F. Kuhn, G. Coquery, J-H An LTN
F. Papon, J. Suprapto DEST
B. Cambou DS

S. Dikun, I. Katili, Engineering UI

Establishing innovative and sustainable transit system in UI's campus and the city of Depok

INRETS LTN, DEST, DS
UI, Faculty of Engineering, Civil Engineering Department Report

INRETS
(Laboratory of New technologies
Department of Transport Economics and Sociology
Scientific Direction)
UI
(Faculty of engineering
Civil engineering department)

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1. Introduction

Now we recall the context and the target of the project Nusantara whose title is « Establishing innovative and sustainable transit system in University of Indonesia's campus and the city of Depok ».

1.1 The context

Large megapolis have a huge increase of population in emerging countries. Jakarta is one of these megapolis with 21 million inhabitants in the metropolitan area, Jakarta 8, 389, 443 in 2000 and Botadebek (Bogor, Tangerang, Depok, Bekasi) 12.6 million in 2000, according to the 2000 National Population Census.

The periphery of Jakarta is heavily dependent on the central city. Botadebek is a "bedroom suburb" for the daily commuters of Jakarta. Jakarta is the center of government and corporate offices, commercial, and entertainment enterprises. The economy of Jakarta dominates its peripheral areas.

In the daytime, total population in Jakarta nearly doubled its population in the nighttime (Kompas, June 18, 2004). The number of daily movement in Jakarta is estimated at six to seven million. Emerging countries as Indonesia want to promote and to increase the funding in high education system.

The University of Indonesia has a Master Plan for the next future which consists in developing the campus and in increasing the number of students from 40,000 now, until 70,000 in a few years. The government of Indonesia has a strong willing to develop sustainable system of transport in particular in urban area and to revitalize railway transport in Indonesia.

Railway from Jakarta to Bogor with two stops in the University of Indonesia UI is being rehabilited and developped with the building of two new railway stations in UI.

1.2 Project's description

The goal of this project is to analyse the mobility in the surrounding of the University of Indonesia and to analyse an innovative and efficient transport system to provide a pertinent offer to satisfy this mobility demand in relation with the other modes, which can be linked with the analysed system of transport.

The project we are proposing with the Technical Faculty of the University of Indonesia can be divided in three workpackages:

-1 Analysis of present and future mobility in the university of Indonesia and in the surrounding of Depok.

-2 Analysis of existing sustainable urban system of transport. The focus will be made essentially on tramway systems. All the tramway systems developped in several cities in France will be compared in the point of view of sustainable development and mobility efficiency.

-3 Analysis of the global system considering intermodality at the two levels:

- Intermodality between the Regional Express Railway RER and the future tramway

- Intermodality between the tramway and the use of bicycles or walk.

Both INRETS (The French national Institute for transport and Safety research) in France and Faculty of Engineering of UI in Indonesia are interested in urban public transit.

INRETS is involved in many urban transit projects in France or foreign countries, and the Faculty of Engineering of UI is interested in a transit system that could serve their campus and the city of Depok (1.5 Million inhabitants in 2005) in which there are located.

A proposal to prepare the development of a Tramway circular line has already been prepared by the railway revitalization team of the Faculty of Engineering of UI and presented on October 2008: a tentative schedule for the project preparation plans to present a final proposal for Bappenas Blue Book at the end of 2009.

A team of INRETS is in charge to study after a comparison of several surface guided systems a transit system, which could be able to serve the campus and several quarters of Depok until the workshop of the Regional Express Rail which is located at around 7 km south of the Campus.

So, to be able to define the best urban transit system for the campus and Depok, it is necessary to get data about present mobility of people living in the campus, in Depok and going to the campus, living in Jakarta and going to the campus and Depok. A team of the Faculty of Engineering of UI involved in this partnership should evaluate present and future mobility in the campus of UI and the surrounding of Depok.

