.

The phasing-in of Metro service proceeded as follows:

- Phase 0 was a preliminary operating phase that introduced the LRVs to the public and provided surface operational experience.
- Phase I began on February 18, 1980, with the N (Judah) line operating with LRVs in the subway in revenue service. Five downtown stations were open.
- Phase II added 2-car trains in revenue service on June 11, 1980, from Embarcadero Station through the Twin Peaks Tunnel to just west of West Portal Station. All nine stations were in use.
- Phase III added on December 17, 1980, the M (Ocean View) and L (Taraval) lines to Metro service. (Headway and fallback scheduling began with this phase.)

- Full operation was inaugurated on June 17, 1981, when the J (Church) line began Metro service. Metro service operates 5 days a week from 4:30 a.m. to 12:30 a.m.

FULL-SCALE OPERATION

When Metro began full-scale operation with all 5 lines running in the subway, the operational plan attempted to respond to a number of problems encountered during the last phases of operation. One serious problem was the capacity of the Metro system. Although there are no entirely accurate ridership figures available, estimates from the data of the automated fare collection equipment and passenger counts of the schedules department indicate that ridership began increasing with the very first phase of Metro. At present Metro carries about 125 000 to 140 000 riders per day, with large concentrations (about 15 000) during the morning and afternoon rush hours. As noted previously, the Embarcadero Terminal (stub-end operation) limited the system capacity to 30 trains per hour if each was turned around in 2 minutes. So Muni decided to run as many multi-car trains as possible to accommodate rush-hour crowds. To accomplish this, it was necessary to couple at the Portals.

To accommodate large numbers of passengers waiting on station platforms, and to avoid overcrowding, it was decided to stop trains at certain predetermined platform locations. Therefore, the Twin Peaks lines (L, M, and K) used the westernmost platform stops, while the Duboce trains (N and J) used the mid-platform stops. In this way passengers were not crowded to one end of the station platforms.

Once Muni had these discrete stopping locations that assisted in queueing passengers and reduced confusion about where to wait for a certain train, it had to guarantee that the train consist would be consistent. In other words, the headway system did not guarantee a particular pattern for train arrival at the portals. As discussed, dispatching three separate lines from diverse terminals and running in mixed traffic produced random arrivals. So when three LRVs would arrive at West Portal Station, inbound, they could be in any order—i.e., K-M-L, L-M-K, L-K-M, etc. Therefore, a transit line coordinator not only coupled trains together but also sequenced them; that is, he would assign them a predetermined order. In this way Metro cars were portal-controlled. Coordinators at both subway portals performed these functions: coupling LRVs, sequencing them, and distributing them to the proper line.

While this was a fairly routine job during base periods, the job got significantly more complex during morning and afternoon peaks when the coordinator had to ensure that all pull-outs were assigned their proper line and then were depleted after the peaks were over. This meant managing the difference between 61 base-period cars and 82 peak-period cars.

In January 1981, when the last of the Metro lines, the J (Church), went into subway operation, the decision was made to inaugurate a headway and fallback operation of Metro. By using this "dynamic" scheduling system it was hoped that Muni could move more riders with the existing LRVs. Since Muni could not have more cars, the ones in service had to be put to more productive use. Of course, a traditional schedule with operators tied to vehicles did not allow for this. It seemed hard to justify a \$300 000 vehicle not working because the operator needed a break or because the schedule had recovery time built into it to allow for any delays incurred while running to the outer terminal.

The two components of the headway and fallback schedule work together to reduce schedule recovery time and allow the operator time out of seat, while keeping the vehicle working. Another feature of the headway system is the ease of adjustment by the transit line coordinator supervising the line when delays occur.

Each of the five Metro lines is monitored by a transit

line coordinator (TLC) positioned at some point on the line. These TLCs work in two shifts, providing coverage from 6 a.m. to 10 p.m. During this time TLCs give each outbound car a leaving time from the outer terminal that keeps cars spaced at 6-minute intervals. TLCs work to keep LRVs moving by giving only a minimal amount of "recovery time" (about 1-3 minutes) at the terminal. If problems occur, the TLC, who is in radio contact with Muni's central communications, uses switchbacks at various locations along the line to restore disrupted service.

If the LRV is kept moving in service, when do the operators get a break? Operators get their break at the Embarcadero Station terminal. When an LRV reaches Embarcadero Station, the operator who brought it from the outer terminal gets off and a new operator takes the car for its next trip. The operator who has just been relieved then becomes part of the pool of operators and waits until he is called for his next trip. The fallback is designed to give operators a break of 8 to 11 minutes. In the case of multi-car trains, the entire crew is replaced with fallback operators.

The implementation of the fallback system meant that an operator might not work the line he had signed on. The new union contract in fiscal year 1980-1981 allowed Muni to have this flexibility within certain limits; that is, operators could make up to three trips on other than their primary line.

The fallback system solved a problem experienced by many operators in the early phases of Metro who found themselves late at the outer terminal and unable to get a break at all. With fallback, some break was guaranteed.

By headwaying the LRVs and using fallback with the operators, Muni was able to keep the LRVs moving. Schedule department estimates indicate that this system allows Muni to maintain capacity with 6 to 8 fewer cars in the base period and 12 to 14 fewer cars in the peak periods than would be required with normal schedules. This "saving" is critical, since Muni is currently limited to its existing 100-car fleet and is dealing with a high-technology vehicle that has proved to be maintenance-intensive.

The Embarcadero Station terminal was still the limiting factor in the Metro system. In fact, the job of dispatching crews at Embarcadero compounded an already laborious and complicated turnaround process. Thus the crew dispatching at Embarcadero was to remain there only until a permanent structure and office could be constructed at Montgomery Station, which is one station west of Embarcadero.

By moving the fallback to Montgomery, Muni attempted to break the bottleneck at Embarcadero by putting the relief operator on the train at Montgomery. Then the operator would ride in the inactive cab and prepare it for its next outbound trip. Once at Embarcadero, with operators in each cab, the LRVs were more quickly activated for their outbound trip, passengers were loaded, and the train dispatched. The operator who had just finished his trip would ride back to Montgomery and join the fallback pool.

The operation of the fallback at Montgomery has proved successful in reducing the time required to turn trains around at Embarcadero. All trains can be ready to be dispatched in 90 seconds or less.

Simultaneously with the move to Montgomery, Muni operations managers addressed the problem of one-sided service in the subway. The line sequencing and distribution control at the portals was moved to Van Ness Station, the first station receiving trains from both trunks. The transit line coordinator here had the job of sequencing the trains and distributing them to the proper line. Thus the TLC had control of all the trains entering the system. Trains were still coupled at the portals to reduce the number of units in the subway and help provide increased capacity during peak hours.

By following an hour-by-hour guide that indicates how many cars should be working each line, the TLC at Van Ness would assign each of five lines the appropriate

number of cars it needed to carry its passengers. When he gave the train its assigned destination the TLC would communicate with the crew dispatcher at Montgomery the consist of each approaching train. (It takes about 4 minutes for a train to move from Van Ness to Montgomery.) During this time the crew dispatcher would assign the crew for the train and the operator(s) would move out of the waiting room and move to the platform at Montgomery to meet the train.

Gaining control of both trunks at Van Ness has proved successful in a number of ways. Service is spread consistently to both trunks, thereby reducing the waiting time for most passengers. By improving the consistency of service, passenger complaints have been significantly reduced.

By working with all the cars, they are distributed in a regular fashion, and so the TLCs on the surface are provided with a more regular outbound flow of LRVs. This allows them to provide the 6-minute headway with a minimum number of switchbacks.

Finally, this system has reduced any large gaps on a particular line caused by a lengthy delay by spreading the available cars among the five lines. When the delay is cleared, the cars trapped behind it are redistributed to lines that may have received a reduced number of cars.

However, no system is without its problems. Although space does not allow an in-depth discussion, following are some of the problems Muni is working to solve:

- Developing new operator dispatching procedures, including deployment of adequate fallback relief, making reliefs, tracking operator trips, and identifying operators and cars.
- Managing changeover from headways to night schedules after 10 p.m.
- Stacking of outbound trains caused by breaking up large trains at Embarcadero to keep proper sequence.
- Proper distribution to lines when the Van Ness trainmaster has too few cars.

Even with these problems, it appears that the dynamic schedule will remain at Metro since it works to help Metro meet its ever-increasing demand.

REFERENCES

1. Peter Straus. Muni Metro: Issues and Strategies. Issue Paper No. 1, 1977.
2. Jack Fritscher (Ed.). Muni Metro Master Plan: System Description, 1979.
3. San Francisco Municipal Railway 5-Year Plan, 1980-85, April 1980.

Base Specifications for Major Subsystems on the San Diego Light Rail Transit Project

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This paper provides information on the development of the base specifications for four major subsystems on the San Diego light rail transit project. These subsystems include transit vehicles, traction power, and signal and fare collection equipment. The plans and specifications were prepared from the operations plan and project design criteria.

On the San Diego LRT project, the plans and specifications of four major subsystems were prepared from the project criteria and were based on the features indicated in the operations plan. These features included a specified circuit time (roundtrip including both turnaround times), provisions for joint operation with freight trains, minimization of operating and maintenance staff requirements, a specific track plan, an indicated fleet size, absolute block limits, and a derivation of installed traction power capacity. The plans and specifications were developed with the philosophy of simplicity, use of proven equipment, and minimization of custom design; however, essential requirements were specified. Where such requirements were not mandatory and supplier or contractor ingenuity could contribute, the plans and specifications were open.

TRANSIT VEHICLE

The specifications of the transit vehicle may be considered in four parts. First, the vehicle had to have certain features and capabilities; second, the order would be for the fleet size; third, to minimize or avoid unexpected operating costs and difficulties, the vehicle design had to

provide for maintainability; and fourth, provisions were made for elderly and handicapped (E&H) passenger access.

With regard to the vehicle features and capabilities, suppliers were required to supply their standard production vehicle, which would have to satisfy the following objectives:

1. The vehicle must meet the requirements of the California Public Utilities Commission General Order 143¹, which deals comprehensively with LRT operations and includes a subsection on vehicle design. It provides minimum requirements for safety equipment, including brake control, door controls, and warning lights, and requires structural integrity for protection in the event of collision.
2. Performance was specified in terms of a 75-minute circuit time. Plan and profile data were given to prospective suppliers to determine computerized velocity-distance-time profiles. To qualify, suppliers were required to submit the data along with their computed energy consumption projections.
3. Peak-hour patronage at the maximum load point required a 15-minute headway to service 1500 passengers per hour. The Metropolitan Transit Development Board (MTDB) looked for a practical standee space, and, as a result, the standing load was generally considered as 2 passengers for each seated at the time. Two-car trains were expected to handle this load. It may be noted that actual San Diego experience indicates that a maximum practical load is 150 seated and standing passengers per car.

4. The question of air conditioning was studied quite extensively before deciding on natural ventilation for these cars, which would run in the San Diego coastal area. Suppliers were asked to describe how air conditioning would be provided and what its estimated energy consumption would be. The study indicated high costs in capital investment, maintenance, and energy consumption, all of which would result in an increase in the life-cycle cost of the system, with negligible benefits to the passengers, if the cars were equipped with air conditioning. Consequently, the traction power subsystem was not sized for air-conditioned cars.

5. The cars were required to be able to operate in multiple units. While initial operation required 2-car trains, system expansion contemplated 4-car trains. Train-lining was required for door operation, passenger signal, internal and external public address, propulsion and brake control, marker lights, and other train functions. A later requirement included trainlining the ticket canceler control (station setting and inspection freeze), but this was eliminated when on-board cancellation was removed from further consideration. The specifications required train-lining by contacts in a button head integral with self-centering couplers.

6. Because of the joint operation with the San Diego & Arizona Eastern (SD&AE) Railway traffic, all special trackwork and embedded track had to accommodate railroad cars and locomotives used in interchange service. Thus the vehicle specifications required the supplier to equip the vehicles with standard railroad wheel tread and flange. The specifications also required a resilient wheel-hub design to mitigate noise.

7. The specifications expressly required double-ended vehicles with doors and stairwells suitable for street-level loading at all stations.

8. The specifications were prepared early in December 1978. They required vehicle delivery beginning in Autumn 1980, i.e., a period of 18 to 24 months.

9. To avoid operating and maintenance problems, the supplier was required to substantiate proven experience in his proposed offer with regard to propulsion equipment, brakes, and doors.

10. The initial specifications required a 60-ft minimum turning radius. Later, the basis of the 60-ft limit was removed and a longer radius (82 ft) was permitted.

With regard to the fleet size, the operating plan indicated a circulation time of 75 minutes. In 15-minute headway service, this results in five 2-car trains. Thus, at maximum capacity, 10 cars are in the base or circulating fleet. In addition to this minimum base fleet, the operations plan required one 2-car train on standby and one 2-car train in scheduled maintenance, resulting in 14 vehicles.

With regard to maintainability, there were some practical difficulties in the specifications. A well-recognized and correct way to specify maintainability is to specify availability, which is a function of reliability and maintainability. The usefulness of this approach depends on the accumulation and proper monitoring of maintenance and reliability data during revenue service. The lack of such statistics made the monitoring question moot. For this small fleet, and the reliance on standard design, this approach could not be considered appropriate. It was realized that the significance of standard equipment means that the equipment is in satisfactory use somewhere. This leads to the specifications requiring the supplier to furnish an operator's certification that the design of the equipment offered has operated for 50 car-years with an operational availability of 90 percent based on a labor distribution of 0.1 man-hour or less per vehicle mile of revenue operation.

With regard to the provisions for E&H passenger access, MTDB had been working with a community committee representing E&H interests. As a result of its work, a number of features for E&H access that affected the vehicle were examined. The one feature new to LRT was a

chair lift. One installed lift was specified per vehicle. With no definitive answer, the basic project criteria relating to standard design was violated in the special interest of the E&H community.

TRACTION POWER SUBSYSTEM

The traction power subsystem includes all equipment and materials, from points of receiving power from the local utility company to points of utilizing that power by light rail vehicles. In general, the subsystem includes traction power substations, catenary, and feeders.

The preparation of specifications depended on four principal items: (a) the LRT system operating strategy; (b) the type of light rail vehicles selected, particularly the vehicle propulsion requirements; (c) the local power company's requirements; and (d) track plan and profile. After establishing these items, the design criteria were used to prepare the basic traction power subsystem specifications. For the substations, the following key criteria were applied:

1. The traction power subsystem must be designed to provide normal operating performance when all substations are operating on-line. This means it must allow (a) trains to operate at 15-minute headways, (b) two 2-car trains to accelerate simultaneously under full performance at any passenger station in the double-track section, and (c) one 2-car train to accelerate under full performance at any location on the single-track sections. The traction power subsystem must withstand the loss of any one adjacent substation without interruption of transit service. Under this condition, a train in the vicinity of the off-line substation should be able to accelerate with its traction motors in series connection if normal performance is not possible.

2. The incoming primary feeder from the local power company to each traction power substation must be limited to a single circuit. This approach simplifies the substation design and thus reduces its cost. A reduction in utility service charges was obtained by requiring that the incoming primary feeder be a non-dedicated line. However, the same primary feed may not service two adjacent substations because the transit system must retain operating capability if any one substation goes off-line.

3. The design of the traction power subsystem must minimize and mitigate the effects of stray currents.

4. The traction power subsystem must be entirely self-protecting and self-supervised, with no remote controls. External trouble annunciation is provided by an outside dome light visible to the train operator at each substation.

5. The substations must be designed to use proven equipment. Each substation must be transportable so that it can be readily relocated, if required. The substations must be factory-tested and when delivered must be ready for connection to the utility interface points.

The next design task was to size and locate substations by use of a series of computer programs. Prior to the computer analysis, a study was made to determine the materials for the catenary conductors for contact and messenger. Because the LRT line is in a sea air environment and also in one that is subject to industrial chemical pollution, the use of any material subject to corrosion was eliminated. Thus the choice for the messenger was reduced to hard-drawn copper. Because the messenger is the principal feeder circuit, the use of copper favors wider substation spacing. However, there is a limitation on how far the substations can be spaced because their spacing has significant effects on negative voltage rise in the track and overhead conductor temperature rise.

Setting economics aside, the best choice for the contact wire appeared to be bronze because (a) it has a greater life duration than that of hard-drawn copper and (b) it has a more definite yield point than copper and thus

mitigates the problem of creep or stretch. But the cost of bronze contact wire is about three times that of hard-drawn copper. Because the temperature range in San Diego is not too great and the amount of contact wire wear is not a real problem in LRT service, the specifications permitted the use of hard-drawn copper contact wire.

The candidate vehicles had an operating voltage range from 420 volts to 720 volts DC. As a result, 650 volts were selected as the 100 percent full-load voltage for the traction power subsystem, as opposed to 600 volts on other systems of this type. Such a selection was of a significant advantage because it allowed a higher line voltage drop, which allows substation spacing further apart than the usual 600-volt rating. To minimize voltage drop and the effect of conductor over-temperature, the overhead conductors for both directions in double-track sections were cross-connected.

One of the most important inputs to the specifications as a result of the computer analysis was the substation duty cycle indicated in Figure 1. The inclusion of this load cycle in the specifications was very important to ensure that the substations, particularly the transformer-rectifier units, would be properly sized for the intended operation in San Diego. The load cycle normally used for substations is not directly applicable to the San Diego LRT operation because it is based on a predictable overload that the system may experience at predictable times and locations. For the San Diego case, the base and peak periods are the same, and it lasts 12 hours every day. However, because the San Diego system is on a non-exclusive right-of-way, irregular stops are frequently necessary, and thus the locations for train acceleration are not preset as one might desire. Consequently, the design of equipment conforming to this special load cycle and that normally used for transit substations would ensure that the substations would operate satisfactorily.

Several features were incorporated in the design of the traction power subsystem to mitigate stray currents. Some of these features, which are generally accepted in the industry in North America, are (a) an ungrounded DC system, (b) relatively short distances between substations, and (c) the use of negative drainage equipment.

The catenary or overhead subsystem that supplies power to light rail vehicles consists of two distinct designs. The first is a single overhead suspension (Figure 2) where the contact wire is suspended by cross-span wires. Because of the relatively low conductance and amperage of the contact wires, underground feeders were installed parallel

to the trackway. This design is utilized in Centre City.

The second type of design consists of a catenary subsystem where a contact wire is suspended from two messenger wires (Figure 3). The tension of the contact wire and messenger wires is maintained constant over a wide temperature range through use of a balance weight system. This latter design is applied along the SD&AE mainline. The base specifications included the following provisions:

1. In Centre City, the catenary subsystem was required to harmonize with the extensive urban design work that had recently been completed on C Street. Consequently, parallel feeders were installed underground, and square tubular poles were selected to support the cross-span wires. The Centre City section was sufficiently defined to ensure that urban design constraints were satisfied.

2. Double insulation as required by California Public Utilities Commission General Order 95² (CPUC G.O. 95) was specified between all live parts of the catenary subsystem and ground for both the SD&AE mainline and Centre City sections.