So, the calendar could be :

1rst year:

Assessment of available informations about mobility in UI and the surrounding. These informations could come from counts of passengers' flows in the railway stations located in University of Indonesia, from counts of cars/motorcycles flows coming in the campus, of counts of students flows carried by the buses of campus, of counts of flows of bicycles. A light survey could possibly complete these data. Design of the present demand of transport of people going to and from the campus. Adjustment of this demand with the prospects of the masterplan UI 2008 for a population changing 40,000 into 70,000 inhabitants (students, teachers, administration staff, etc.).

Choice of the better-appropriate system producing a high level of performances and the best impact on the environment, to serve the campus and Depok and being able to be extended in several lines to become a urban rail system network in the future. This choice will be done on using multi-criteria analysis, prepared in the frame of the thesis "Effects of insertion and operation of a new guided surface transit system", presently under study with a LTN's doctorate student. For the last quarter 2009, the teams should be able to evaluate the cost for a final proposal for Bappenas Blue Book. For the end of the year a report will be delivered and a seminar will be held.

2nd year:

An analysis of the global system considering intermodality at the two levels has to be done:

- Intermodality between the Regional Express Railway RER and the future tramway with a study of the best geometric insertion to obtain a link RER platform to Tramway platform without a long pedestrian way for the exchange Tramway-RER.

- Intermodality between the tramway and the use of bicycles or walk. Indeed, the fact to introduce a new rail system in the campus forces to canalize the different traffics of cars, motorcycles, bicycles, pedestrians and tramways with appropriate road signs and signals to avoid accidents. A best share of road domain or public domain with a median separate right of way for the tramway for example, could help to avoid conflicting traffics and improve safety.

The Laboratory of New Technologies of INRETS has launched one year ago a thesis whose subject is "Effects of insertion and operation of a new guided surface transit system: what choice for a sustainable system ? " This research, first of all, aims at giving a general panorama of existing and/or new guided surface transit systems and explains them in terms of capacity, investment and operation costs, compared with some systems between the standard tramway and the articulated bus of bus rapid transit (BRT) system. The second target of this study is to make a description as complete as possible, of these new rolling stocks for the new guided surface transit systems with a close look of innovative equipments and their performances in terms of operation and safety. On the other hand, we shall examine different constraints of their development: width of the right-of-way, physical characteristics of infrastructures (slope, curve radii, type of pavement, etc.) and the predictive effects on the town and the whole transit network. Finally, we shall propose a method of assessment that helps decision makers choose a new guided surface transit system being optimal to a local context. The interest to collaborate with an indonesian team about a new urban transit system serving a campus and an high density city of 1.5 million inhabitants linked to a mass rapid transit RER serving the center of Jakarta is to adapt european surface guided transit system generally operating in medium density cities in France and other european cities to high density cities of the metropolitan area of Jakarta. The method of assessment that will be proposed in the thesis must take different density levels into account, the case of Depok could help for studies of urban transit systems in asian cities.

The team of the Faculty of Engineering knows transportation's context in Indonesia and lives every day the problems of serving the campus with buses, bicycles, cars and motorbicyles. This team could give the constraints to design a new surface guided transit system for Depok city and the campus, so the partnership of french and indonesian could arrive to the best design of a transit system's project similar to european transit system but taking into account the indonesian constraints. This team with architects has already prepared drawings of improvments of the two mass rapid transit stations serving the campus (Sayembara Perencanaan & Perancangan Stasiun UI1 & UI2 Kampus UI Depok) and the map of future housing on the campus for the next ten years.

The laboratory of new technologies gather four teams, one involved in energy management, traction, supercapacitors, batteries, etc, a second is involved in diagnostic and maintenance of the track and catenaries, a third is involved in rail and steel wheel contact, derailment, etc., a fourth is involved in systems of public transit and urbanism, in intermediate systems and certification about safety of new transit systems. This collaboration will offer to the four teams of the Laboratory of new technologies the possibility to apply to the design of the new vehicles, to the entire system of indonesian project the last traction equipment (batteries, super cap..) , the urban insertion of the tramway's line necessary to the best safety of pedestrians, bicycles, motorcycles, cars in the campus and outside in Depok.

The french team accustomed in several expertises of new transit systems projects in France, generally could learn more about high density cities by introducing the transit system in an indonesian context. A second department of INRETS, the DEST is involved in this project, accustomed in research on walking and cycling in household transport surveys, within the Eco-mobility coordinated programme, was involved in the organization of a seminar on Eco-mobility and member of Velocity Paris 2003 programme committee.

Now as we said above, in the frame of the project we try to make the choice of the better-appropriate system producing a high level of performances and the best impact on the environment, to serve the campus and Depok and being able to be extended in several lines to become a urban rail system network in the future.

We begin to examine the different surface guided sytems which could be appropriate in serving the campus and the city of Depok notably several kind of tramways systems being Under operation in France.

2. Serving the University of Jakarta in Depok with public transit

2.1 Introduction

Jakarta, capital of Indonesia Republic, had a growing and sprawling population to the suburbs of Bogor, Tangerang and Bekasi which became the metropolitan region of Jabotabek[1]. Total area counts 6580 km², population is estimated around 21 million of inhabitants in 2000 of which 8.4 million inhabitants in Jakarta.

2.2 Transportation Jabodetabek Region

Jabodetabek is an agglomeration with 7.409,78 Km² areas consisting of DKI Jakarta with 661,5 Km² area, as the Capital of Indonesia, and 7 local governments such as Municipality of Depok with 20,29 Km² area, Municipality of Bekasi with 210,49 Km² area, Municipality of Tangerang with 184 Km² area, Municipality of Bogor with 118,5 Km² , Regency of Bekasi with 1.484 Km² area, Regency of Tangerang with 1.110 Km² area, and Regency of Bogor with 3.441 Km² area. The administrative Region of Jabodetabek is shown as figure below :

[1] Jabotabek : Jakarta-Bogor-Tangerang-Bekasi

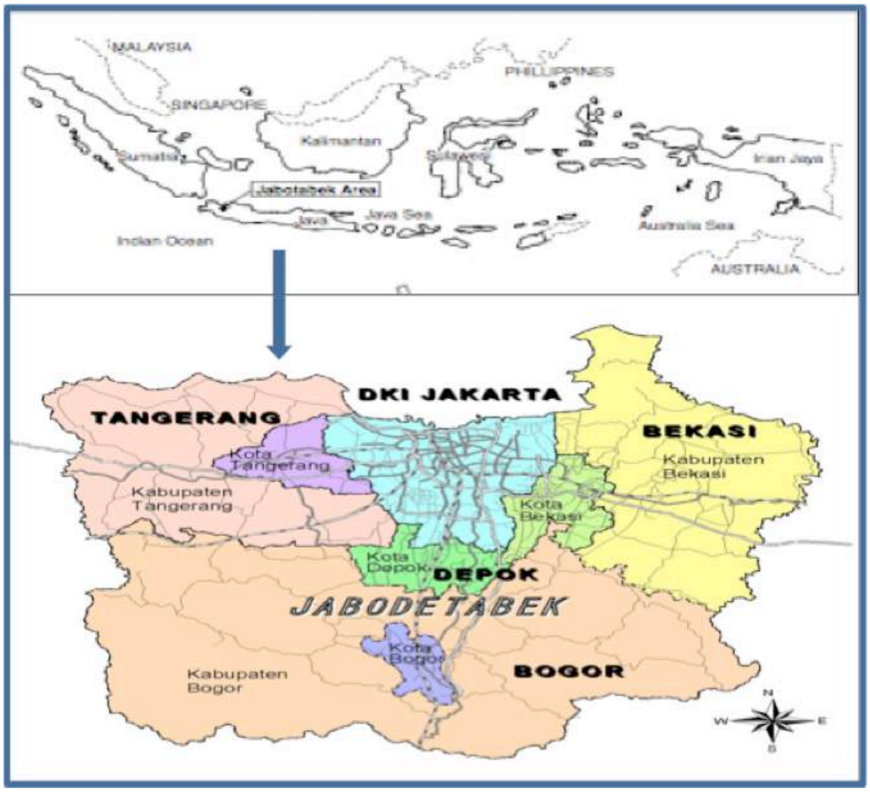
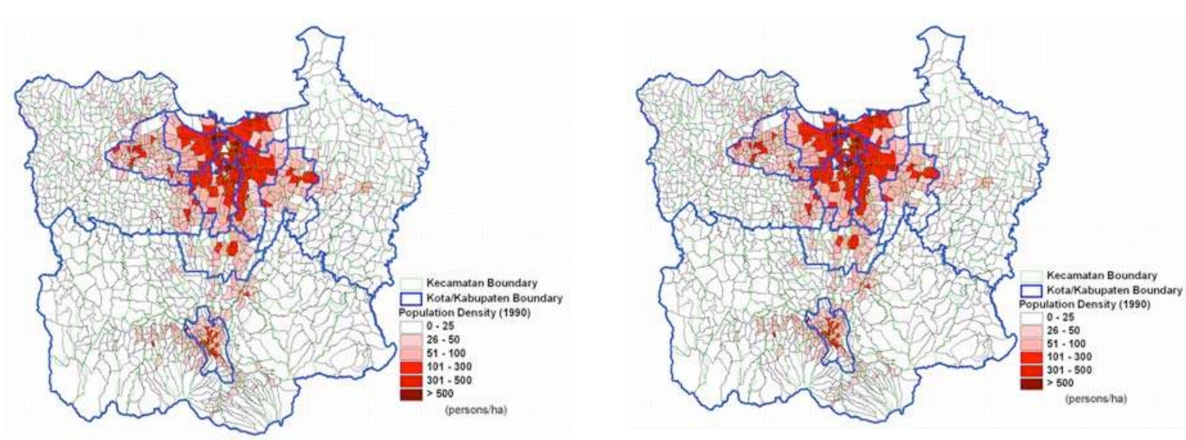