3. Between the ambient temperature limit of 25°F and 130°F, the contact wire must be at or above the minimum heights specified by CPUC G.O. 95. In Centre City, 19 ft is the minimum height above top-of-rail. Along the SD&AE mainline, the minimum clearance is 22 ft above top-of-rail. The 22-ft clearance was difficult to maintain over such a wide temperature range. Thus, on the SD&AE mainline, the messenger and contact wire tensions are maintained constant over this temperature range with balance weights.

4. To obtain an economical pole design for the SD&AE mainline, the contractor was given three options: (a) prestressed concrete (selected by the contractor), (b) tapered tubular steel, or (c) wide-flange structural members.

5. Side clearances were specified to conform to CPUC G.O. 26D³ where freight and LRV traffic operates jointly and to CPUC G.O. 143 where no freight would operate.

Two different overhead wire configurations that have approximately equal conductivity were specified: (a) one 750-kcmil copper messenger supporting one 4/0 grooved copper contact wire and (b) two 185-mm² (approximately 730 kcmil) supporting one 120-mm² (approximately 4/0)

Figure 1. Traction power substation duty cycle.

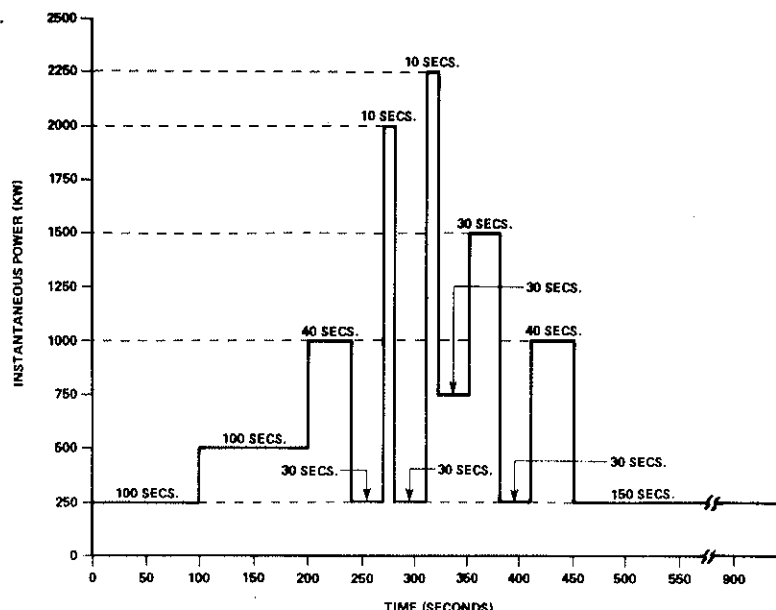


Figure 2. Single overhead suspension.

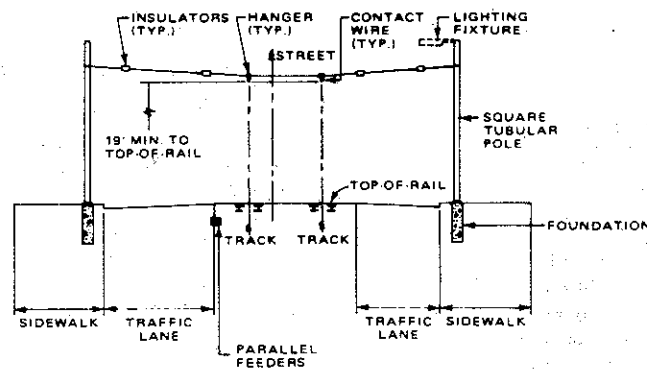
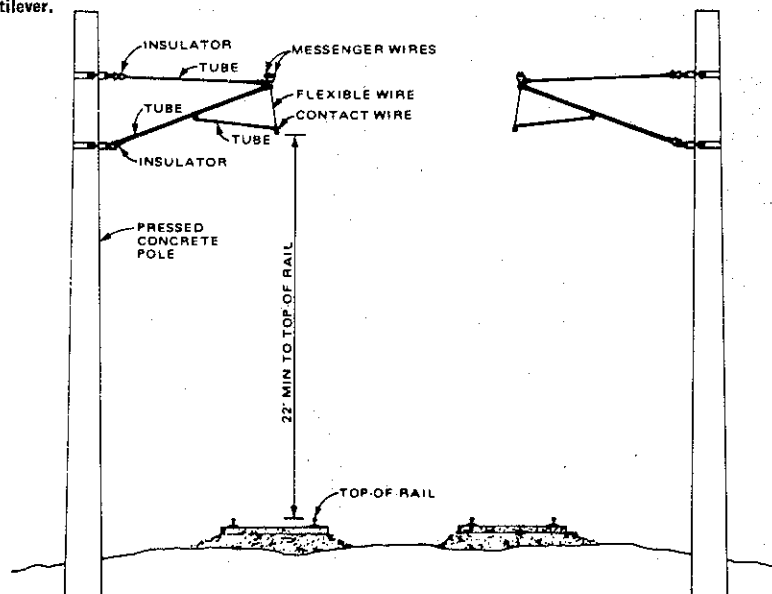


Figure 3. SD&AE catenary-cantilever.



grooved copper contact wire (selected by the contractor).

Once the configuration, weight, and cross section of the messenger and contact wires were determined, the maximum spacing between support structures and system height was determined, resulting in a maximum span length of 200 ft.

Two types of catenary support structures, cantilever and headpin, were specified for the SD&AE mainline. The primary structure, preferred for esthetic reasons and cost savings, is the cantilever structure. The cantilever arm assembly can be installed on poles located either to the side of a track or midway between tracks to allow one pole to support the catenary for both tracks. The inability to meet side clearances in track sections with existing highway structures or existing transmission towers did not permit center-pole cantilevers to be installed in all double-track sections.

The common characteristics of both structures is the inherent relief of tension in the event of broken messenger or contact wires. The cantilever assembly is hinged at the pole so that tension is relieved in the event of a broken wire through rotation of the cantilever assembly about the pole. In the case of headspans, tension is relieved by the deflection of the cross-span wires in the event of a broken contact wire and by free movement of the messenger wires on their pulley supports in the event of a broken messenger wire.

The movement of contact wire and messenger wires relative to their support structures is essential to a constant tension system. Balance weight assemblies are installed at 4000-ft maximum intervals known as tension length. The messengers and contact wires are secured at the midpoint of each tension length. Each balance weight assembly consists of a pulley with a number of concrete or iron weights to keep the sag and tension of the wires constant. Spans of adjacent tension lengths were overlapped at each end of each tension length. The overlap spans were arranged to permit the pantograph to pass smoothly from one tension length to the next.

SIGNAL SUBSYSTEM

The signal subsystem specifications were developed in three distinct areas. These areas covered (a) the protection of trains, (b) the protection of motor vehicles at railroad grade crossings, and (c) the control of traffic signals in downtown San Diego. The specifications for the train protection subsystem were a direct outgrowth of the operations plan, which called for absolute block signaling (i.e., no following train moves within a given signal block). Several specific design features, incorporated into the absolute block subsystem to meet special requirements for the San Diego LRT project, were as follows:

1. Because of movements of both transit and freight trains, the subsystem would have to meet all applicable safety requirements of both the California Public Utilities Commission and the Federal Railroad Administration.

2. Signaling would be accomplished by wayside color light indicators and manual operator response so as to eliminate the need for any on-board signal equipment on either transit cars or freight trains.

3. Switches at the ends of double-track sections would be powered by switch and lock movements.

4. All mainline switches to freight leads and spur tracks would be protected by electric locks. All locks may be unlocked by mainline train presence at the switch. In addition, some locks at freight leads or long spur tracks may be unlocked by absence of mainline traffic within the respective block control zone. This latter feature allows an operating freight to clear the mainline for transit moves should such action become necessary.

5. Central control of trains would be by radio only. With only five trains on the system at any one time, a radio dispatcher can readily control operations under any system conditions.

Signals in the block subsystem are established at freight train braking distances. Track circuits for the block subsystem are a combination of 60 and 100 Hz. The 100-Hz circuits are used where the tracks are located below several 138-kV transmission lines and may be subject to induced electrical interference.

An interesting feature of the signal subsystem is the need at ends of the line to discriminate between freight and transit trains where their respective trackage diverges. To avoid having any on-board ID equipment and for simplicity, the specifications called for a contact switch mounted on the overhead contact wire. Operation of the switch coupled with approach block occupancy calls for the transit route. Occupancy with no switch operation requests the freight route.

The project criteria required that all at-grade crossings of the SD&AE mainline be fully protected. The specifications accordingly required a full complement of automatic gates and flashing lights at each of the 28 crossings. In addition, at those locations with traffic-signalized intersections adjacent to the crossings, a preemption interface was provided to the traffic signal controllers to avoid giving motor vehicles conflicting signals.

Of interest in the crossing subsystem was the desire to be cost-effective by retaining several existing crossing protections. Problems that arose during start-up demonstrated that this older equipment was not capable of handling the number of cycles caused by a transit-type headway. Failures occurred primarily in gate mechanisms and power supplies, and most of these were replaced.

A relatively new feature for LRT operations was specified in downtown San Diego, where vehicles operate on the city streets. This was a subsystem of timed preemption of traffic signals to allow trains to proceed from station to station without stop. This subsystem was considered necessary if trains were to meet the run-times required by the operations plan. In addition, C Street, a one-way street for motor vehicle operation, had turns across the tracks prohibited.

Operation of the preemption subsystem on 12th Avenue was as expected; operation on C Street was not. The problem here was interference between preemption and the city's progressive signal phasing. The city and MTDB have arranged a trial arrangement to (a) not preempt and (b) to place all signals on the street into a common all green-all red timing sequence. Due to station spacing, trains move from station to station under signal control, with direction of move eliminated as a disrupting factor. Thus, the arrangement operates with a mixture of timed preemption on 12th Avenue and standard signal phasing control on C Street, and this appears reasonably effective.

FARE COLLECTION SUBSYSTEM

The specifications of the fare collection equipment were developed somewhat more subtly than the specifications for the three subsystems just discussed. In addition to the project criteria, the development of the specifications had to consider the fare concept. Five factors were considered:

1. The cost of fare collection must be a small fraction of the fare collected.

2. The subsystem must be suitable for regional bus transfers, including compatibility with present collection methods.

3. The subsystem must be able to cope with changes in the tariff, including changes in the value of tariffs.

4. A very important requirement was that the subsystem must not constrain vehicle loading to designated entrances or restrain station passenger circulation by virtue of paid and free areas.

5. The associated equipment must have been in proven revenue service and dependable.

Other issues, especially security, are inherent requirements of any conceptual choice. The issue of security involves protection of money handling and the prevention of passenger fare evasion. Once it is realized that absolute security is not possible, a design can be made for the most secure scheme without requiring a large staff and extraordinary facilities.

The ensuing study showed that the total cost of a barrier-free ticket system would be less than that of a farebox scheme. The ticket scheme is compatible with the regional bus systems, and it is flexible with regard to tariff changes. In addition, the ticket subsystem, especially inclusive of multi-ride tickets and monthly passes, enables fast boardings through all doors. No restraints are placed on the station design. In addition, the expected rate of fare evasion would be on the same order as the evasion rate for farebox and transfer-type systems. Having selected a barrier-free fare subsystem, provisions were made for ticket inspection by roving conductors who inspect tickets rather than lift them. MTDB proceeded to obtain powers of arrest to enforce penalties in the event an inspector locates an evader.

Two principal types of machines were specified—a vending machine and a canceler. The vending machine is coin-operated to vend tickets automatically in accordance with the passenger's selection of destination and fare class. The canceler is an automatic validator of a multi-ride ticket. In these specifications, the vending machine and canceler are placed in the same standing unit.

At the time bids were invited, the MTDB had not determined the applicable tariff. The specifications required a six-valued tariff—i.e., the product of fares and class of fares would be six. Later, MTDB decided on two zones and three classes, one of which merely upgrades a bus transfer. This tariff was readily introduced after the machines were built.

A key feature of the vending machine is coin processing. The specifications required the use of U.S. coins only; these included nickels, dimes, quarters, half-dollars, and the Susan B. Anthony dollars. In order to keep the base equipment simple, no change-making ability was required.

The specifications required the vendor to print and validate (i.e., cancel) tickets on the vend transaction. The imprint shows the time and location of the vend and the amount paid. Security is provided by a special imprint, a small saddle tank locomotive in this case, and by the use of specially imprinted paper stock. This is the essential minimum information required for on-board inspection. The ticket printer also prints the bookkeeping data generated from the microprocessor and required for accounts of the transactions of the machine.

The coin vault has a 4-liter volume. The specifications required a secure arrangement so that the contents

could be held in a vault until released in the counting room. An improvement proposed by the supplier and accepted by MTDB calls for locating the vault in the pedestal; this means that there is no reason for accessing the machine to change the coin vault.

The canceler operates on separately purchased multi-ride tickets only. Multi-ride tickets are canceled by guillotine, with validation data stamped on the ticket with each guillotine cut.

Because the consequences of a vendor failure are serious, the specifications required that the machine flag itself out of service if it ran out of paper, had a jammed coin acceptor, or otherwise could not process a vend. In addition, provisions are made for remote flagging over leased telephone lines to a central office. This feature allows immediate dispatching of service in the event a vendor is out of service.

SUMMARY

The plans and specifications of the four major subsystems were derived from the operations plan and project design criteria. The specifications for the vehicle were developed first because it was on the critical path of the project, and

the design of the other subsystems depended on it. This was followed by the specifications for the traction power subsystem and simultaneously by the signal and fare collection specifications. The plans and specifications prepared for this project attracted competitive bidding and are considered to have successfully fulfilled the intent of the LRT operations plan and project design criteria.

REFERENCES

1. General Order 143, Rules for Design, Construction and Operation of Light Rail Transit Systems including Streetcar Operations. California Public Utilities Commission.
2. General Order 95, Rules for Overhead Electric Line Construction. California Public Utilities Commission.
3. General Order 26D, Regulations Governing Clearances on Railroads and Street Railroads with Reference to Side and Overhead Structures, Parallel Tracks, Crossing of Public Roads, Highways and Streets. California Public Utilities Commission.

Self-Service Barrier-Free Fare Collection: An Early Look at San Diego's Experience

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With the opening of revenue service on July 26, 1981, the San Diego light rail transit system also inaugurated a self-service barrier-free fare collection system. Experience to date indicates that the fare collection system not only is achieving the objectives set forth but also is having other residual benefits. There are 18 stations and 27 ticket vending machines along the 16-mile line. These vending machines produce a validated ticket upon insertion of the correct fare, and they can also validate a 10-ride ticket. Valid tickets, bus transfers, or monthly passes must be in the possession of each rider (i.e., valid proof of payment). Thus far, fare evasion has been found to be far less than 1 percent of the daily riders. Patrons generally have positive feelings about the fare collection system. Capital costs were low and primarily a function of the type and complexity of the vending machines. Likewise, the operational benefits include low labor intensity (ticket inspectors are required for policing proof of payment) and efficient boarding and unloading of passengers using all doors on one side of the train (e.g., eight for a two-car train). An important result of the ticket inspection team is the public relations benefit gained. The ticket inspectors have become ambassadors of a sort. The nature of the system means there are no conductors and no station attendants; also, the train operator does not participate in any patron functions. Therefore, the ticket inspectors become the only employee of the operation that the public comes in contact with. A firm yet positive attitude was stressed during their training program, and this has seemingly paid off with resulting positive attitudes from patrons. The early results of self-service barrier-free fare collection in San Diego demonstrate its cost-effectiveness.

Self-service, barrier-free fare collection systems have recently been implemented in Edmonton and Calgary, Canada, and in San Diego, California. Portland, Oregon, is also preparing for a major effort to implement such a system for the entire bus network.

Attention to self-service fare collection has heightened over the past few years through various research efforts.⁵⁻¹⁰ However, implementation has been stalled for a variety of reasons, but primarily due to a skepticism that such a system would work. According to recent research, the self-service concept represents such a significant departure from current U.S. transit systems' fare collection procedures that a series of demonstrations are recommended.⁷

With the recent start-up of light rail transit in San Diego, the self-service, barrier-free fare collection system was also inaugurated. The system was particularly patterned after European examples without benefit of demonstration results. An early look at San Diego's experience confirms the benefits cited by the research.

BACKGROUND

As part of the guideway feasibility studies conducted by the San Diego Metropolitan Transit Development Board (MTDB), a key concern of the impact and economic analyses centered around the type of fare collection system to be used.^{1,2} The fare collection system can have significant bearing on the capital costs (e.g., turnstiles, fare machines, "paid" areas), operating costs (e.g., conductors, revenue collection personnel, maintenance of machines, ticket booth personnel), and, in San Diego's case, the operating plan.

In the early stages of the feasibility study, the MTDB's Board of Directors determined that light rail vehicle technology would be most appropriate for San Diego. With that determination, efforts began to focus on use of the self-service, barrier-free fare collection system. The planning principles adopted by the MTDB's Board of Directors in December 1976 called for a practical, low-cost guideway project. These adopted principles recognized the necessary practicality involved with designing a rail transit alternative suitable to San Diego's conditions. These principles stated that, for a guideway transit system to be feasible in San Diego, it must have a low capital cost, operate mostly at grade, operate a long distance, be capable of operating at a high speed, have a low operating cost burden, and minimize the potential for adverse environmental impacts.

With regard to the fare collection system, these principles converted into the following:

- Low-cost station facilities—the ability to construct relatively low-cost shelters with no escalators, elevators, turnstiles, or barriers.
- Minimal operating cost per unit of revenue collected—the ability to cut down on labor costs by eliminating conductors on board for fare collection and ticket and fare collection personnel at stations (to be replaced with a ticket inspection team).
- High-speed, multi-door boarding—the ability to minimize dwell times at stations by permitting use of all doors on a multi-car train for boarding.

The light rail transit project adopted by the MTDB's Board of Directors and subsequently implemented initiated revenue service on July 26, 1981. The line, called the San Diego Trolley, runs 16 miles between Centre City San Diego and the International Border at San Ysidro (Figure 1). There are a total of 18 station stops, with 11 located outside Centre City at an average spacing of around 1.25 miles. A top speed of 50 mph is reached in the non-Centre City portion of the line. On-street operations in Centre City are limited to 25 mph (or the posted traffic speed limit).

The key determinant to the feasibility of the light rail project was the potential for operating cost efficiencies to be obtained in the South Bay corridor. To realize these savings, labor costs had to be reduced while ridership was being maximized. Thus, the self-service fare collection system became a critical part of the feasibility determination, one that the MTDB's Board of Directors followed through into operations despite skepticism from the community^{3,4} and from transit operators. Typical of the attitude of the transit community was the technical review from an area operator in San Diego that concluded with the following:

Based on the amount of difficulty we presently experience and the hassles on the buses currently caused by fare collections, we must express our skepticism about the self-service fare system proposed in the MTDB plan. Self-service fare systems may be common in Europe; however, to our knowledge there are no systems operating in the United States. Granted such a system would facilitate the loading of passengers and would make possible lower cost stations, particularly in the downtown area; but there is also the very real possibility of losing a great deal of revenue due to persons paying the wrong fare or no fare at all.¹⁴

It is relevant to note that the MTDB's Board of Directors was not skeptical. Thanks to an intensive eight-city tour of European transit systems, the Board was convinced that the self-service fare collection system would work in San Diego.¹¹

DESIGN CRITERIA

The light rail project was adopted by the MTDB's Board of Directors in late 1978. A key facet of the feasibility determination was the emphatic requirement to stay with the light rail operating philosophy. Thus, the critical step in going from planning to implementation was to develop design criteria that accurately and realistically carry out the philosophy. It was important, too, that the eventual criteria were adhered to all the way through to operations.