Figure 1: Localisation of Jabotabek's region

According to Study SITRAMP (2004), the total population size in Jakarta - Bogor-Depok-Tangerang-Bekasi (Jabodetabek) Metropolitan area amounted in 2000 to round 21 million people. The population size in Jakarta and Bogor-Depok-Tangerang-Bekasi (Bodetabek) was recorded at 8.4 million and 12 million people respectively, while average household sizes in DKI Jakarta and in Bodetabek were calculated at 3.74 and 3.84 respectively. Urbanization in Bodetabek between 1990 to 2000 was 3.7 percent per annum while the growth in Jakarta was merely 0.2 percent per annum, where the distribution of population density is shown by following Figures.

Population Density 1990 | Population Density 2000



Source : SITRAMP 2004 | Source SITRAMP 2004

Figure 2: Spatial Distribution of population and Residents in Jabodetabek Area

This urbanization and the distribution of population density currently still continues growing as shown in the table below :

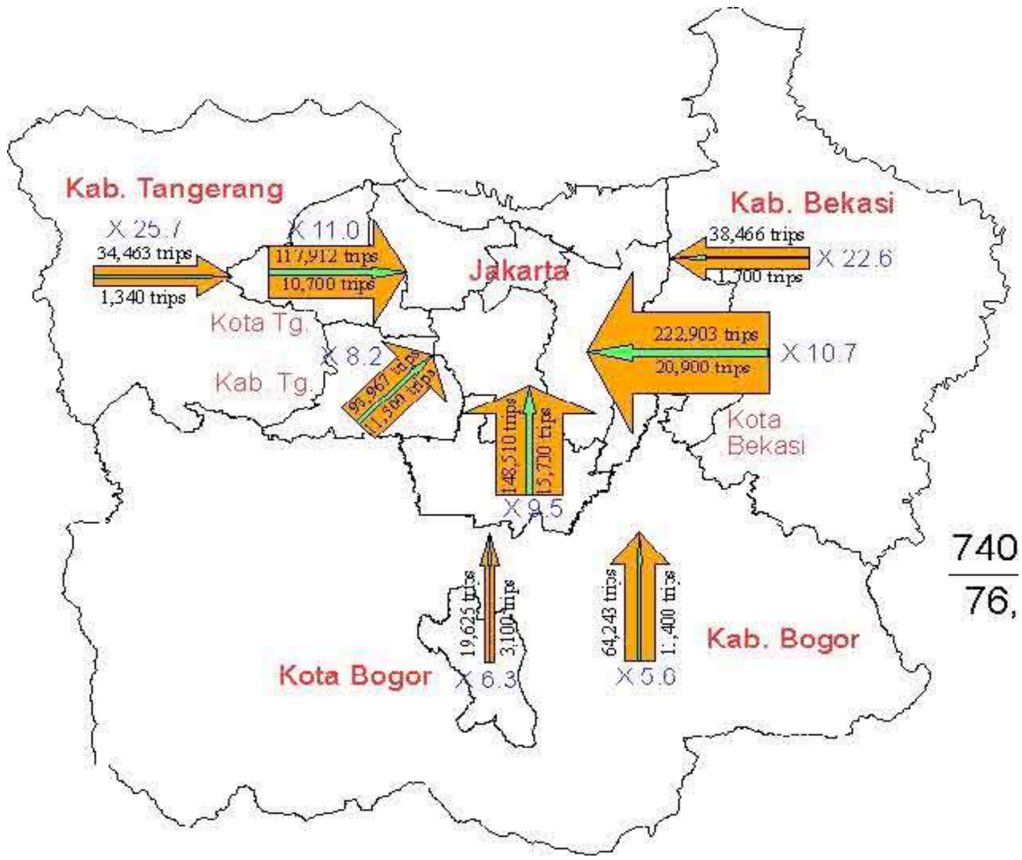
No	Cities	Population		Area (Km2)	Densty (Pop/Km2)		Growth of Density
		2001	*2007*		*2001*	*2007*	
1	*2*	*3*	*4*	*5*	*6*	*75*	*8*
1	DKI Jakarta	8,423,379	9,057,993	661.5	12733.76	13693.11	0.013
2	Mun.Bogor	760,329	866,034	118.5	6416.28	7308.30	0.023
3	Reg.Bogor	3,532,490	4,251,838	3441	1026.59	1235.64	0.034
4	Mun.Depok	1,184,045	1,412,772	200.29	5911.65	7053.63	0.032
5	Mun.Tangerang	1,354,256	1,603,496	184	7360.09	8714.65	0.031
6	Reg.Tangerang	2,949,286	3,473,271	1110	2657.01	3129.07	0.030
7	Mun.Bekasi	1,708,337	2,143,804	210.49	8116.00	10184.83	0.043
8	Reg.Bekasi	1,698,215	2,125,960	1484	1144.35	1432.59	0.042
9	**Jabodetabek**	**21,610,337**	**24,935,168**	**7409.78**	**2916.46**	**3365.17**	**0.026**

Source : Jabodetabek in Figures, BPS, 2001-2007

Figure 3: Evolution of Population and Density in Jabodetabek Region

The table describes that between 2001 to 2007, the growth of density in Jakarta is only 1.3 percent whereas in other cities (Bodetabek) range 2,3 to 4,3 percent. This indicated the tendency of population distribution and residents spreading out he Jabodetabek cities including the city of Depok.

The Status of Jakarta as the Capital City with so many economic activities and offering much more employees than Bodetabek cities, attract people of Bedetabek cities to work in Jakarta but living outside of Jakarta. This expansion of urbanized area has generated the commuter trips between Jakarta and surround cities (Bodetabek). Commuting trips from the surrounding areas to DKI Jakarta has increased about 10 times between 1985 and 2002. At present 700,000 people are commuting every day to Jakarta. These trips are concentrated in the CBD of Jakarta (SITRAMP, 2004) as shown in the figure below:



Source: SITRAMP 2004

Figure 4: Increase of Commuting Trips to Jakarta in 1985 – 2002

STRAMP (2004) find some transport problems of Jabodetabek such as road accidents, road congestions, economic loss and environement deterioration. Many road congestions are found notably in the CBD area of the cities. If no improvement were made for transportation network, almost all the roads would be very congested in 2002, as described in the following figure.