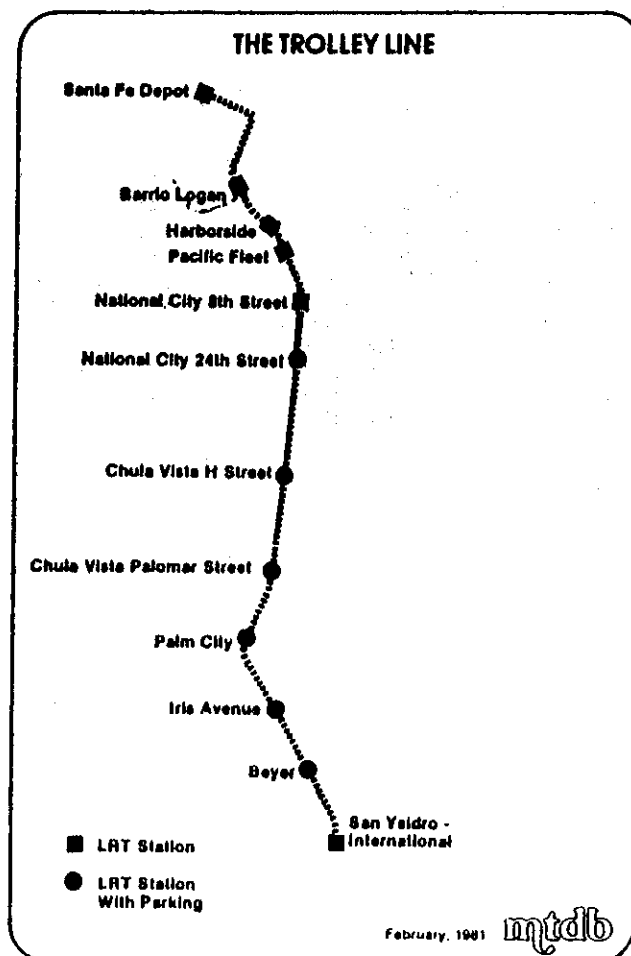
Bechtel, in a coordinated effort with Tom Parkinson, pulled together the initial technical study supporting the various operational facets of the self-service, barrier-free system.¹ Their work provided the basis for detailing the equipment needs as well as operational features of the system. In addition, this effort included cost analyses comparing the self-service system to a more standard rapid transit fare collection system with turnstiles and paid loading areas.

The operational criteria essentially revolved around a key consideration: the higher the percentage of prepaid users on the system, the lower the dependence on fare collection personnel and machines. Even so, there still was a need for single-ride fare collection capability.

The criteria finally adopted called for a self-service, barrier-free system with the following capabilities:

1. Machinery that would provide for six-value fare tariffs;
2. Accommodation of on-vehicle and off-vehicle ticket vendors and on-vehicle ticket cancelers and validators;

Figure 1. Trolley line: Santa Fe Depot - San Ysidro International.



3. Fare policies encouraging prepayment of fares at off-system locations; and

4. Development of effective legal means to form and carry out policy and procedures to deter evasion.³

After adoption of the design criteria, it was decided that the fare collection equipment should provide a single-ride ticket already validated. After further staff evaluation, the on-board ticket validation machine was discarded as a practical option. Instead, it was decided to have all validation occur off the vehicle to allow the most efficient passenger boarding possible. In combination with the location of the vending machines at the stations, the criteria were further modified to include that the machines be especially vandal-proof and ruggedly constructed.

DESCRIPTION OF THE FARE COLLECTION MACHINE

Bids on the fare collection devices were received in September 1979. The resultant low bid was obtained from Autelca of Gumligen, Switzerland. The resulting machine, called the BE-20 by Autelca, has the capability of providing a single-ride cash-fare ticket and validating a multi-ride ticket. The MTDB specifications required coin fares only but included the Susan B. Anthony dollar; no change is provided.

The two types of tickets considered are the single-ride ticket, which is dispensed on deposit of the required coin fare and indicates type of tariff, date, time of day, station number, and a security symbol, and the multi-ride ticket ("Ready 10"), which is validated with information similar to the single-ride ticket. Upon inserting the ticket into the proper slot, the machine prints the information and guillotines off one-tenth of the ten rides available. As many as 10 people could ride using the one Ready 10 by inserting the ticket for multiple validations (once for each individual riding). A two-ride ticket ("Ready 2") has also been developed and operates in the same way as the Ready 10.

In addition to being proof of payment, the ticket received from the machine is valid as a transfer to all connecting bus carriers in the metropolitan area. Bus transfers to the trolley are also accepted but sometimes require an upgrade. This transfer arrangement is part of an areawide agreement among all fixed-route public transit operators in the San Diego metropolitan area and encourages efficient transfer among all routes regardless of operator.

This areawide transfer agreement is also coordinated with a fare policy in which all operators participate. The fare policy is a variation of a flat fare structure and has set fares based on service function rather than zones. The level-of-service concept is based on average passenger trip length and covers three classes: (a) metro—higher speed, express and trolley routes; (b) urban—trunkline, arterial routes; and (c) local and feeder—local, neighborhood routes. The fare policy permits free transfer between routes of similar function, although a transfer from urban or local and feeder to metro requires an upgrade.

The resulting fare structure is as follows:

- Single-ride fare:
 - Metro (includes trolley) = \$1.00
 - Urban = 0.80
 - Local and Feeder = 0.60
- Senior citizen and handicapped fares: 0.40
- Transfer upgrade (from urban and local feeder to metro): 0.20
- Transfer between metro bus and trolley: Free

For the trolley only there is a special 25 cent fare for the Centre City zone. The Ready 10 offers a discounted fare and sells for \$7.50 (or 75 cents a ride). The Ready 2 is sold at full value, or \$2.00.

Rounding out the fare policy is the area's monthly pass

("Ready Pass"). The pass is accepted by all operators and offers a discount for the regular rider (sells for \$31 per month). It is usable on all systems and on all fixed-route services (i.e., no upgrade is necessary).

TICKET MACHINE PERFORMANCE

Machine performance, from both the public and maintenance viewpoint, has been very satisfactory. As with most other equipment being used, the basic machine has been in use at other properties for many years.

The 27 machines in service are vending 190 066 tickets and validating 34 637 multi-ride tickets in an average month. In December 1981, there were 180 reports of machine malfunction, of which 25 percent were false reports (the machines were working properly when inspected). Through maintenance procedure changes, the failure rate has been decreased 50 percent over that experienced in the first month of operations. Further improvements are expected.

About 20 percent of the service calls are due to a jammed validator. In some cases validators are being intentionally jammed (vandalism) and in others it is due to the condition of the multi-ride ticket stock. The stock will be changed when tickets are reordered to eliminate this problem. Vandalism and machine tampering have not been major problems.

TICKET INSPECTION

The self-service fare collection system used in San Diego is not an "honor system" but relies on each passenger having proof of payment. This proof can take the form of validated single-ride tickets, Ready 10s, Ready 2s, bus transfers, or Ready Passes. For enforcement, ticket inspectors conduct random checks throughout the system.

The ticket inspection team consists of six individuals plus a supervisor. They are uniformed and are equipped with two-way radios. Radio communication is necessary to keep in contact with the control center and security.

The training of the ticket inspectors (TIs) is especially important because these people are essentially the only representative of the operation with which the patron comes in contact. Therefore, the TIs must be firm for fare inspection purposes, but they also must have positive personalities in order to handle potentially difficult situations. Further, they must be able to help patrons who are in trouble with some facet of the operation or who need information on how to use it or how to transfer.

The TI training program takes 2 weeks and includes a mix of security instruction with ticket inspection procedures. The training was conducted under contract with a local private security firm schooled in police officer training and emphasized the community public relations aspects of the inspection services.

In preparation for the start of service, MTDB had some knowledge of ticket inspection procedures gained from the European trip and discussions with Edmonton (which started a self-service program in 1980) and consultant assistance from the Zurich transit system. Even so, development of the operating procedures had to be specific to San Diego and essentially was a "ground floor" effort. The type of vending machines, transfer arrangements, and operating plan of the trolley are all critical and unique conditions that required focused attention in order for the procedures to have application. In other words, one cannot just duplicate operating procedures from another system. The overall philosophy of ticket inspection must be established, and this can have different policy backing from one area to another.

After several months of development, a standard operating manual for the TIs was formally issued.¹² No grace period was established for patrons when service was initiated in July 1981. Rather, the TIs were instructed to start out using the standard procedures. In this manner, the TI was relieved from having any discretion as to what consti-

tuted a legitimate excuse for not paying a fare. However, there is an administrative procedure for dismissing citations, and this is used in certain deserving cases.

Observations, confirmed by letters and informal correspondence, indicate that the TIs have become an effective and popular representative of the transit system. Their job entails far more public relations and information help than writing citations, and this function is proving to be a positive and interesting part of the patron's ride. Also of significant help, due to the international market associated with the line, is the requirement that all of the TIs be bilingual.

Needless to say, there must be a penalty associated with fare evasion. In 1980, the state legislature passed laws that permitted MTDB to contract for security services and established a fine for fare evasion up to \$500. In March 1981 the MTDB's Board of Directors adopted a fare ordinance that established bail at \$20 for first-time evaders. On a second offense the individual would face a fine of \$50, and a similar fine plus a mandatory court appearance on a third offense. State law provides that MTDB receive 85 percent of the fine revenue received from fare-evasion cases.

To ensure enforcement support from the courts, meetings were held with key judges before service was initiated. Ticket inspection procedures were reviewed and in some areas changed based on the judges' advice. As a result, a good partnership has been achieved.

After the first 6 months of operation, results of the self-service fare collection system are positive: 2 001 000 riders, 829 000 riders checked, 2231 cited for evasion. The inspection rate has averaged just about 41 percent of all riders. Thus, this experience shows an evasion rate of 0.27. This rate has remained constant, even though the TI team has been working with six members rather than seven for the last several months.

An internal audit of the ticket inspection procedures and the TIs' performance was conducted after service was in operation for a month.¹³ In general, the results confirmed the adequacy of the procedures but helped assist in making various changes to tighten up. All things considered, the self-service system has been achieving the primary objectives that had been established.

INFORMATION PROGRAM

One aspect of the self-service system where the San Diego effort has appeared deficient concerns the in-place information system. The inherent nature of this fare collection system requires the patron to obtain information by reading or observing signs. Since there are no conductors and no station attendants, the signs at a station become critical information components. Not only must the information be readable and accurate, but the graphics must be reasonably appealing in order to catch the attention of patrons and lead them through the various components of buying a ticket and waiting for a train.

The initial signing was, at best, minimal. Perhaps this was a wise strategy from a cost standpoint, in that the new signing program has been developed based on actual surveys of riders and thus should be more responsive to actual, observed needs.

In providing information under a self-service situation, the TIs are normally the only system employee that a patron comes in contact with. It is significant to note that they themselves provide an important information function and are instructed to be as helpful as possible with patrons. This role for the TIs has provided unexpected benefits: They are a sort of roving ambassador for the trolley. In addition to giving out information, either orally or some of the pamphlets, they also try to make the ride a positive, enjoyable experience by being friendly and engaging without detracting from their inspection function. For example, they carry punch-out fold-up trolleys that they give to children riding the trains.

CONCLUSIONS

1. In San Diego's case, the self-service barrier-free fare collection system has achieved positive results:
 - The labor intensity for fare collection is low.
 - The fare evasion rate is low.
 - Boarding and unboarding times are minimized.
2. The self-service fare collection system does not risk abuse when
 - The fare is reasonable compared with the quality of service.
 - The penalty is sufficiently high to encourage payment.
 - Enforcement is readily visible.
3. A complementary signing and information system is required for the self-service system to work effectively.
4. The ticket inspection team can offer a positive face to the transit system and provide a roving ambassador function in addition to inspection functions.

REFERENCES

1. Bechtel, Inc., for San Diego MTDB. Task No. 10, System and Vehicle Specifications, January 15, 1978.
2. Bechtel, Inc., and the San Diego MTDB. Workshop Paper: Fare Collection System, January 8, 1979.
3. David Smoller. Trolley Apt to Strain Rider Honesty; Officials Admit It May Be Easy to Avoid Paying a Fare. Los Angeles Times, March 16, 1981.
4. Tom Goff. Is the Honor Fare System on the Tijuana Trolley a Ticket for Trouble? Los Angeles Times, March 19, 1981.
5. Self-Service Fare Collection: Review of Legal and Labor Constraints on U.S. Implementation. Mitre Corporation; UMTA, May 1979.
6. Volume II—Self-Service Fare Collection: Survey of European Transit Properties. Mitre Corporation; UMTA, May 1979.
7. Volume I—Self-Service Fare Collection: Review and Summary. Mitre Corporation; UMTA, August 1979.
8. Ticketing Procedures in Self-Service Systems. Mitre Corporation; UMTA, February 1980.
9. Implementation Requirements for Self-Service Fare Collection System. Mitre Corporation; UMTA, June 1980.
10. Manuel Padron and Richard Stanger. No-Barrier Fare Collection. TRB, Transportation Research Record 614, 1976.
11. European Transit System Tour: Trip Report, San Diego Metropolitan Transit Development Board, December 1977.
12. Standard Operating Manual, Ticket Inspection Force, Issue No. 1. San Diego Metropolitan Transit Development Board, July 26, 1981.
13. Review of Ticket Inspection and Revenue Collection Procedures. MTDB Administration Committee Agenda Item No. 93, San Diego Metropolitan Transit Development Board, and Peat, Marwick, Mitchell & Co., January 21, 1982.
14. MTDB Final Report. Internal Memorandum to Board of Directors, San Diego Transit Corporation, July 6, 1978.

Surface LRT Operation in Downtown Calgary

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This paper deals with the operation of the Calgary light rail transit line called "C Train" in the downtown area. The line operates for approximately 1 km (0.6 mile) on a standard street that it shares with a peak-hour volume of more than 100 buses. The limitations of this shared roadway system and the special operating rules for both bus and C Train are explained. The effects on the suburban bus system and the interface between feeder buses and the C Train are explored. The paper discusses the reasons for selection of the surface lane on 7th Avenue and the designation of 7th Avenue as a transit and pedestrian mall.

Calgary's C Train line is 12.5 km (7.5 miles) long and runs for most of its length within the right-of-way of the main line of the Canadian Pacific Railway. Once the line leaves the railroad right-of-way it enters a 700-m (2280-ft) tunnel emerging at the south side of the Stampede Grounds. After crossing the Stampede Grounds the line enters a 470-m (1545-ft) tunnel to cross beneath the main Canadian Pacific Railway line, which runs along the south side of the downtown core in an east-west direction.

The line emerges from the tunnel and enters the intersection of 7th Avenue and 3rd Street S.E. at a 45-degree angle. The line then proceeds along 7th Avenue at grade to a terminal at 7th Avenue and 8th Street S.W. This on-street portion of the line is 1 km (0.6 mile) long.

The operation of a light rail line on a downtown street presents a unique challenge and unusual operational problems. The special operating rules for both the C Train and buses on 7th Avenue are discussed in detail, along with the special road markings and signing.

BACKGROUND

The Downtown Master Plan for Calgary (CALTS, April 1976) designated 7th Avenue as a transit mall and a pedestrian corridor. There were two major factors in this decision:

1. There would be no benefit to including 7th Avenue as a major roadway in the downtown system because it lacks suitable connections with other east-west roadways.
2. Large volumes of pedestrian traffic made a major pedestrian corridor necessary in downtown.

Three alternatives considered for the provision of LRT on 7th Avenue were elevated, subway, and surface. The surface operation was chosen because of its lower capital cost and superior pedestrian access.

Nine stations are located on 7th Avenue. Important features of the stations are

- Access to the intersections at each end of the station,
- Access to Calgary's overhead ("15") pedestrian system, (a "15" is an elevated pedestrian walkway across a street between buildings that is approximately 15 ft above the roadway and interconnects many downtown buildings, thus allowing pedestrians to reach their destinations in comfort and safety),
- Use of extensive glazing and curved forms to reduce the apparent bulk of the stations,
- Offset loading locations to distribute passengers over the length of the station, and
- Space for accumulation of passengers for peak-hour and special-event loading.

The stations are spaced approximately 3 blocks apart, with bus stops located in the adjacent blocks. A major bus/LRT interface is at 1st Street West, approximately at

the midpoint of the 7th Avenue section; this is the timed transfer point for the downtown area.

SURFACE LRT OPERATION ON 7TH AVENUE

The operation of both buses and light rail vehicles on a standard downtown street presented many unique operational problems for Calgary Transit. Bus and C Train movements on 7th Avenue are controlled by a standard traffic signal system; i.e., there is no preemption for the C Train. Some of the problems and the solutions used to overcome them are discussed in the following.

C Train Operational Challenges

North Tunnel Portal

Trains exiting the north tunnel are in immediate conflict with pedestrians, eastbound buses turning left, and southbound buses turning onto 7th Avenue to go west.

The following solutions were developed. For pedestrians, a special crosswalk and signs were put in place. A special traffic signal governs C Train entry onto 7th Avenue, and a signal phase was added to allow the C Train to enter 7th Avenue while all other traffic is stopped. Eastbound buses are stopped at a special stop line approximately 5 m (15 ft) west of the standard location. Buses are prohibited from entering 7th Avenue on a red light. (Right turns on a red light are permitted in Alberta provided the vehicle comes to a complete stop first.)

Pedestrian-Train-Bus Conflicts

The problem of jaywalking pedestrians presents a safety hazard both to themselves and to the trains and buses. The solution involved placement of special "Do Not Jaywalk" signs, a high level of police enforcement, increased fines, and a 40-km/hr (25-mph) speed limit for buses and trains on 7th Avenue.

Signal Progression

The normal method of signal progression based on a vehicle's maintaining a speed that ensures a series of green lights would not work because the C Train was required to stop at all stations.

The solution was to install a computer-directed signal controller that "interlocks" traffic signals, so that once the train leaves a station it receives green lights to the next station.

Intersections

Trains proceeding through a green light did not clear the intersection during the green phase. This resulted in delay of automobile and bus traffic on cross streets.

The solution was to instruct C Train operators to proceed only on a "fresh" green light—that is, a green light shown in conjunction with the pedestrian "walk" indicator.

Another problem at intersections occurred when a 3-car train that stopped westbound at the 4th Street West intersection or eastbound at the 3rd Street West intersection would overlap about 5 m (15 ft) into the preceding intersection.