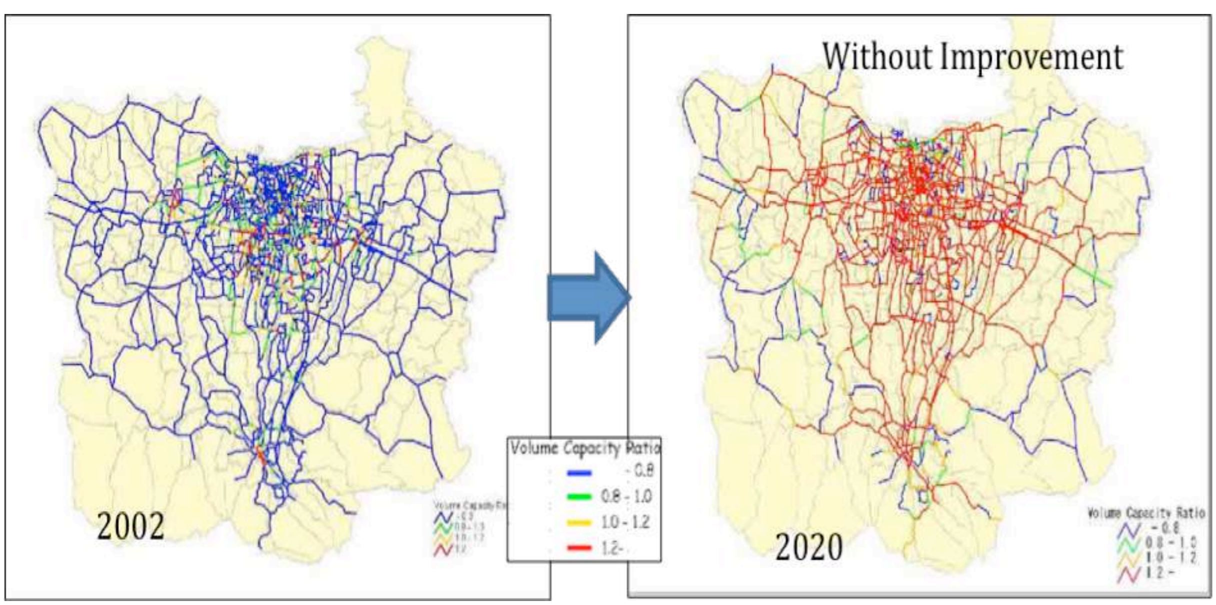


Figure 5: The evolution of traffic congestion assuming no improvement.

Without transport improvements, the traffic congestion would cause the accumulated economic loss predictably to Rp. 65. Trillion, which consists of Rp. 28,100 billion for additional vehicle operating costs and Rp. 36,900 for longer travel times at the present value discounted by 12 %. Concerning the environmental problem, out of 33 air survey stations, 25 roadside stations were observed to register PM_{10} concentrations exceeding the environmental standard. Moreover, the monitored PM_{10} values at 10 stations exceed more than twice of the standard value. The health impacts from PM_{10} in Jabodetabek could be valued at Rp. 2,815 billion in 2002.
Furthermore Sitramp (2004) describes that the total length of Road infrastructure in DKI Jakarta province is less than 10 percent of the total length of Road in Java Island. The comparison between the road infrastructure in total and the area of Jakarta is only 4 percent, whereas it should be range between 10 – 15 percent for such city level. Sitramp (2004) find that the daily trip in Jabodetabek Region in 2000 is around 29.168.330 trips each day. This is predicted in 2008 by 30 Million trips per day. The condition of motorization and the movement in Jabodetabek Region can be shown in the table below:

Modes	**Daily Trips**	**Composition of Each Mode**	**Composition of *Motorized modes***
1	*2*	*3*	*4*
Total Commuter Trips	29.168.330	100,0%	-
Non-motorized modes of transport	8.402.771	28,8%	-
Motorized modes of transport	20.765.559	71,2%	100,0%
- Motorcycle	2.954.512	10,1%	14,2%
- Private Car	6.404.503	22,0%	30,8%
- Bus	10.938.646	37,5%	52,7%
- Urban Railway transport (RER)	416.426	1,4%	2,0%