To solve this problem, the 3rd Street S.W. and 4th Street S.W. traffic signals were interlocked to present a single green phase to avoid having trains blocking the intersection.

8th Street West Terminal

A problem arose at the 8th Street West terminal when the crossover movement of the train from the westbound to the eastbound track created a potential conflict with both eastbound and westbound buses.

As a solution, a "center" line was painted to the outside of the eastbound track. Buses must stay to the north of this line. If a train is at the eastbound 8th Street West platform, buses may pass the stopped train. A cross-hatched area was painted in front of the platform. When a train is in this area, the bus may not pass the train. Thus, when a train is ready to leave, the operator pulls into the cross-hatched area and is given the right-of-way over the buses.

Special Operating Rules for 7th Avenue

Because of the great possibility of conflict between the two transit modes on 7th Avenue, special operating rules for both buses and trains became necessary. The following summarizes the main deviations from normal operating rules.

Bus

1. Buses may not overtake and/or pass a C Train moving in the same direction as the bus while on 7th Avenue with the exception of a C Train that is in the 8th Street S.W. station.
2. Buses may not pass a station on the right of the bus when a C Train is approaching from the opposite direction.
3. Buses entering 7th Avenue must do so only on a green light. Right turns on red lights are prohibited.

C Train

1. C Trains must not enter an intersection unless the traffic signals are displaying both a walk and a green signal indication.
2. Westbound C Trains may not leave the 7th Street S.W. station until signaled to do so by the switch supervisor.
3. Eastbound C Trains may not leave the 8th Street S.W. station until signaled to do so by the switch supervisor.
4. C Trains shall reduce speed to 30 km/hr (18 mph) when passing under "+15" walkways.
5. C Trains shall reduce speed to 10 km/hr (6 mph) when passing through the 8th Street switch.
6. As with all stations, trains shall sound the bell briefly before moving from a station to alert passengers that the train is proceeding.

Emergency Vehicles

Early in the operation of the C Train, several near-misses between trains and emergency vehicles occurred. A joint meeting between transit, police, and fire department officials resulted in the following rules being drafted.

Fire Department and Ambulance

1. Fire Department and Ambulance Service vehicles will enter 7th Avenue only while on emergency calls.
2. While in motion on 7th Avenue, Fire Department and Ambulance Service vehicles shall have their emergency warning lights and siren in operation at all times.
3. When stopped on 7th Avenue, Fire Department and Ambulance Service vehicles shall, wherever possible, not block the C Train tracks.

City Police

1. City Police vehicles when passing a C Train traveling in the same direction shall activate their warning lights.

2. When stopped on 7th Avenue, City Police vehicles shall, wherever possible, not block the C Train tracks.

General

Emergency vehicles on emergency calls shall, while crossing 7th Avenue, reduce speed so as to allow stopping short of a C Train in motion on 7th Avenue.

Service Vehicles

The following rules were adopted for operation of service vehicles on 7th Avenue:

1. With the exception of Calgary Transit vehicles, entry of service vehicles to 7th Avenue is prohibited except when essential to the completion of the service task.
2. When the nature of the service task requires vehicle access to 7th Avenue, a permit must be obtained 24 hours prior from Calgary Traffic Operations and from Calgary Transit Rail Control. No obstruction of the tracks is permitted.
3. Service work in general must be performed during off-peak hours. Should the nature of the work dictate cutting of power or obstruction of the tracks, such work will be done between 1:00 and 5:00 a.m. or on a Sunday.
4. Costs of replacement bus service shall be borne by the service company.

Control System

The 7th Avenue section of the line is controlled by the standard traffic signals, with the light rail vehicle operating on line-of-sight and governed by all traffic signs and signals. Maximum operating speed for buses and LRVs is 40 km/hr (25 mph).

A special traffic signal governs C Train exit from the tunnel section and provides an additional phase on an existing traffic light controller.

Effect of the C Train on Bus Service

Prior to the commencement of C Train service in the Macleod Trail corridor, transit service was provided by

1. High-speed, limited-stop, high-frequency Blue Arrow Service on three routes. The Blue Arrow Service express bus system was designed to bridge the gap between conventional bus service and LRT. These routes operated on future LRT corridors.
2. Main-line CBD service on one route.
3. DART (Dial-a-Ride Transit) feeder service to the Blue Arrow.
4. Conventional feeder service to the Blue Arrow and the mainline service.
5. Multiple-trip morning and evening Pennant Express. Pennant Express routes picked up passengers in a limited catchment area and proceeded nonstop to the downtown core. A premium fare was charged. Service levels were usually three morning trips (7:00, 7:08, and 7:15 a.m.) from the pick-up area and return trips at 4:00, 4:30, and 5:00 p.m. from the downtown core. The name Pennant Express originated from a colored flag or pennant displayed on the front corner of the bus.

A decision, approved by the City Council, was made that

1. Service that by its nature competed with the C Train would be revised or removed;
2. Feeder service to the C Train would be revised to provide a high level of service to the C Train and a localized crosstown service to activity centers in the area; and
3. Service levels on the C Train would offer a

minimum headway of 15 minutes at all times.

Consequently, a network was devised that consists of feeders to the C Train based on a maximum ride of 20 minutes on the bus. A single main-line bus to the CBD was maintained with routing into the Anderson and Chinook C Train stations. All Blue Arrow and Pennant Express service was deleted. DART service was replaced by fixed-route feeders.

Buses meeting C Trains at stations are scheduled to arrive 3 minutes before the train and depart 3 minutes after, thus allowing 6 minutes for transfers. Connections at stations are staggered to equalize train loading.

A train loading at Anderson station at 7:20 a.m. could theoretically meet 9 buses from 9 feeder routes. If each bus brought 40 passengers, this would take most of the available capacity in the train. Therefore, each train meets 3 feeder routes to equalize train loading. Selection of specific feeder-to-train and feeder-to-feeder combinations is dependent on known volumes on feeder routes and known feeder-to-feeder transfer volumes.

Significant fine tuning of these connection patterns was required during the first 3 months of operation.

When compared with a transfer operation involving several types of bus routes, the train-to-feeder timed transfer has two significant differences:

1. The high dependability of the train arrivals results in a smaller window requirement in the feeder schedule to ensure connections.

2. The difficulty in achieving across-platform bus-to-train transfers results in the need to allow increased transfer times due to significantly longer transfer walking distance.

The first time savings almost exactly offsets the second additional time requirement, so that actual transfer window allowance virtually equals that in a bus-to-bus operation.

Another significant effect on the transfer time is route length. Calgary chose route configurations with round-trip times of about 48 minutes, with 2 station stops of 6 minutes. This fits well with the C Train frequency of 6 minutes peak and 10 minutes off-peak.

From this experience it is evident that the higher the percentage of passengers arriving by feeder bus, the greater the ability to control train loading. Also, in cases of system failure, there is a great predictability of equipment needs to provide short-term solutions.

An introductory free fare week was provided a week before the changes in bus routes took effect. This was designed to ease the initial loading on the C Train.

Public input to the changes was gained by a series of meetings in the affected communities commencing a year before start-up. An ongoing "countdown" campaign kept the public aware of the changes. Approximately a month before start-up, a descriptive brochure was delivered to every house in Calgary. One week before start-up, supervisors in uniform handed out information packages to all

affected passengers both on and off the buses.

The results were overwhelming in terms of C Train ridership, from an initial 25 000 per day to the present 45 000 per day. During the 10-day Calgary Stampede, more than 1 000 000 rides were calculated as originating or terminating at the two Stampede stations. When one adds an estimated 36 000 regular rides per day to this, a staggering total of 1 330 000 rides or 133 000 average per day was achieved. This high ridership necessitated some unconventional steps to maintain service:

1. Electro-mechanics rode the trains, curing minor problems and doing door maintenance while in service.

2. Supervisors were stationed at the two Stampede stations to "move" passengers clear of doors and provide crowd control.

3. Portable fareboxes were brought in to supplement overtaxed ticket-vending machines.

4. Buses were used to supplement train service during peak flow. This met with mixed success because many passengers preferred to wait for the train.

5. A mobile on-site command post was used to direct service.

At present the C Train corridor shows a 30 percent increase in ridership, with daily rides in the area of 48 000 per day with a near-capacity 4500 rides in the peak hour on 25 cars in 9 trains (seven 3-car and two 2-car).

Calgary is currently experiencing 100 revenue trips per year per capita and has a goal of 150 trips by the year 2000.

Feeder bus ridership has not reached the desired levels, although park-and-ride lots are overfilled. A campaign using door-to-door leaflets and special bus boards is under way in an attempt to increase feeder bus ridership.

In 1976, 33 percent of all trips entered the CBD by public transit. Now 44 percent of all trips are by public transit. Part of this growth is due to the C Train. There were 109 buses operating on the Macleod Trail corridor. At present there are 82 buses operating in the corridor.

A similar reduction in hours of operation has not occurred, as feeder bus headways have been matched to the train to provide a high level of service and increase ridership.

Actual hours of operation were in fact increased by 72 percent on weekdays, 110 percent on Saturdays, and 52 percent on Sundays. As a result, 75 percent or 30 000 C Train riders reach the C Train by feeder bus.

CONCLUSION

The C Train and feeder bus combination has proved to be a success, as indicated by capacity ridership on the train.

The City of Calgary is proceeding with construction of the northeast and northwest LRT lines as soon as possible. Planning for the southwest and north lines is in the proposal stage.

The existing south line will be extended a further 6 km (3.7 miles) by late 1984.

Factors to Consider in Designing a Joint Bus-Light Rail Transit Mall

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Cities are turning more and more to bus and LRT transit mall solutions primarily because the costs of building a transit mall for servicing downtown areas are between \$15 and \$30 million per mile (1981 dollars) whereas building a subway would cost between \$60 and \$120 million per mile in a CBD environment. Ongoing energy, maintenance, and security costs are also much less with a transit mall than with a subway station alternative, and pedestrian access is much quicker and easier, particularly for elderly and handicapped persons. This paper identifies and describes key design factors considered in the development of a joint bus-light rail transit mall for the downtown area in San Jose, California. Other light rail mall designs researched for this paper include recent projects in San Diego, Buffalo, Calgary, Denver, Portland, and Sacramento. Secondary design considerations are also addressed, as are detailed design elements. A unique design solution was developed for the downtown San Jose transit mall to maximize its potential benefits. This solution utilizes a wide median island from which transit passengers can board either buses or light rail vehicles while maintaining separate lanes for each mode and maintaining auto access to all properties. The two one-way bus-LRT transit malls have thus been designed to interface effectively with three major modes of transportation: light rail transit, buses, and automobiles.

Light rail transit malls are a relatively new phenomenon in North American cities. They are an evolving form of the downtown pedestrian mall, which swept the country in the 1960s, and the bus transit mall, popularized in the past 5 years. Given the renewed interest in both light rail transit as an urban transportation strategy and in high-quality pedestrian environments as an urban redevelopment strategy, light rail transit malls are beginning to appear in a number of North American cities' downtown plans for the 1980s. North American cities that have either recently opened a light rail transit mall or are in various stages of

planning, design, or construction of such a facility are listed in Table 1.

At about the same time that North American transit experts were rediscovering the "streetcar" by visiting modern light rail installations in Europe, an interest in bus transit malls began to spring up. First tested on Nicollet Avenue in Minneapolis in 1967, the basic idea of a transit mall is to combine a pedestrian mall with an exclusive roadway for transit vehicles. In 1976, Portland, Oregon, received approval to construct a bus transit mall on 2 one-way downtown streets. In the same year Chestnut Street in Philadelphia was converted into a bus transit mall in time for celebrating the nation's bicentennial. Since 1976, bus transit malls have been constructed with federal assistance in Chicago (State Street), Denver (16th Street), New York-Brooklyn (Fulton Street), New York-Manhattan (Broadway Plaza), and Long Beach, California (Pine-First-Long Beach Boulevard). While these transit malls do not involve light rail transit, they do provide a wealth of useful information regarding mall traffic circulation, paving materials, landscaping, lighting design, utilities, construction costs, maintenance costs, and economic impacts.

Light rail transit malls have a number of advantages over their alternatives—a subway, on one extreme, and mixed traffic, on the other. A subway is very expensive to both build and maintain, takes a long time to construct, and therefore lengthens the construction impacts on businesses. Transit riders, especially the elderly and handicapped, must take considerable time to reach the subway, often 3 stories below the surface. Riders in the subway cannot see the city or its landmarks—only tunnel walls and the car interior. On the other hand, a subway provides total separation, eliminating all interferences from surface traffic, which results in faster vehicle speeds and greater schedule reliability. In adverse weather, a subway provides a shelter from the elements.

LRT surface operation in mixed traffic is inferior to that on a transit mall for obvious reasons. Auto traffic

Table 1. Recent LRT transit mall projects.

City	Mall Name	Type	Status
San Diego	C Street	2-way LRT, 1-way autos	Open July 1981
Calgary	7th Avenue	2-way LRT and buses	Open May 1981
Buffalo	Main Street	2-way, exclusive LRT	Under construction, open 1984
Portland	Morrison and Yamhill Streets	1-way couplet, LRT and autos	Final design, open 1985
Denver ^a	California	2-way LRT, 1-way autos	Concept planning
Sacramento	K Street	2-way, exclusive LRT	Preliminary engineering
San Jose	First and Second Streets	1-way couplet, LRT, buses, and autos	Preliminary engineering

^aSubway options are also being considered in Denver.

will force a slow, unreliable, and unacceptable LRT schedule. Sidewalks (or small islands) will not be wide enough for safe transit loading and unloading plus normal downtown pedestrian volumes. LRT patronage will be lower and operating costs higher without a reserved right-of-way separated from autos. This can be partially accomplished without the expense of building a mall but will not be as fast and reliable and would not provide the high levels of pedestrian and landscaping amenities usually sought by planners.

Some of the major design factors examined during the conceptual design of the San Jose transit mall, and which should be examined when developing any LRT transit mall design, are street width; transit system orientation; transit vehicle volumes and peaking characteristics; transit passenger volumes and peaking characteristics; auto access, including parking; delivery truck access; traffic circulation; urban renewal; and urban design.

Secondary design considerations, although not as critical as the primary design factors, still must be very thoroughly reviewed and analyzed. Some of these include utilities and sidewalk basement vaults; aesthetics and landscaping; air and noise quality impacts; marketing and imageability; equity; construction costs; maintenance costs; elderly and handicapped considerations; bicycle access; and transit shelters.

FOUR BASIC BUS-LRT TRANSIT MALL CONCEPTS

Four basic transit mall design concepts that accommodate both bus and LRT modes are described below using text and illustrations. Examples of each mall type are also listed for cities where either they have already been installed or serious design work is under way. Mall concepts 1 and 2 involve the separation of bus and LRT modes, each on its own mall or street, whereas mall concepts 3 and 4 involve the combination of bus and LRT modes on the same mall(s) or street(s), albeit in their own separate lanes. Concepts 1, 2, and 3 all involve two or more transitway streets, while Concept 4 requires only one. Concepts 1 and 4 involve two-way street traffic patterns, while Concepts 2 and 3 involve one-way traffic patterns. Limited auto access is possible with all concepts except Concept 4. All will permit emergency vehicle, utility service vehicle, and goods delivery access during most times of the day in most situations.

Mall Concept 1—Separated Bus and LRT Traffic, Parallel Facilities

Mall concept 1 involves two-way LRT-only traffic on one mall or street and one-way or two-way bus and auto traffic on one or more parallel streets. Limited auto access may be allowed on the LRT transit mall. Examples of this concept include San Diego (in operation); Buffalo (under construction); and Sacramento (planned).

Mall Concept 2—Separated Bus and LRT Traffic, Intersecting Facilities

Mall concept 2 contains one-way (or two-way) LRT traffic on one or more malls or streets and one-way (or two-way) bus traffic on one or more cross streets or malls. Limited auto access may be allowed on all streets. Examples include Portland (one-way bus malls in operation; one-way LRT cross streets under final design) and Denver (two-way electric shuttle bus mall under construction; possible two-way LRT cross-mall planned).

Mall Concept 3—Combined Bus and LRT Traffic, Shared Facility but Separate Lanes

Mall concept 3 has both buses and LRT on one-way parallel mall pairs or couplets; bus and LRT traffic will each have their own lanes and will not share rights-of-way in most cases. Limited auto access may be allowed on both mall

streets. An example is San Jose (under design).

Mall Concept 4—Combined Bus and LRT Traffic, Shared Facility, Shared Lanes

Mall concept 4 involves both buses and LRT on two-way mall streets; in some instances, most likely at LRT stops, both buses and LRT may have to share the same lane or right-of-way. Auto access is not advisable with such a mall scheme. An example is Calgary (in operation).

PRIMARY DESIGN FACTORS

Many varied factors should be carefully considered and weighed in identifying possible mall location and design alternatives for a given situation and in evaluating those design alternatives. Each city's mall design presents a unique set of design opportunities and constraints. However, it is possible to identify a set of primary or general design factors that can be used as a valuable checklist in the design of any transit mall. These are described below in no particular order of importance.

- **Street Width:** Existing as well as future "plan-line" street width, property line-to-property line as well as curb-to-curb, is very important. Many downtown streets in the western United States have a standard right-of-way width of 80 ft. Narrower street widths are more difficult to work with and limit the available design options possible.
- **Transit System Orientation:** Center-city orientation (radial) versus suburban grid (timed-transfer) orientation, the split between express and local services, and the level of transfer activity versus trips beginning or ending in the CBD mall area, all influence transit mode separation, number of lanes required, length of transit loading zones, stop locations, etc.
- **Transit Vehicle Volumes and Peaking Characteristics:** Local and express buses, light rail, articulated buses, length of LRT trains, headways, dwell times, pulse or random arrival rates, and fare collection systems all influence transit mode separation, number of lanes required, length of loading zones, stop locations, etc.
- **Transit Passenger Volumes and Peaking Characteristics:** Morning and evening waiting passenger volumes by time blocks (5-minute increments desirable), the number of transfers (line-to-line if possible), the fare collection system, and other sidewalk pedestrian volumes all influence the choice of a mall design concept; the required widths of sidewalks or median; the length, number, and location of transit stops; and the location of bus lines and LRT lines with heavy transfer activity in close proximity to one another.
- **Auto Access and Parking:** Is auto access necessary? Is it desired? How much? Where—to parking lots, garages, retail stores, drop-off zones? If auto access must be accommodated, it must be managed carefully so as to have a minimum impact on transit vehicles and pedestrians. Will lost curb parking have to be replaced? How and where? Since auto curb parking is almost always eliminated by the implementation of a transit mall, this impact should be faced squarely and early in the planning process.
- **Delivery Truck Access:** Options for delivery truck access include parking on side streets, access alleys behind stores, or off-street or on-site access. If none of these options are workable, some type of loading zones must be provided on the mall itself, either with loading zone duckouts or by using mountable curbs and allowing small

delivery trucks to park in designated areas on widened sidewalks (or median islands if included in the street cross section).

- **Traffic Circulation:** Avoid primary auto and truck traffic arteries, through routes, freeway access routes, etc., for transit mall consideration. Find secondary arterials that also provide good bus and LRT access and circulation. What will the impacts be on parallel traffic arteries if one or two streets are removed from the general traffic circulation system? How will truck deliveries be made? Are there any good mitigation measures, such as construction of a new parallel highway by-pass, street widening, elimination of curb parking during peak periods, conversion to one-way street pattern, or the use of alleyways and side streets for delivery truck loading zones?
- **Urban Renewal:** Would the potential mall street provide a much-needed stimulus to help bring about desired redevelopment projects? Would it act as a catalyst to clean up a blighted area in need of building facelifts or renovations? Would it help rid an area of undesirable land uses, such as porno shops, X-rated movie theaters, seedy bars, and pawn shops? Would it help rid the area of vagrants, drunks, prostitutes, or youth gangs?
- **Urban Design:** Where is the desired major axis or spine of downtown retail development? A transit investment is most likely to have higher payoffs for a retail and commercial street than for an office and financial center street. A street with hotels, theaters, restaurants, and convention facilities would also benefit greatly from mall landscaping improvements. Where does the city want to call its "heart"? Where does the city wish to stimulate focused new development?

SECONDARY DESIGN FACTORS

In addition to the many and varied primary design factors just identified, there are a number of other somewhat less important design factors to consider when identifying and evaluating bus-LRT transit mall designs for a particular city's downtown situation. These are listed below.

- **Utilities and Sidewalk Basement Vaults:** The size, location, and condition of existing as well as planned utility lines can influence a mall's location, design, and costs. If urban renewal or expansion requires the street(s) to be torn up for utility work anyway, this may lessen additional costs and the impacts of adding transit mall construction. Sidewalk basements can present some interesting legal, political, and structural problems and are expensive if they have to be completely rebuilt because the sidewalk serves as the roof of the vault.
- **Esthetics:** The existence of or the potential for a mall street's total esthetic design, including existing and planned building facades, existing street landscaping, etc., can influence a mall's location and design.
- **Air and Noise Quality:** The localized air pollution and noise impacts can influence a mall's location and design. Significant reductions in both vehicular noise and carbon monoxide levels can be possible with an exclusive LRT transit mall over an existing heavily trafficked street.
- **Marketing and Imageability:** A transit mall can be an important positive image-builder for both the city as a whole and the downtown area specifically as well as for the area's transit system. As such, it should become an important marketing tool to be exploited.
- **Equity:** The perceived fairness of distributing both the positive and the negative impacts of a

transit mall to the adjacent property owners and merchants can influence a mall's design and location. For example, putting all buses on one street and all LRT vehicles on another may not be acceptable if the businesses along the noisier and more polluted bus mall perceive they are getting penalized to the benefit of other businesses along the quieter and less polluted LRT mall.

- **Construction Costs:** The choice of a one-street mall design instead of a more expensive two-street mall design solution is highly influenced by construction costs; they can also influence the length of a mall (number of blocks) and choice of construction materials and design "extras."
- **Maintenance Costs:** The comments on construction costs also apply here. There is a potential for trade-offs, however, between more expensive construction materials that may result in lower maintenance costs.
- **Elderly and Handicapped Accessibility:** Good access and ease of making transfers for the elderly and handicapped can influence the choice of "separated" versus "combined" transit malls, one-way versus two-way traffic, curb loading versus median island loading, mid-block pedestrian crosswalks, wheelchair lifts versus high platforms for LRT, and the like.
- **Bicycle Access:** Requests by bicycle groups for mall access to bicycles, bicycles carried on external racks or aboard transit vehicles, bicycle lockers or racks on sidewalk areas, etc., can influence a mall's design, safety, and operation.
- **Transit Shelters:** The need for and size of transit shelters, their design and placement, lighting, heating, etc., can influence a mall's design, construction, and maintenance costs.

OPTIONS FOR MALL CONCEPT 3

There are a number of different ways in which each of the four basic mall design concepts can be implemented. For illustration, there are at least three different options for the implementation of mall concept 3. All of these options involve 2 one-way transit malls with both buses and LRT on both streets, functioning as a couplet. They use a standard 80-ft street right-of-way and do not use bus duckouts. Each of these alternatives can accommodate auto traffic and delivery truck traffic in various ways. Two of the options use center medians for loading of transit passengers.

Option A would put the automobile traffic in an exclusive lane separated from the bus and LRT transit vehicles by a median. In this way, the transit-only lanes would be almost self-enforcing, as it would be impossible for an automobile to change from the auto lane to a transit lane except at intersections or median island cuts. All bus loading would take place from the median island, while the light rail vehicles would load from the left-hand sidewalk. If right-hand loading platforms are used elsewhere in the LRT system, doors on both sides of the light rail vehicles would be required for this option. The light rail tracks would be paved flush to allow the buses to utilize the LRT land when bypassing stopped buses.

Option B would put the light rail vehicles in the median-separated lane. In this option, the buses would still load from the median, but the light rail vehicles would have the option of loading from either the sidewalk or a wide median island, or both. This option would not be as self-enforcing as option A in keeping the autos out of the bus-only lane, but it does provide the advantage of having all pneumatically-tired vehicles in the same pathway. Transit buses could then use the semi-exclusive auto lanes to bypass stopped buses. With this option, there would be no danger of having the LRT track blocked by either a stalled bus or car. Another advantage to this scheme is that it will require only one transit shelter on the median

at each major bus and LRT stop, instead of one shelter on the sidewalk and one shelter on the median, as in option A.

Option C does not include a median. Instead, the sidewalks would be widened to provide room for both the increased pedestrian and transit patron use and for the transit mall street furniture. The light rail vehicles would be located on the left side of the street, in a nonseparated exclusive lane, and would load from the left sidewalk. This option would again require doors on both sides of the light rail vehicles if right-hand loading is used elsewhere in the system. The buses would operate in a semi-exclusive bus-only lane on the right side of the street and would load from the right sidewalk. The autos would then operate in the center lane, sharing this lane with buses that would be bypassing stopped buses. Autos would have to merge into the transit lanes to turn off of the mall.

For the San Jose transit mall project, option B of concept 3 was selected to undergo detailed analysis and comparison against concept 1. Concept 4 was considered for a short time, but because of strong merchant support for auto access on every street, the one-street mall was eliminated early in the scoping process as not having sufficient room to adequately accommodate all three modes of transportation (buses, LRT, and autos). Concept 2 (LRT mall crossing the bus mall) was not applicable to the San Jose project, since the corridor for the LRT line is along the same north-south axis as the proposed bus transit mall.

After completion of the technical evaluation and analysis, concept 3B was chosen as the final bus-LRT mall design. The primary reasons for this selection were as follows:

1. There would be slightly better transit efficiency and significantly better transit convenience with concept 3B, based on the results of the travel time simulations and the percentage and direction of transfers on the mall. The running time savings on a one-way transit couplet versus a two-way transit street is about 20 percent because of the better signal progression possible with traffic moving in only one direction versus two.

2. Vehicular access and circulation would be somewhat clearer and easier with concept 3B.

3. Concept 3B was thought to provide a more unique and esthetic landscape design opportunity for the mall and would tend to improve the downtown environment and economy somewhat better, since the benefits and impacts of both transit modes would be spread equally over two streets.

4. Concept 3B answers the very specific concern of downtown merchants who wanted to separate waiting transit patrons from general pedestrian traffic by providing all transit loading and waiting areas along the mall on the wide median island instead of on the sidewalks in front of their retail shops.

DETAILED DESIGN CONSIDERATIONS

Once a basic mall design concept has been chosen, numerous detailed design issues must then be considered. These considerations fall into two broad categories: (a) design elements that must be considered for any urban street improvement project and (b) design elements that are unique to a transit street improvement project. The fact that the street(s) will be used as a transit arterial will, of course, affect the decisions in both categories.

The basic building blocks that must be considered in the design of any urban street improvement project are given in Table 2. Major items to consider during detailed design include paving materials, landscaping, lighting, and street furniture.

- **Paving Materials:** A wide variety of paving materials are available for the mall designer to choose from, ranging from granite paving blocks at the high cost end (Denver; \$15-\$20/sq ft) to unit pavers or brick in the middle cost range (Portland, San Diego, and Calgary; \$8-\$12/sq ft) to concrete sidewalks and asphalt pavement at the low end of the cost spectrum (\$4-\$5/sq ft). The choice of paving materials should be based on life-cycle cost estimates, normal maintenance

Table 2. Bus LRT transit mall construction costs (1981 dollars).

Item No.	Description	Units ^a	Unit Cost	Range of Total Construction Cost (Percent)
1.	Light rail track and electrification	lineal ft	250.00-350.00	10
2.	Sidewalk pavement	square ft	4.00-20.00	10-35
3.	Roadway pavement	square ft	4.00-20.00	10-15
4.	Landscaping	square ft	1.00-1.50	2
5.	Street furniture	square ft	5.00-6.00	10-15
6.	General conditions	square ft	4.00-5.00	10
7.	Demolition	square ft	4.00-5.00	10
8.	Utility modifications	square ft	2.00-3.00	6
9.	Art and sculpture	square ft	1.00	2
10.	Contingencies	square ft	2.00	4
	Subtotal	square ft	35.00-43.00	100
11.	Engineering	5-6 percent of the construction cost		
12.	Administration and inspection	5-6 percent of the construction cost		

^aNote: The quantity measurement for Items 1, 2, and 3 should be the actual lineal and square footages for these items. The quantity measurement for Items 4 through 10 is the total square footage of the proposed mall project.

cost considerations, esthetic considerations, and budget constraints. Because the choice of paving materials can vary the total mall construction budget by 15 to 20 percent, the selection should not be made lightly.

- **Landscaping:** Street trees are the most predominant part of the landscaping element, and, although they are generally only about 2 percent of the total mall project budget, their selection can be the subject of much debate in the community. Things to look at when deciding on the type of tree include (a) shape, (b) deciduous versus evergreen, (c) hardness in an urban environment, (d) a nonaggressive root system, (e) availability, (f) suitability to climate, and (g) maintenance costs and problems (droppings, leaf pickup, etc.).
- **Lighting:** Often subject to the overall city street lighting policy, the design of the lighting system for the mall can either make or break the use of the mall during evening hours. The complete lighting design needs to provide both attractive standards and luminaires during the daytime, and, just as important, it needs to provide a pleasant, adequate, and secure light source during evening hours. A major consideration is the selection of the light source. The mall designer can choose from high-pressure sodium (pinkish-white), low-pressure sodium (pale yellow), mercury-vapor (bright white), incandescent (pale white), or a combination of these light sources. In determining the choice of light source, the mall designer must weigh the adequacy of the light against the cost of energy to provide the light. Other issues to consider include the type of standards (ornamental, modern, or traditional); the height of the standards (low-level standards for pedestrian-oriented light, high-level standards for a broad light pattern for traffic vehicles, or a combination of high and low standards; there is a good possibility of combining high-level light standards and trolley wire support poles in one single pole); the number and position of luminaires on the standard; interference (street trees blocking the light from high-level standards, for example); and normal light intensity versus high light intensity desired at transit stops.
- **Street Furniture:** The types of street furniture that must be considered for any street improvement project include trash receptacles, benches, fire hydrants, drinking fountains, sculpture, newspaper racks, telephones, bicycle racks, etc. The major criteria for all of these items is durability, followed closely by esthetic considerations.

Design elements that are unique to a bus-LRT transit mall project include the LRT track, overhead wire system, transit shelters, traffic signal transit priority treatment, LRT platform design, elderly and handicapped considerations, and fare collection methods.

- **LRT Track:** There are a number of acceptable standards to choose from for LRT track on downtown streets. For most installations, girder rail will be the preferred type. Other factors that must also be considered are the desire to minimize noise and vibration and the need to tear up the street for track maintenance, repair, or replacement.
- **Overhead Wire System:** In the design of the overhead wire system on the mall street(s), esthetics must be the primary concern. Toward this end, the feeder wires for the electrical power should always be buried underground, while the overhead wire should be as unobtrusive as possible. There are at least three options for mounting the overhead wire: (a) a combined pole

for both street lighting and mounting the wire; (b) a totally separate pole for mounting the wire (these poles could also be used to hang banners, etc.); or (c) stringing the wire from eyelets placed in adjacent building facades. Any design must ensure that trees will not interfere with the overhead wire, even at maturity.

- **Transit Shelters:** There are two main decisions to be made with regard to transit shelters: Is there a need for shelters at all? What type of shelter is preferable? Considerations for the first decision include climate, security, marketing, safety, and comfort weighed against esthetics, cost, and maintenance requirements. If a shelter is desirable, there are three types that can be considered: canopy only; partially enclosed; or totally enclosed. Again, the considerations of climate, security, etc., should determine the type of shelter to be installed. Also to be considered are items to be placed within the shelter, such as benches, lighting, transit maps, change machines, fare collection machines, telephones, and electronic transit information systems.
- **Traffic Signal Priority Systems:** There are two basic options for LRT signal priority systems: signal preemption or signal progression timed to favor the light rail vehicles. Signal preemption, effective for combined transit vehicle headways 4 to 5 minutes or longer, can be achieved either with a standard railroad track circuit connected to the traffic signal, an overhead trolley wire trip switch, or a system that is not physically connected such as the 3M "Opticom" light emitter. Two advantages of the "Opticom" system (used by San Diego) are that buses using the mall can also be allowed to preempt the signal and the driver of the transit vehicle has the option of switching the system "on" or "off." The total number of transit vehicles trying to preempt will have to be considered when calculating the headways, however, and for many systems a signal progression timed for the LRT vehicles may be as effective in the downtown as signal preemption and at much less cost.
- **LRT Platform Design:** Loading platforms for the mall can be either high-level (Calgary) or low-level (San Diego, Portland, and Buffalo). Things to consider when deciding between the two options include (a) movement of pedestrians on the mall street(s) may be more difficult with high-level platforms; (b) joint use of the trackway with buses would not allow high-level platforms; (c) joint use of a common median island for loading both LRVs and buses may not allow for enough room for both high LRT and low bus platforms; and (d) for elderly and handicapped access, high-level platforms merely move the problem of the elevation difference from the train to the sidewalk. In general, with very high anticipated patronage volumes, a high-level platform is preferable; however, the size of the doors on the LRV, the number of doors used for loading, and the location of these doors are also significant factors. With low-level platforms, the loading area can either be located on the sidewalk, a median, or both.
- **Elderly and Handicapped Considerations:** In addition to the normal considerations for the elderly and handicapped in urban street projects (i.e., wheelchair ramps or no elevation differentials between sidewalks and crosswalks), a transit improvement project must also provide the means for the elderly and handicapped to use the transit system. The Santa Clara County Transit District is working toward providing a fully accessible bus system by installing wheelchair lifts on all buses.

For LRT, in addition to high-level platforms, there are two options for providing wheelchair access to the vehicles at low-level platforms. The first method is to install wheelchair lifts on each vehicle similar to the bus lifts (San Diego). The major disadvantages of this system are the time delays when operating the lift and the vehicle maintenance and reliability problems associated with on-board lifts. In addition, with double-ended cars, two lifts per car would be required. The second method is to provide a fixed-location wheelchair lift at each LRT station (Portland). The advantage to this system is simpler car design, the avoidance of interference with train operations due to lift failures, and less expensive capital and operating costs. Disadvantages include alignment of the front door of the LRV with the platform lift, time delays to operate the lift, vandalism and security problems in an exposed urban environment, and maintenance at a number of far-flung locations rather than all at the LRV maintenance yard.

- **Fare Collection:** The fare collection method along the downtown transit mall must be fast, convenient, and easily understandable. Options include self-service fare collection, a free-fare zone within the downtown, or the standard, pay-as-you-enter, front-door farebox system. The advantages of the self-service fare or the free-fare zone include speeding up boarding, reducing dwell times, and reducing the platform space required for passengers. The major disadvantage of the self-service fare is that fare collection machines would have to be installed in a hostile urban environment. The major disadvantage of the free-fare zone in downtown would be the loss of revenue to the transit district.

SUMMARY

In summary, it has been shown that there are a variety of factors that must be considered in the design of a bus and/or LRT transit mall. Analysis of these factors will often indicate the type of mall design that is appropriate for a given situation, and, as has been demonstrated by the diversity of mall designs for the cities mentioned in this paper, there is not a single mall design that can be universally accepted as best.

The proposed San Jose transit mall will use a unique design solution that is expected to provide the maximum transportation and land use benefits to downtown San Jose. This solution was arrived at after consideration of the same common design factors reviewed by the mall designers of San Diego, Buffalo, Calgary, Denver, Portland, and Sacramento. Because of the inherent differences among cities, however, each mall design is unique in its own way.

Once a mall design concept has been chosen, the designer is faced with the task of picking the individual elements. The selection of each mall building block should be done carefully and with a great deal of thought. There will be much community debate over the best paving material to use, lighting fixtures, street trees, etc., and the mall designer will do well to listen to everyone's input in order to tailor the mall to the city and people who will be using and paying for it.

REFERENCES

1. San Jose Transit Mall Technical Report. Santa Clara County Transportation Agency, City of San Jose, April 1981.
2. Streets for Pedestrians and Transit: An Evaluation of Three Transit Malls in the United States. UMTA-DOT Final Report, February 1979.

Traffic Impacts of Light Rail Transit

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In August 1981, the San Diego Metropolitan Transit Development Board (MTDB) began operation of light rail vehicle service from downtown San Diego southerly to the San Ysidro International Border. This 16-mile-long light rail system operates for most of its length in joint use with freight service in an at-grade, double-track operation (Figure 1). In the Centre City, trolleys operate at-grade on an exclusive path within city streets. The general alignment (Figure 2) includes C Street, which is ultimately planned as a transit and pedestrian way.

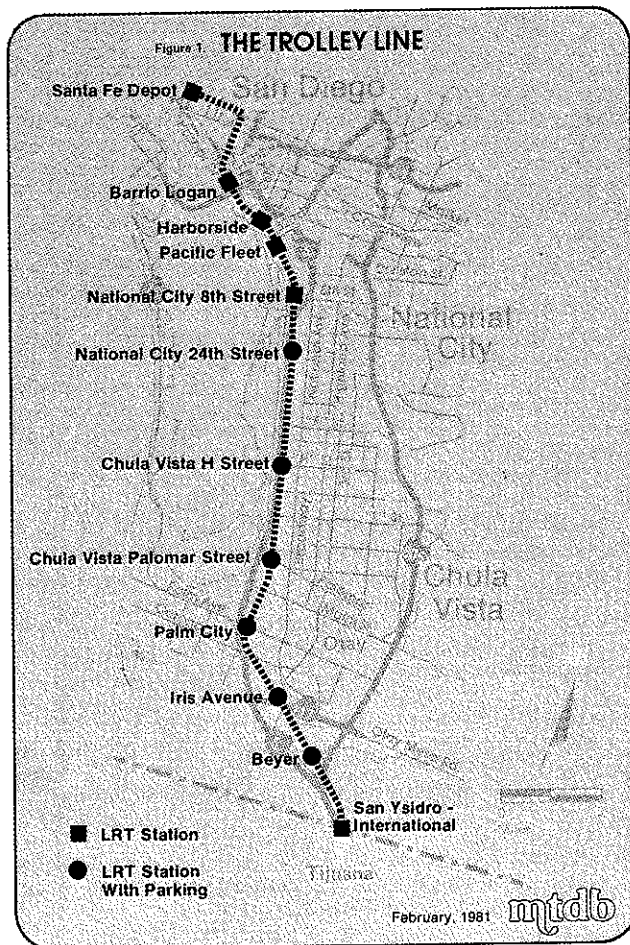
During the first 4 months of operation, the trolley system carried 1 854 000 passengers. Daily ridership averaged 11 500, with 14 000 to 17 000 passengers using the system on Saturday.

Even before the south line of the trolley was put into operation, MTDB began planning for an East Line extension. The general alignment for the East Line extension is shown in Figure 3. The extension includes 13 passenger stations spaced about 1.25 miles apart. The East Line extension is described in more detail in the Appendix to this paper.

Although the feasibility study for the East Line

showed the extension to be practical in terms of patronage estimates, construction impacts, and overall environmental impacts, there were some questions regarding potential impacts of light rail vehicles on traffic operations in the downtown areas of the cities of Lemon Grove and La Mesa. In these two areas, the light rail vehicles would operate parallel to the major north-south streets serving the two business districts. In Lemon Grove (Figure 4) the light rail tracks would actually be located between Imperial Avenue (a citywide arterial street) and Main Street (a business district collector street). The light rail vehicles through La Mesa (Figure 5) would operate at-grade between Spring Street (an arterial street) and Nebo (a local collector street).

Because of the potential effect of light rail vehicle operations on the east-west streets crossing the tracks, the businessmen and city councils of both cities expressed serious concerns over downtown traffic operations that might result from implementation of the East Line trolley extension. The purpose of this paper is to review the existing and potential operations of the streets within the downtown areas of Lemon Grove and La Mesa to evaluate



the potential impacts of the trolley at-grade operations.

EXISTING CONDITIONS

Within the City of La Mesa, Spring Street is a 4-lane street providing additional roadway width for left-turn pockets at major intersections. Spring Street carries approximately 2 400 total vehicles in the afternoon peak hour.

In Lemon Grove, Imperial Avenue serves as the main north-south artery, also providing a general 4-lane cross section with left-turn lanes at major intersections. Imperial Avenue carries approximately 2 000 vehicles in the afternoon peak hour.

Analysis of traffic operations during the afternoon peak hours showed that each downtown area had one intersection operating at level of service D, with the remaining intersections all working at more acceptable levels of service.

TRAFFIC IMPACT ANALYSIS

Duration of LRT At-Grade Crossing

The time needed for the LRT train to cross the at-grade intersections is based on several variables. The LRT and gate operating characteristics and the intersection geometrics generally influence the duration of LRT at-grade crossings.

The duration analysis was conducted using a "worst-case" condition. The LRT will travel at various speeds and dwell for different times as necessary for passenger operations. Moreover, the duration of the trolley stop will depend on the number of passengers boarding and alighting

during a certain period of time. As shown in Table 1, the "worst-case" condition was established to reflect the peak demand during the afternoon peak hour on weekdays. The travel speed was estimated to be 20 percent slower than the usual speed in the downtown area to give conservative consideration to the gate blockade. Other operating characteristics of the "worst-case" condition (which match the South Bay LRT operations) are also shown in Table 1.

For those LRT vehicles going through the intersections, the intersections would be blocked for the 25-second lead time, plus the time it takes to proceed through the intersections, plus the time it takes to raise the gates. For those LRTs dwelling at the intersections for passenger operations, another 20 seconds for passenger boarding and alighting and 6 seconds for LRT acceleration and deceleration would be added to the gate blockade. As shown in Table 2, the resultant durations of gate blockade at the 11 major intersections range from 48 seconds to 74 seconds. It should be noted that these durations represent the "worst-case" condition. If the trolleys travel faster (for example, 30 mph), the durations could be reduced accordingly.

Estimation of Vehicular Queue at LRT Crossing

In urbanized areas, the traffic flow is usually controlled by the traffic signal system. As a result of this control system, the traffic arrives at intersections "cluster by cluster." The flow characteristics would be described by the equation of the Poisson distribution in general:

$$f(x; \lambda) = e^{-\lambda} \frac{\lambda^x}{x!} \text{ for } x = 0, 1, 2, \dots$$

where λ is the arrival rate.

For the purposes of this analysis, the statistical significance of the 95 percent confidence level was used. Therefore, the Poisson distribution equation could be expressed as follows:

$$F(x; \lambda) = \sum_{k=0}^x e^{-\lambda} \frac{\lambda^k}{k!} = 95\%$$

The traffic characteristics mentioned earlier were used to estimate the vehicular queues for different approaches at the 11 intersections. The results of these analyses are summarized in Table 3.

Estimation of Time for the Queue to Dissipate

The first phase after the LRT leaves the intersection is always given to the traffic movement with the longest queue. The signal timing for this movement is based on the time needed to dissipate the queue.

The times needed for the vehicular queues to dissipate were estimated using Greenshield's model: Time needed to dissipate = 3.7 seconds + 2.1 seconds $\times (n - 1)$, where n is the number of vehicles in the queue. Although it is known that Greenshield's estimation on the starting delay is fairly conservative (especially since the first vehicle in the queue would not need 3.7 seconds to leave after a 50-second gate blockade), it was used because of the safety consideration. The resulting times for the queues to leave the intersection are summarized in Table 4.

TRAFFIC SIGNAL COORDINATION AT LRT CROSSING

Preemption-Period Clearance

When the LRT is approaching the intersection and giving the preemption signal, the traffic signal should have a certain period of time to clear the LRT route. The preemption-period clearance would contain a 4-second amber to clear the intersection, a 6-second flashing red to move the vehicles on the LRT route, a 4-second amber to clear the LRT route, and a 2-second all red to prepare for the nonconflicting traffic movements. This 16-second

Figure 2.

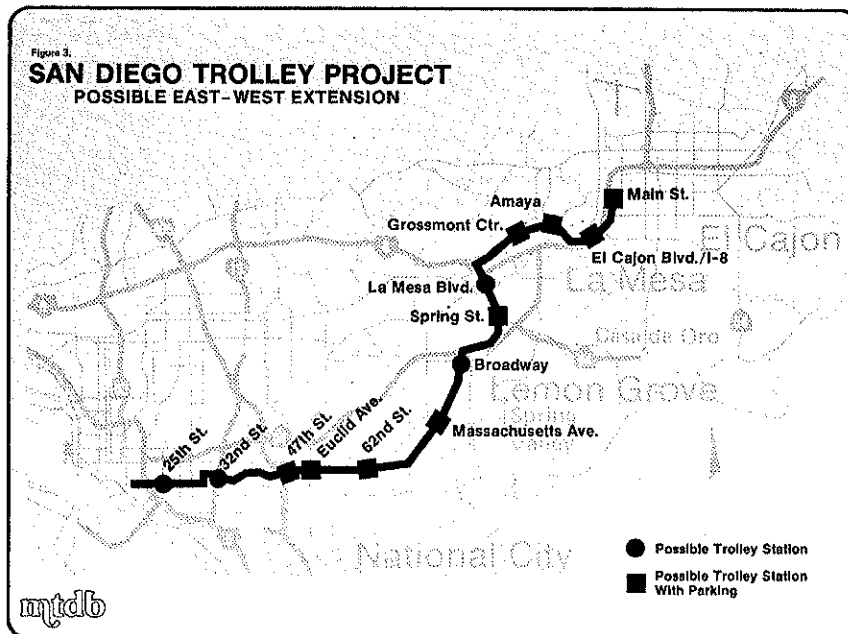
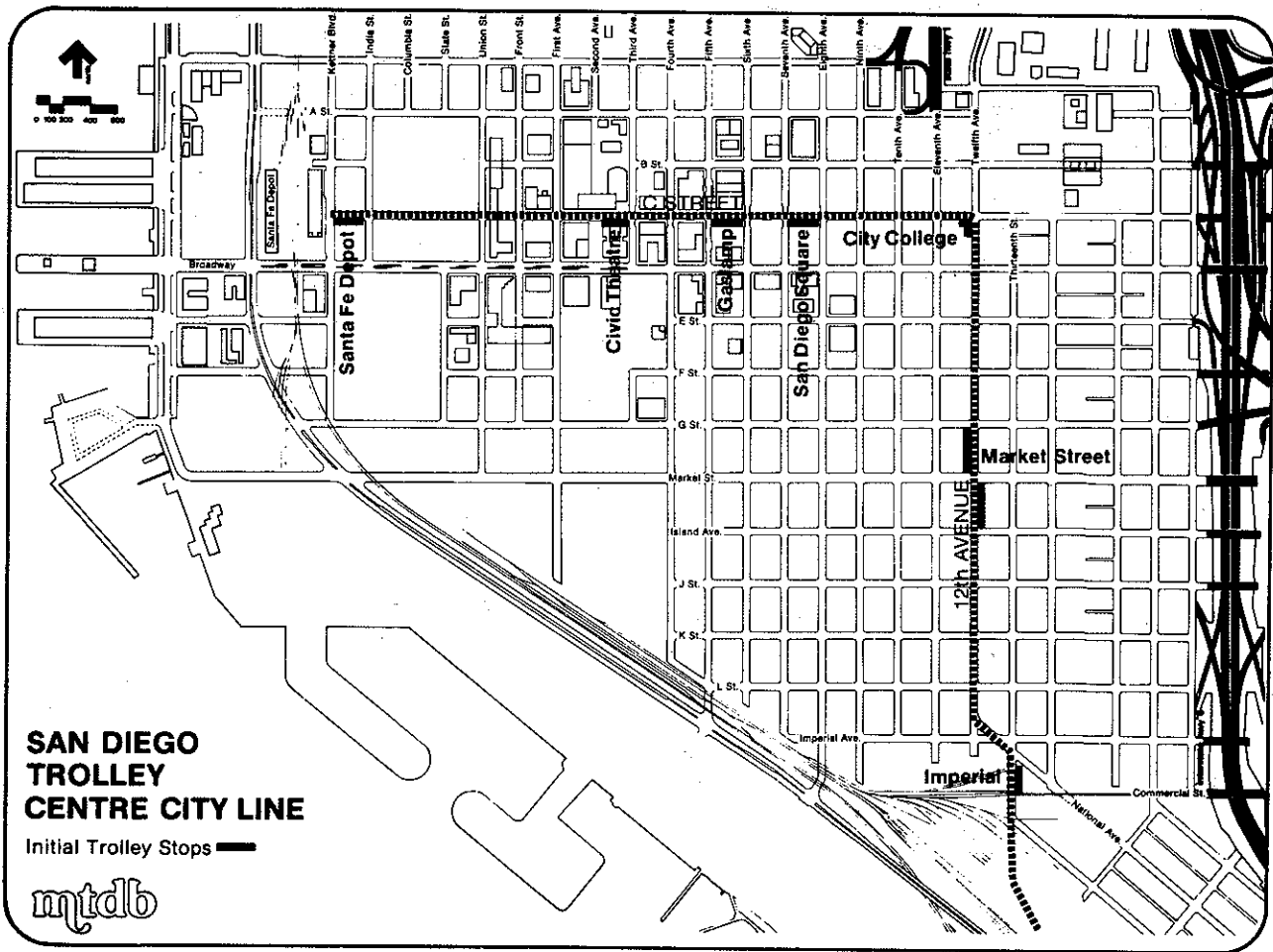


Figure 4. Area roadway system and lane configurations, City of Lemon Grove.

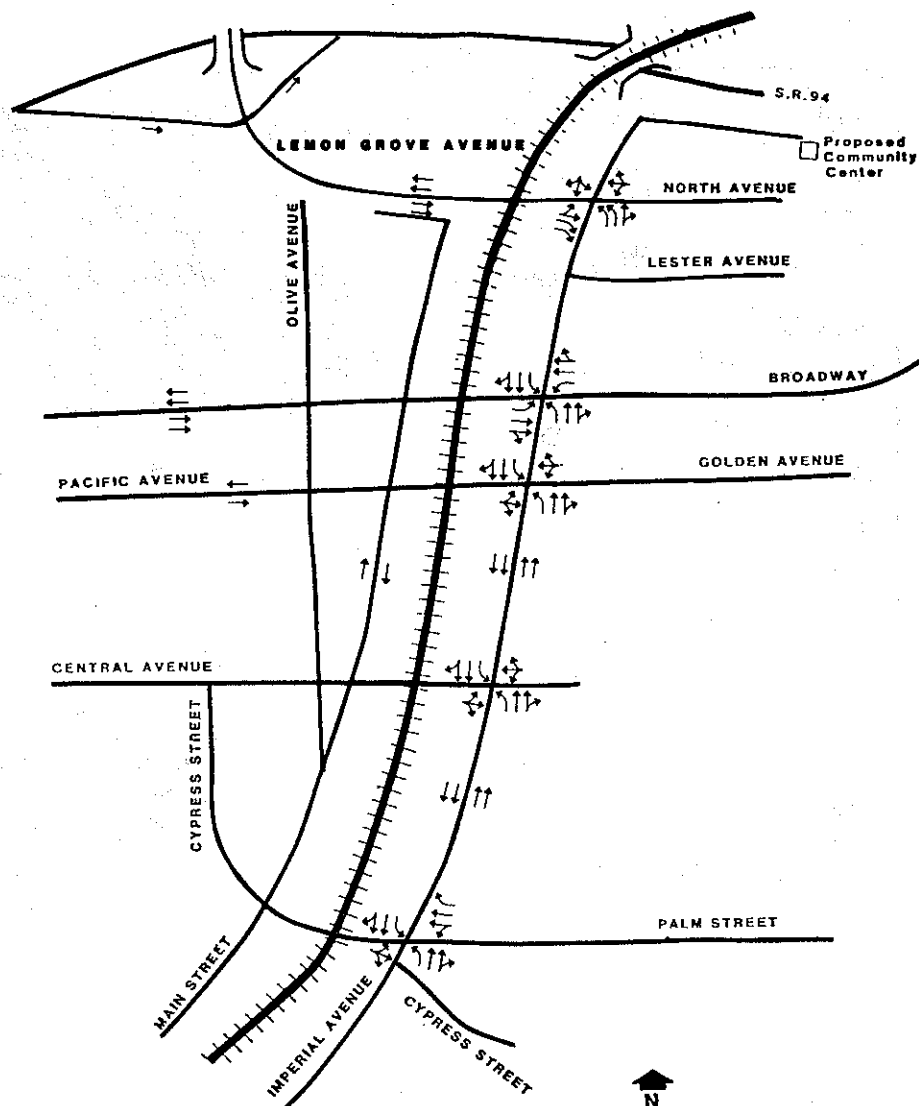


Table 1. Time required for at-grade crossing.

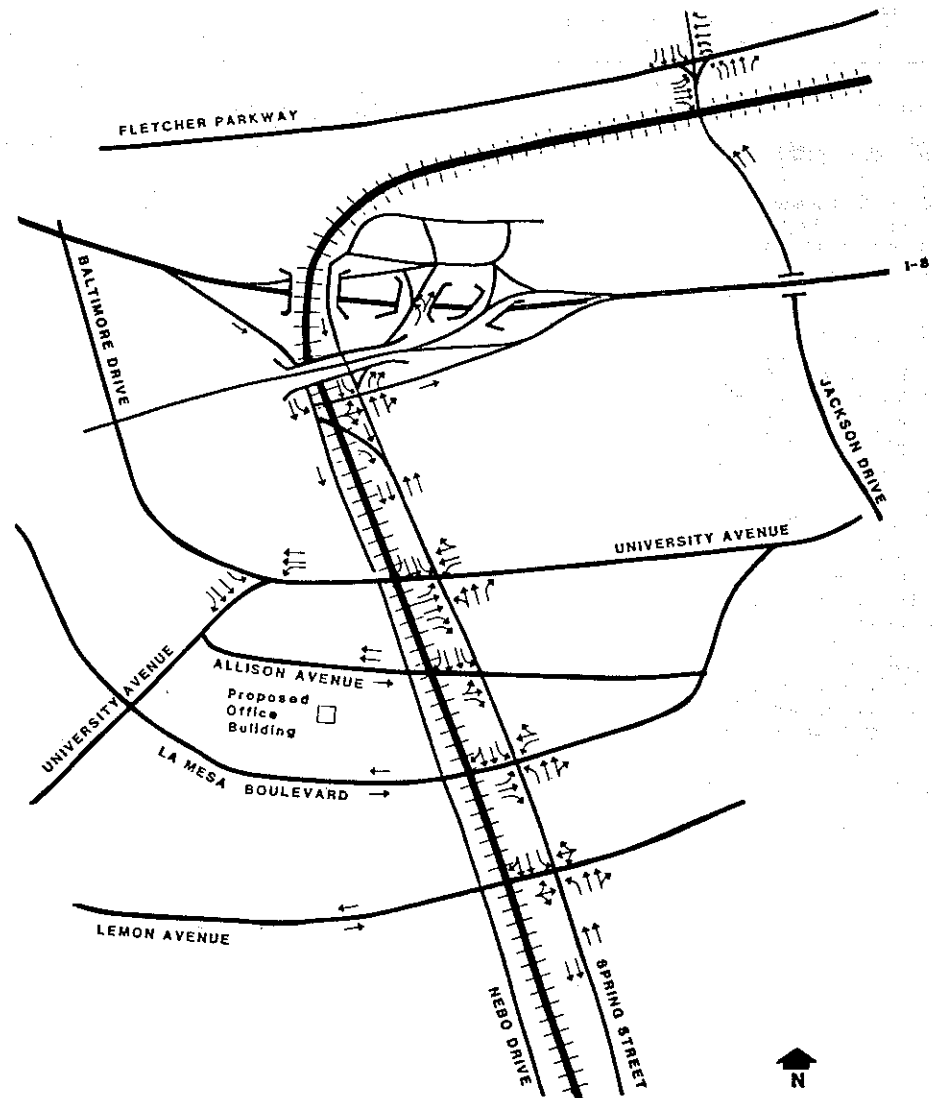
Operating Characteristics	Worst-Case Condition
<u>LRT</u>	
Passenger operations: 15-20 seconds ^a	20 seconds
Length: 2-car trolley (160 ft) during nonpeak period ^a	320 feet
4-car trolley (320 ft) during peak period ^a	
Travel speed: 25 mph in urbanized area, 28 mph average ^a	20 mph (29.3 fps)
Acceleration and deceleration: 3 mph per second ^a	3 mph/second
Frequency: every 15 minutes, each direction ^a	8 times/hour
Lead time (advance): 20-30 seconds ^b	25 seconds
Clearance (after): 50 feet ^c	50 feet
<u>Gate</u>	
Time for lowering or raising: 5-8 seconds ^c	8 seconds

^aSource: MTDB

^bSource: Public Utilities Commission Code 75-C, paragraph 7-2

^cSource: Southern Pacific Railroad

Figure 5. Area roadway system and lane configurations, City of La Mesa.



preemption-period clearance could also be used for pedestrian crossings.

Preemption Period Hold

When the LRT is 9 seconds away from the intersection, the traffic signal should turn green to those movements parallel to the LRT route.

When the LRT passes the 50-ft clearance point and the gate starts to raise, the traffic signal would turn yellow to clear the intersection and then another 2-second all reds to prepare for dissipating the vehicular queue built up during the gate blockade.

INTERSECTION CAPACITY

Because the LRT is crossing the intersection, the gate must be down for a certain period of time to control the conflicting traffic movements. During this gate blockade, the traffic signal gives the green to the traffic movements parallel to the LRT route. Thus, the actual time "loss" in terms of the overall intersection capacity would be only the preemption-period clearance, which is 16 seconds for each LRT crossing, as described in the previous section. The LRT is scheduled to run every 15 minutes for each direction. Thus, the overall intersection capacity will

decrease by approximately 4 percent per hour.

Table 5 shows that the 4 percent decrease of the intersection capacity will not deteriorate the intersection level of service to an unacceptable level. Some intersections would operate at capacity because of the population and employment growth in those areas and the resultant background traffic, as opposed to the impacts of the LRT.

PREEMPTION SYSTEMS FOR LRT AND EMERGENCY VEHICLES

As stated previously, the LRT operation will have priority over other traffic. Also, emergency vehicles legitimately have priority over "all" vehicles. Obviously, a conflict exists when the LRT and the emergency vehicle approach the same intersection simultaneously.

It is impossible for emergency vehicles to travel as fast as they can in urbanized areas. "Normal" traveling speed would be 30 to 40 mph. If the emergency vehicles give the preemption signal to the traffic light 1000 ft away from the intersection, it would then take the emergency vehicles 17 to 23 seconds to reach the intersection. Thus, for a 50-second gate blockade, there would be no delay for the 40-mph approaching emergency vehicles if the LRT vehicle was past the 33rd second in its preemption cycle.

Table 2. Durations of gate blockade at intersections.

Intersection	Length of Track at Intersection (ft)	Loading and Unloading (seconds)	Acceleration and Deceleration (seconds)	Duration of Gate Blockade (seconds)
<u>City of La Mesa</u>				
Jackson Drive and Fletcher Parkway	100	-	-	49 ^a
Spring Street and I-8 on-off ramps	330	-	-	57
Spring Street and University Avenue	200	-	-	52
Spring Street and Allison Avenue	80	-	-	48
Spring Street and La Mesa Boulevard ^b	80	-	3	51
Spring Street and Lemon Avenue ^c	60	20	6	74
<u>City of Lemon Grove</u>				
Imperial Avenue and Lemon Grove-North	100	-	-	49
Imperial Avenue and Broadway ^b	80	-	3	51
Imperial Avenue and Golden-Pacific Avenues ^c	80	20	6	74
Imperial Avenue and Central Avenue	60	-	-	48
Imperial Avenue and Palm-Cypress Streets	60	-	-	48

^aAs an example:

Duration of gate blockade at Jackson Drive and Fletcher Parkway
 = 25 seconds + (100 ft + 50 ft)/29.3 fps + 8 seconds + 320 ft/29.3 fps
 = 25 seconds + 5 seconds + 8 seconds + 11 seconds
 = 49 seconds

^bThe gates will be raised at the intersections of Spring Street and La Mesa Boulevard and Imperial Avenue and Broadway for the passenger operations at the LRT stations.

^cThe gates remain down when loading and unloading passengers at the LRT stations at the intersections of Spring Street and Lemon Avenue and Imperial Avenue and Golden-Pacific Avenues.

If the LRT travels at 20 mph, it would take 7 seconds for it to come to a complete stop. The faster the LRT runs, the longer it would take to stop. Assuming that the LRT speed would not exceed 30 mph in the urbanized area, the maximum time needed for the LRT to stop would be 9 seconds.

Therefore, even in a conservative situation (a 40-mph emergency vehicle with a 30-mph LRT), there would be only a 16-second period over the 50-second gate blockade period that the emergency vehicle would be blocked by the LRT crossing. This yields a 32 percent chance for the LRT to block emergency vehicles. This percentage will be reduced if either the LRT or the emergency vehicle travels slower. If the emergency vehicle gives the preemption signal to the traffic light 1500 ft away from the intersection, there would be a 16 percent chance for the LRT to block the 40-mph approaching emergency vehicle. If the emergency vehicle travels at 30 mph, there would be no delay at all.

IMPACT RESULTS

Because the LRT crossings are relatively short in duration (48 to 74 seconds), the traffic impacts of the LRT operation are not as severe as the city councils had feared. The short duration of the blockage means that the number of vehicles lined up during a crossing can always be cleared in one signal cycle after the gates go up. These conclusions are based on the assumption that the traffic signal system adjacent to the LRT crossings will be modified so

that north-south traffic parallel to the LRT tracks can operate on a green signal indication when the gates across the east-west streets are down.

The traffic study found that the impact of the LRT operation on the downtown street systems of La Mesa and Lemon Grove would be very small as long as the following recommendations are implemented along with the LRT operation:

1. A traffic signal system with LRT preemption equipment must be implemented to detect the approaching LRT vehicles. The preemption detection would then begin a traffic signal sequence that cleared the east-west traffic off the LRT tracks, closed the railroad gates, gave north-south traffic a green indication as the LRT vehicle passed across the east-west street, raised the gates after the LRT vehicle passed, and finally gave the next green indication to the movement at that particular intersection with the longest back-up during the LRT crossing (either the east-west traffic or the northbound left turn).

2. All signalized intersections at LRT crossings should be restriped or widened to provide a southbound right-turn lane so that right-turning vehicles have a place to store while the gates are down. If this is accomplished, then two southbound lanes of through traffic can continue to operate while the gates are down.

3. Special emergency vehicle preemption equipment should be included in the LRT line so that, whenever possible, police and fire vehicles would be able to preempt the LRT vehicle. In fact, because of the higher operating

Table 3. Estimates of vehicular queues at LRT crossing.

Intersection	No. of Approaching Lanes	No. of Vehicles Queue for a 95 Percent Probability (per lane)
Jackson Drive and Fletcher Parkway		
Northbound	2	11
Southbound	2	8
Eastbound, right turn	1	9
Westbound, left turn	2	2
Spring Street and I-8 off ramp		
Southbound	1	17
Eastbound, left turn	1	4
Spring Street and University Avenue		
Northbound, left turn	1	9
Southbound, right turn	1	4
Eastbound	3	5
Westbound	2	4
Spring Street and Allison Avenue		
Northbound, left turn	1	7
Southbound, right turn	1	6
Eastbound	1	12
Westbound	1	11
Spring Street and La Mesa Boulevard		
Northbound, left turn	1	5
Southbound	1 ^a	16 (6)
Eastbound	1	15
Westbound	1	7
Spring Street and Lemon Avenue		
Northbound, left turn	1	5
Southbound	1 ^a	20 (3)
Eastbound	1	9
Westbound	1	9
Imperial Avenue and Lemon Grove Avenue		
Northbound, left turn	2	9
Southbound	1 ^a	7 (5)
Eastbound	3	8
Westbound	1	6
Imperial Avenue and Broadway		
Northbound, left turn	1	9
Southbound	1 ^a	12 (5)
Eastbound	3	7
Westbound	2	6
Imperial Avenue and Golden and Pacific Avenues		
Northbound, left turn	1	5
Southbound	1 ^a	14 (5)
Eastbound	1	7
Westbound	1	5
Imperial Avenue and Central Avenue		
Northbound, left turn	1	2
Southbound	1 ^a	10 (2)
Eastbound	1	6
Westbound	1	3
Imperial Avenue and Palm and Cypress Streets		
Northbound, left turn	1	3
Southbound	1 ^a	11 (6)
Eastbound	1	11
Westbound	2	5

^aThere is no right-turn lane; this assumes the first vehicle in the curb lane is the right-turner, which would block the curb lane during the LRT crossing.

Note: If a right-turn lane is provided, the number in parentheses is the maximum queue in the right-turn lane (for a 95 percent probability).

Table 4. Estimates of time for queue to dissipate.

Intersection	No. of Approaching Lanes	Time for Queue to Dissipate (Seconds)
Jackson Drive and Fletcher Parkway		
Northbound	2	25
Southbound	2	18
Eastbound, right turn	1	21
Westbound, left turn	2	6
Spring Street and I-8 off ramp		
Southbound	1	37
Eastbound, left turn	1	10
Spring Street and University Avenue		
Northbound, left turn	1	21
Southbound, right turn	1	10
Eastbound	3	12
Westbound	2	10
Spring Street and Allison Avenue		
Northbound, left turn	1	16
Southbound, right turn	1	14
Eastbound	1	27
Westbound	1	25
Spring Street and La Mesa Boulevard		
Northbound, left turn	1	12
Southbound	1 ^a	14
Eastbound	1	33
Westbound	1	16
Spring Street and Lemon Avenue		
Northbound, left turn	1	12
Southbound	1 ^a	8
Eastbound	1	21
Westbound	1	21
Imperial Avenue and Lemon Grove Avenue		
Northbound, left turn	2	21
Southbound	1 ^a	12
Eastbound	3	18
Westbound	1	14
Imperial Avenue and Broadway		
Northbound, left turn	1	21
Southbound	1 ^a	12
Eastbound	3	16
Westbound	2	14
Imperial Avenue and Golden and Pacific Avenues		
Northbound, left turn	1	12
Southbound	1 ^a	12
Eastbound	1	16
Westbound	1	12
Imperial Avenue and Central Avenue		
Northbound, left turn	1	6
Southbound	1 ^a	6
Eastbound	1	14
Westbound	1	8
Imperial Avenue and Palm and Cypress Streets		
Northbound, left turn	1	8
Southbound	1 ^a	14
Eastbound	1	25
Westbound	1	12

^a Assuming right-turn lane is provided.

Table 5. Intersection level of service.

Intersection	1980 Without LRT		1985 Without LRT		1985 With LRT			
	V/C ^a	Level of Service	V/C ^a	Level of Service	Preemption Clearance (seconds)	Percent in an hour	V/C ^a	Level of Service
<u>City of La Mesa</u>								
Jackson Drive and Fletcher Parkway	0.70	B/C	0.79	C/D	16 x 8 = 128	4	0.82	D
Spring Street and I-8 on-off ramps	0.49	A	0.55	A	16 x 8 = 128	4	0.57	A
Spring Street and University Avenue	0.79	C	0.89	D/E	16 x 8 = 128	4	0.93	E
Spring Street and Allison Avenue	0.73	C	0.82	D	16 x 8 = 128	4	0.85	D
Spring Street and La Mesa Boulevard	0.82	D	0.96	E	16 x 8 = 128	4	1.00	E/F
Spring Street and Lemon Avenue	0.52	A	0.65	B	16 x 8 = 128	4	0.68	B
<u>City of Lemon Grove</u>								
Imperial Avenue and Lemon Grove-North	0.57	A	0.75	C	16 x 8 = 128	4	0.78	C
Imperial Avenue and Broadway	0.88	D	1.00	E/F	16 x 8 = 128	4	1.04	E/F
Imperial Avenue and Golden-Pacific Avenues	0.57	A	0.65	B	16 x 8 = 128	4	0.68	B
Imperial Avenue and Central Avenue	0.51	A	0.57	A	16 x 8 = 128	4	0.59	A/B
Imperial Avenue and Palm-Cypress Streets	0.55	A	0.63	B	16 x 8 = 128	4	0.66	B

^aVolume/Level of Service E capacity.

speed of the emergency vehicles, and because of the short stopping distance requirements for the LRT vehicle itself, the actual delays to emergency vehicles are likely to be very small. In most cases, the emergency vehicle can "signal" the crossing of its approach approximately 17 to 23 seconds before it arrives at the railroad crossing. An LRT vehicle traveling at 20 mph can stop in 7 seconds. Therefore, with emergency vehicle preemption added to the system, delays to emergency vehicles can be substantially minimized.

DEMONSTRATION PROJECT

On January 14, 1981, a demonstration project simulated LRT vehicles operating on a 15-minute schedule through La Mesa. This was done by simultaneously actuating the railroad crossing gates every 7.5 minutes across three

adjacent La Mesa streets: University Avenue, Allison Avenue, and the Interstate 8 freeway off-ramp. The demonstration project was jointly conducted by MTDB, the California Department of Transportation, and City of La Mesa staff. The experiment was carried out over a 45-minute period (4:15 p.m. to 5:00 p.m.). The activity at the intersections was recorded on film through time-lapse photography.

The conclusion from this test project was that there was no significant adverse traffic impact resulting from the gates being lowered for a simulated light rail train crossing every 7.5 minutes. A review of the time-lapse filming reveals that all traffic queues were dissipated in one traffic cycle and there was no added congestion observed despite the fact that the recommendations described above are not in place. The longest backup observed during the test project was the northbound left turn onto University Avenue.

Design Consideration for LRT in Existing Medians: Developing Warrants for Priority Treatments

THOMAS J. STONE and WILLIAM A. WILD, CRS Group Engineers, Inc.

This paper examines current light rail transit planning and design criteria for at-grade crossings and suggests that an alternative criterion be used to determine if priority treatment is justified for LRT at such crossings. Current practice is assumed to be represented by the recently completed UMTA-funded research into light rail surface operations, which suggests that the appropriate evaluation criterion is the impact of light rail on the estimated level of service of the intersection of the arterial carrying light rail and the cross street. This paper, however, argues that the use of the level of service criterion significantly favors the automobile mode over the LRT mode for a wide range of automobile volumes and LRT passenger volumes because it does not consider the volume of people carried by transit. The criterion used to make this determination is the total estimated person-delay induced at the intersection for both automobile users and transit riders. The results suggest, therefore, that at-grade LRT solutions that employ priority measures may be warranted for a wider range of situations than previously deemed appropriate. The design situation used for illustration is the insertion of LRT into an existing highway median. However, the methodology used to evaluate overall intersection performance, both with and without priority treatment for LRT, is applicable to other design situations as well. It is recommended that additional research be conducted by applying the person-delay criterion to other design situations. It is hoped that ultimately a set of warrants will be adopted for LRT priority treatments that are based on the person-delay criterion.

This paper initially addresses current LRT planning and design practice for determining the feasibility of inserting LRT into existing street medians. The criterion used is the traditional traffic engineering practice of estimating intersection level of service with and without LRT, and with and without priority treatment. This design illustration is taken from the initial draft of a report prepared for UMTA.¹ In this paper, the level of service evaluation criterion used in the UMTA research is compared to the total person-delay evaluation criteria. The results of the Light Rail Surface Operations Report are first summarized. The particular design situation examined is the placement of a 2-track light rail line into an existing median located in the center of a heavily traveled arterial. Several design variations are discussed to illustrate possible geometric changes required in the location of motor vehicle traffic lanes due to the additional right-of-way needed for station platforms. A range of cross-traffic volumes is considered. The impacts in terms of traffic congestion due to traffic signal preemption in favor of the light rail vehicle are examined parametrically, not only for cross-street vehicular volumes but also for various LRV headways and different station platform locations. The analysis performed for UMTA suggests that surface operation of LRT should be accommodated only when excessive impacts (where "excessive" is defined by the intersection utilization reaching a certain level) on the movement of motor vehicles and pedestrians can be avoided.

THE ILLUSTRATIVE EXAMPLE

The specific design situation evaluated herein from the Light Rail Surface Operations Report is the case where the light rail line is assumed to be accommodated in an

existing 50-ft-wide median of a 130-ft-wide arterial. Because of the street's width, no substantial changes to the roadway were contemplated for the arterial's two 40-ft-wide one-way roadways. Two traffic lanes and one parking lane were assumed to exist. The prototypical arterial section is shown in Figure 1. Two different types of intersections were investigated: major 4-lane cross streets with turning lanes, and 2-lane minor cross streets with no turning lanes. Traffic signals were assumed for each intersection type. Left-turn bays were assumed to exist at the major street crossing.

Geometric Design

Several different geometric design treatments for light rail were investigated, including closure of minor street crossings, both near- and far-side LRT station locations, alternative traffic signalization schemes, and the differing effects of alternative platform locations on on-street parking. Figure 2 shows a configuration with station platforms located on the far side of the crossing, opposite left-turn lanes. This arrangement permits optimum use of the available street space, because special left-turn traffic signal phases would be provided at station locations. At other similar intersections, left turns could proceed without a protected signal phase. Left turns would be prohibited at minor intersections.

Figure 3 shows one of the alternative geometric designs that was investigated; this design places the station platforms on the near side of the intersection next to left-turn lanes. This requires parking to be removed and the approach lanes to be shifted toward the curbs to provide space for the left-turn lane. This would result in the loss of about 30 percent of the parking supply on one block for both station platforms. Figure 4 shows another alternative, which shifted the alignment of the LRT track to provide space for a left-turn lane. This design would allow complete retention of the existing curb parking supply but necessitates reverse curves on the LRT tracks. With the geometry shown, the curves could have radii of about 1500 ft with no spirals. This would permit a maximum LRT operating speed of about 30 mph through the curves.

Preferential Control of LRT Movements

Intersection traffic control in these examples would be provided by standard traffic signal indications, and LRV movements would be accommodated by any of several preferential control strategies. The draft Surface Operations Report¹ suggests that selection of the appropriate strategy is a function of the degree of transit priority deemed appropriate for light rail, the traffic volume and capacity of the intersection, the type of traffic signal system, and the intensity of LRV movements.

It is further suggested in the Surface Operations Report that conflicts with pedestrians could be controlled by the existing pedestrian signals and/or could be supplemented by pedestrian signals mounted on the median on either side of the tracks. In addition, warning signs and/or audio signals could be placed on either side of the tracks to warn of approaching LRVs.

EVALUATION METHODOLOGY

To illustrate the effect of at-grade light rail operation on

Figure 1. Typical cross section for median light rail treatment.

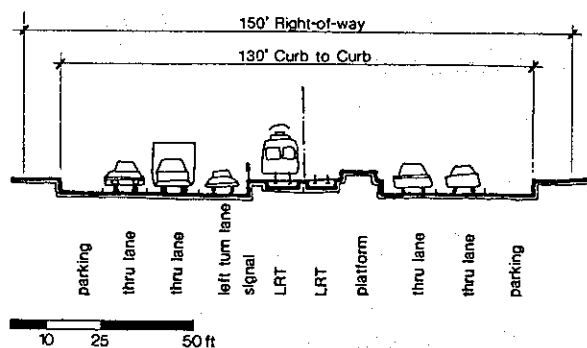


Figure 2. Major crossing with far-side platforms.

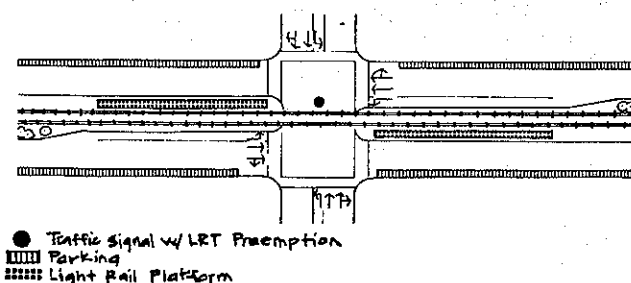


Table 1. Interpretation of levels of service for city streets.

Operation	Factor ^a	Utilization Interpretation ^b (During Peak Periods)
Excellent	to 50	Relatively free flow, average speeds 30 mph (constrained only by roadway alignment and/or speed limits)
Very good	50-75	Stable flow, slight delay at key intersections, average travel speed 25+ mph
Good	75-85	Stable flow, occasional delay and intervehicular conflicts at many intersections, average speed reduced to 20+ mph
Fair	85-95	Approaching unstable flow, delays at critical intersections as long as 2 or more signal cycles, average speed as low as 15 mph
Poor	95-100	Unstable flow, continuous backups on approaches to critical intersections, traffic from minor cross streets has difficulty entering or crossing main traffic stream, average speed likely to be at or below 15 mph
Forced flow	100 or greater	Vehicles back up from critical downstream signals through upstream signalized intersections, stop-and-go conditions, average speed less than 15 mph

^aPercent of theoretical capacity.^bAs defined in the Highway Capacity Manual, 1965.

these different intersection configurations and traffic characteristics, the Surface Operations Report authors prepared detailed intersection capacity calculations using techniques outlined in the Highway Capacity Manual, 1965. The concept of "level of service" was used, correlating traffic volumes and intersection capacity data with projected average travel speeds and subjective descriptions of travel performance, as shown in Table 1. The inter-

Figure 3. Major crossing with near-side platforms: parking removed.

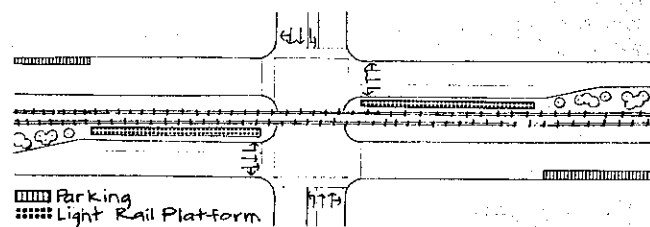
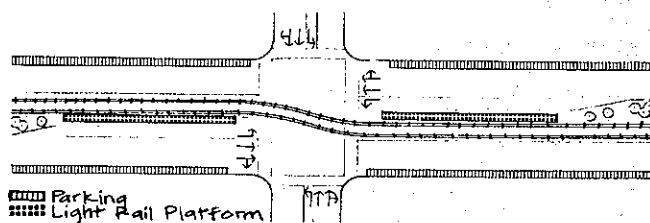


Figure 4. Major crossing with near-side platforms: no parking removed.



section utilization factors used in the analysis indicate the percentage of theoretical capacity of the intersection that is being used. The report suggests that typical urban traffic design practice adopts the "good operation" category as the design standard, with a utilization factor of 85 percent of capacity often considered the dividing line between good and poor traffic conditions. The authors further indicate that local policies may alter this standard, because what is acceptable at one intersection may not be so at another, and an acceptable standard in one community may not be another's. For the purpose of illustration, the 85 percent point was adopted as an indicator of changes in vehicular operating conditions from "good" to "poor" due to the incorporation of LRT. The report's authors suggest that combinations of LRT operating frequencies and traffic volumes that cause the utilization factor at an intersection to exceed 85 percent are taken to indicate circumstances that may call for grade separation, alternate LRT routing, increased LRV headways, or provision of alternative routings for motor vehicles.

Intersection utilization factors (or volume/capacity ratios) using a range of traffic parameters were calculated for the various designs. Calculations were made for the unconditional traffic signal preemption control strategy in order to demonstrate the theoretical "worst case" impacts on auto traffic. Preemption intervals of up to 20 seconds were used, including time for driver reaction and clearing the intersection of vehicles blocking the track. The signal cycle was assumed to be 60 seconds. Utilization factors were calculated for three alternative operational strategies:

- Left turns from the arterial onto the cross street (across the LRT tracks) controlled with a special signal phase;
- Left turns prohibited from the arterial onto the cross street; and
- All traffic stopped during LRV passage.

The utilization factors without LRV preemption were also included for comparison. In this case, the LRV would be subject to the same signal phasing as motor vehicle traffic on the arterial. It was assumed that when left turns across the track are permitted, the LRV would be given a red signal to clear the intersection for the motor vehicle left-turn phase.

The LRV approach speed was assumed to be 40 mph, the LRV trains were assumed to be 200 ft long, and the intersection crossings were assumed to be 1, 3, 5, and 10 minutes, i.e., 2-, 6-, 10-, and 20-minute light rail headways.

Utilization factors were not calculated for LRT operation with unconditional signal preemption and near-side platforms, because with near-side platforms the time required to stop and serve passengers prior to crossing the preempted intersection is variable. With preemption it is necessary to compensate for this uncertainty by placing a light rail vehicle detector at the LRV stop line to detect when the vehicle begins to proceed. The variation in dwell time means that this detection, and hence the initiation of the signal preemption sequence, could occur at any time within the signal cycle with near-side platforms. Consequently, the impact of preemption on intersection level of service was felt to be too difficult to quantify.

Analysis of the Results

Table 2 shows the results of the analysis of the major cross street for two alternative treatments of left turns, for the LRT design alternatives shown in Figures 3 and 4, with unconditional preemption granted to the light rail vehicles. In Figure 5 the utilization factor is plotted against the cross-street volume for a range of LRT headways for the controlled left turns alternative. The results show that many of the potential situations fall in the so-called unacceptable range, thereby implying that LRT may not be acceptable in an at-grade configuration in many situations. It should be noted that these results were obtained for the design situation where all left turns are assumed to be signal-controlled. As shown in Table 2, prohibition of left turns reduces the utilization factors by 4 or 5 percentage points across the range of cross-street volumes.

Analysis of these results points out a key conceptual difficulty with the use of the traditional level-of-service approach. The results imply that, as the frequency of the LRT operation increases, the feasibility of preemption decreases because it causes an "unacceptable" impact on cross traffic. However, higher frequency LRT operation actually may mean that a far greater number of people are traversing the intersection with light rail than without it, thereby greatly increasing the overall person-carrying

capacity of the intersection. Thus, the true situation may be just the opposite from that implied by the results: Traffic signal preemption may be easier to justify for high-frequency LRT lines than for lower ridership, low-frequency lines.

TOTAL PERSON-DELAY AS AN EVALUATION CRITERION

The use of intersection level of service, or of the inter-

Figure 5. Utilization factor versus cross-street volume for a range of LRT headways (with preemption).

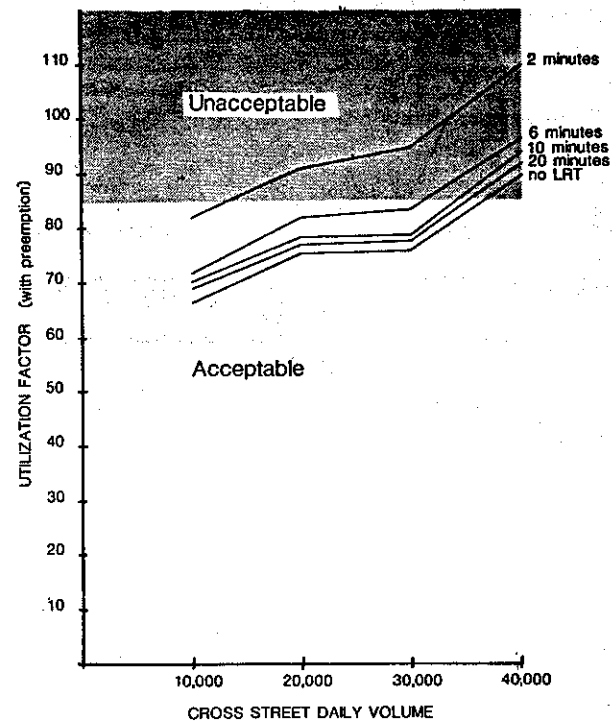


Table 2. Effect of preemption for light rail on peak-hour utilization rates at an intersection with a major cross street.

Preempt Strategy	Platform Location	Cross-Street Volume	LRT Headway (minutes)					
			2	6	10	20	-	
			Intersection Crossing Interval (minutes) ^a					
			1	3	5	10	No LRT	
A. Parallel traffic moves with LRT, left turns controlled	Far side or none	10K ^b	82	(76)	72(66)	70(64)	69(63)	67(62)
		20K ^b	92		81	78	77	76
		30K ^c	95		83	80	80	78
		40K ^c	110		97	93	92	91
B. Parallel traffic moves with LRT, no left turns	Far side or none	10K ^b	77	(82)	67(72)	65(70)	65(69)	63(67)
		20K ^b	87		76	74	73	72
		30K ^c	90		79	76	75	74
		40K ^c	106		93	90	89	87

Note: Figures in parentheses assume pedestrian actuation every other cross-street phase.

^aIntersection crossing interval equals one-half the headway operated in each direction.

^bTwo lanes plus parking.

^cThree lanes, no parking.

section utilization factor, as the sole evaluation criterion considers only automobile passengers and drivers. If, however, a criterion can be developed that considers the impact of alternative design treatments on both auto and transit users, then a more comprehensive evaluation will result. The criterion of total person-delay would measure the overall impact on the movement of people, rather than simply on the movement of autos. To use this criterion it is necessary to estimate the total person-delay resulting from the incorporation of light rail into the median of our hypothetical street.

Delay to Auto Drivers and Passengers

May and Pratt estimated the average delay to individual autos as a function of load factor defined as in the Highway Capacity Manual, or the proportion of green signal intervals that are fully utilized in the peak hour.² In addition, Crommelin related the load factor to the intersection utilization factor.³ By combining these results, it is possible to estimate the average individual vehicle delay as a function of the intersection utilization factor. Table 3 shows the actual combined results from May and Crommelin.

Figure 6 shows the relationship graphically. Regression analysis performed on the data suggests that a power curve provides the best fit (with $r^2 = 0.97$):

$$\text{Delay} = 0.22 e^{5.77 (\text{IUF})}$$

where e = base of Napierian logarithms and IUF = intersection utilization factor. By apply this formulation to the results of the Surface Operations Report, it is possible to estimate the total delay to automobile users resulting from implementing light rail into our hypothetical arterial. Table 4 shows the delay to auto users resulting from unconditional preemption for light rail for the same hypothetical major intersection. The figures represent the induced delay in person-hours for a single peak hour.

Delay to Light Rail Passengers

It is possible to estimate the total delay to light rail passengers that would result if light rail were not to be granted preemption. This analysis can be made parametrically, but for the purposes of this paper, to make this estimate the following was assumed:

- Time lost in deceleration and acceleration is neglected;
- Cycle length is 60 seconds with 50/50 split;
- The 3-car LRV train is approximately 240 ft long;
- The LRVs are fully loaded (160 passengers) in the peak direction;
- The LRVs are half full in the off-peak direction; and
- There is no signal progression (random arrival at any point in the signal cycle).

For these simplifying assumptions, the total peak-hour delay to transit passengers is shown in Table 5. This represents the expected delay in person-hours over the entire peak hour, assuming vehicles are equally likely to arrive at the signal at any point in the signal cycle.

By subtracting estimated auto user delay (from Table 4) from these figures, it is possible to determine the net overall person-delay avoided by preemption. Table 6 shows these results, which are also expressed in person-hours for a single peak hour.

Analysis of the Results

Figure 7 plots the net savings in delay due to preemption against the cross-street volume. The results here can be compared against those shown in Figure 5 for the more conventional effectiveness measure, the utilization factor. Some striking differences are evident. First, the delay

criterion gives results that are more consistent with the objective of maximizing the overall person-carrying capacity of the intersection—namely, as the frequency of LRT service increases, the savings in overall person-delay also

Table 3. Relationship between load factor, intersection utilization factor, and average vehicle delay.

Level of Service	Load Factor	Intersection Utilization Factor	Average Vehicle Delay (seconds)
A	0.0	0.68	10.0
B	0.1	0.71	15.0
C	0.3	0.77	18.5
D	0.7	0.90	39.0
E	1.0	1.00	--

Figure 6. Average individual vehicle delay versus intersection utilization factor.

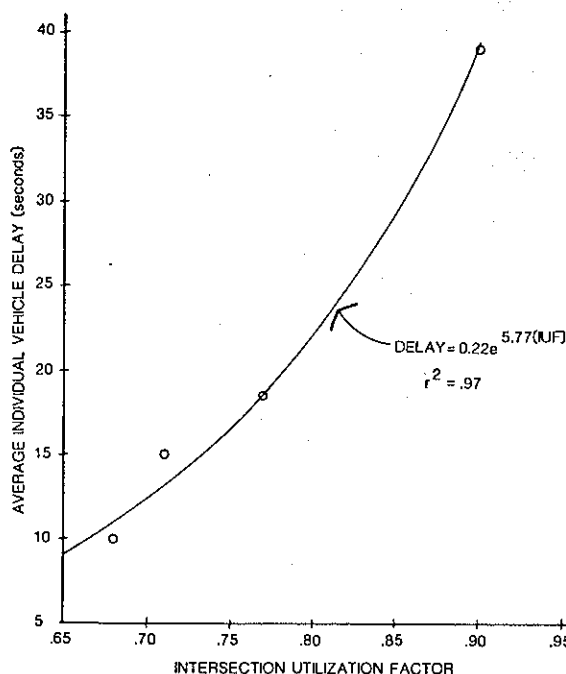


Table 4. Auto user delay.

Preempt Strategy	Cross-Street Volume	Auto Person-Hours of Preempt-Caused Delay				
		LRT Headway (minutes)				No LRT
		2	6	10	20	
A. Left turns controlled	10K	5.2 (3.5)	1.3 (0.7)	0.7 (0.3)	0.5 (0.1)	0
	20K	19.4	4.3	1.6	0.8	0
	30K	35.8	7.1	2.6	2.6	0
	40K	∞	25.0	7.4	3.6	0
B. No left turns	10K	3.8 (5.2)	0.8 (1.3)	0.4 (0.7)	0.4 (0.5)	0
	20K	13.9	2.6	1.2	0.6	0
	30K	25.8	5.7	2.1	1.0	0
	40K	∞	19.8	9.0	5.8	0

Note: Assumptions are the same as for Table 2, plus a 10 percent peak-hour factor and an average auto occupancy of 1.3.

increase. It must be pointed out, however, that in the illustrative example, as cross-street volumes approach 40 000 and headways reach about 6 minutes, the delay to autos becomes quite significant. Thus, the justification for priority treatment for LRT generally increases as the line volume increases, until the headways are so short and cross-street volumes are so high as to begin to greatly increase auto delay. Second, it is found that preemption can be justified for all but two of the combinations of LRT headways and cross-street volumes, whereas the utilization factor criterion resulted in many more design situations falling into the so-called unacceptable category.

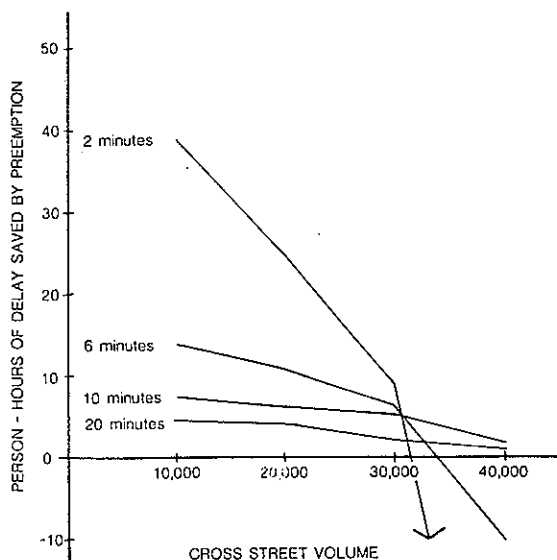
CONCLUSIONS AND RECOMMENDATIONS

Much additional research is needed before warrants for signal preemption can be adopted based on the total person-delay criterion. However, the results obtained in this analysis certainly suggest that the technique would yield design decisions that are more consistent with maximizing the person-carrying capacity of the street space of

cities. It is recommended that additional research be conducted, with emphasis given to addressing the following issues:

- Consider the effects on other adjacent intersections, rather than just on an isolated intersection.
- Consider the additional delay due to motorists seeking alternative routes.
- Include the additional delay to light rail passengers due to deceleration and acceleration for stops that otherwise would not need to be made.
- Consider the effect of providing signal progression for light rail along the length of the line.
- Consider the effect of conditional preemption, such as granting early or extended green for light rail.
- Extend the analysis to a wider range of generic geometric design situations.
- Compute net annual savings in delay and convert to dollars using an appropriate value of time. Compare the value of time savings (or time lost) to the cost of a grade separation to determine if a separation is justified.

Figure 7. Person-hours of delay saved by preemption versus cross-street volume (for the controlled left-turn case).



Such research would be aimed at adopting a set of warrants for priority treatment for light rail. Decisions regarding grade separations then, it is hoped, would begin to be made on a sound technical basis. Unfortunately, design decisions are often made to grade-separate new light rail lines on grounds other than maximum use of the right-of-way to carry people in the most cost-effective manner. In the present era of limited capital funding for

Table 5. Transit person-hours of delay in peak hour without preemption.

Headway (minutes)	Person-Hours of Delay
2	45
6	15
10	9
20	4.5
No LRT	—

Table 6. Net person-hours of delay avoided by preemption during peak hour.

Preempt Strategy	Cross-Street Volume	LRT Headway (minutes)				
		2	6	10	20	No LRT
A. Left turns controlled	10K	39.8 (41.5)	13.7 (11.5)	8.3 (8.7)	4.0 (4.4)	-
	20K	25.6	10.7	7.4	3.7	-
	30K	9.2	7.9	6.4	1.9	-
	40K		-10.0	1.6	0.9	-
B. No left turns	10K	41.2 (39.8)	14.2 (13.7)	8.6 (8.3)	4.1 (4.0)	-
	20K	31.1	12.2	7.8	3.9	-
	30K	19.2	9.3	6.9	3.5	-
	40K		4.8	0	-1.3	-

Note: Figures in parentheses assume pedestrian actuation every other cross-street phase.

transit, the importance of this issue cannot be overstated, because at-grade solutions may be the only affordable high-capacity transit option for many cities dependent on local funding capability.

REFERENCES

1. Deleuw, Cather & Co. Light Rail Surface Operations Report. Draft prepared for the Urban Mass Transportation Administration, 1981.
2. Adolf May, Jr., and David Pratt. "A Simulation Study of Load Factor at Signalized Intersections." Traffic Engineering, February 1968.
3. Robert W. Crommelin. "Employing Intersection Capacity Utilization Values to Estimate Overall Level of Service." Traffic Engineering, July 1974.