Source : Sitramp, 2004

Figure 6: Composition of Commuter trips in Jabodetabek classified in modal choice in 2000

Origin - Destination	Volume of movement (Veh/day))	Volume ofTrip (trip/day)
1	*2*	*3*
DKI Jakarta – Tangerang	412.543	1.221.079
DKI Jakarta - Bekasi	499.198	1.503.654
DKI Jakarta – Bogor/Depok	424.219	1.369.626

Source : Sitramp, 2004

Figure 7: Commuter Movement Jakarta - Bodetabektrips in Jabodetabek in 2000

According to the table above, the contribution of railway transport to commuter transport in Jabodetabek is the lowest by only 1.4 %. This predictably has been decreasing up to 0.4 percent today. In Jakarta, there are 5.300 units of non-busway fleet consisting of middle and standard bus, and 9.800 units of Minis Buses spread out of 358 lines, for meeting the daily demand of five million passengers. As the share of urban railway services in the

Jabodetabek transportation system is only of a small portion, it is rather imperative for Jabodetabek to have an efficient rail-based urban public transport system. Unfortunately, the present bus service is far below a level of satisfaction. Today's operations of buses in Jabodetabek are characterized by poor quality of services, including the lack of scheduled operations, poor condition of buses, degrading safety and comfort levels, and the like.
In 2003, DKI Jakarta administration has innovated by introducing TransJakarta Busway System as a backbone of urban transport as implemented in Bogota. The development of this BRT system predictably will be finished for all corridor in 2010. The provincial government of DKI Jakarta has launched « Jakarta Macro Transportation System in 2004 and officially published the related regulation called « Perda » No. 84 year 2004 concerning the Scheme of Macro Transportation. The Local Government of DKI Jakarta has been developing Monorail System and will install Subway infrastructure, which has high capacity.
DKI Jakarta Macro Transportation System in 2010 is established as followed:

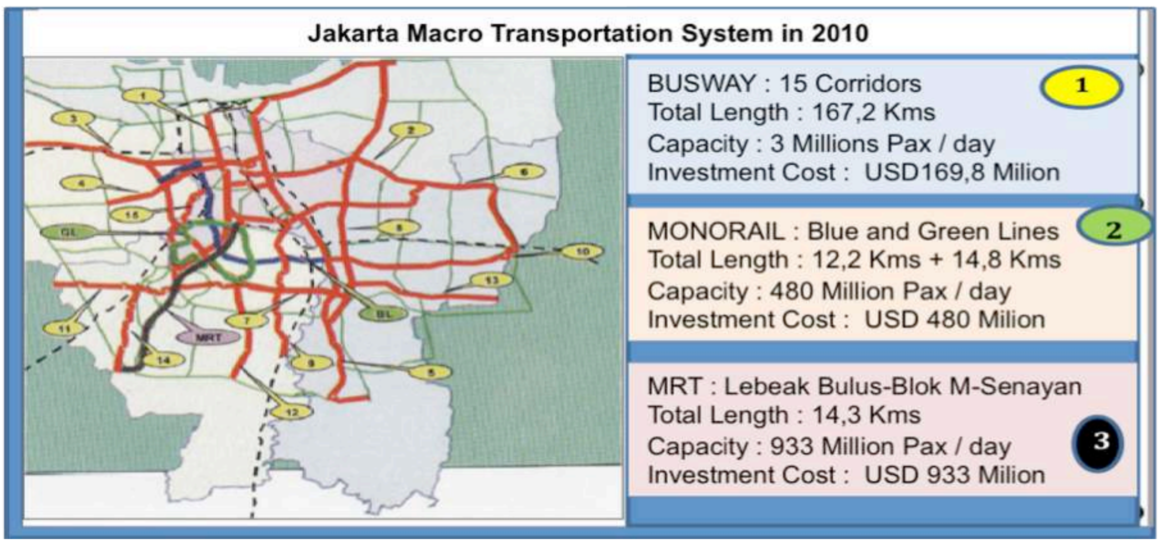
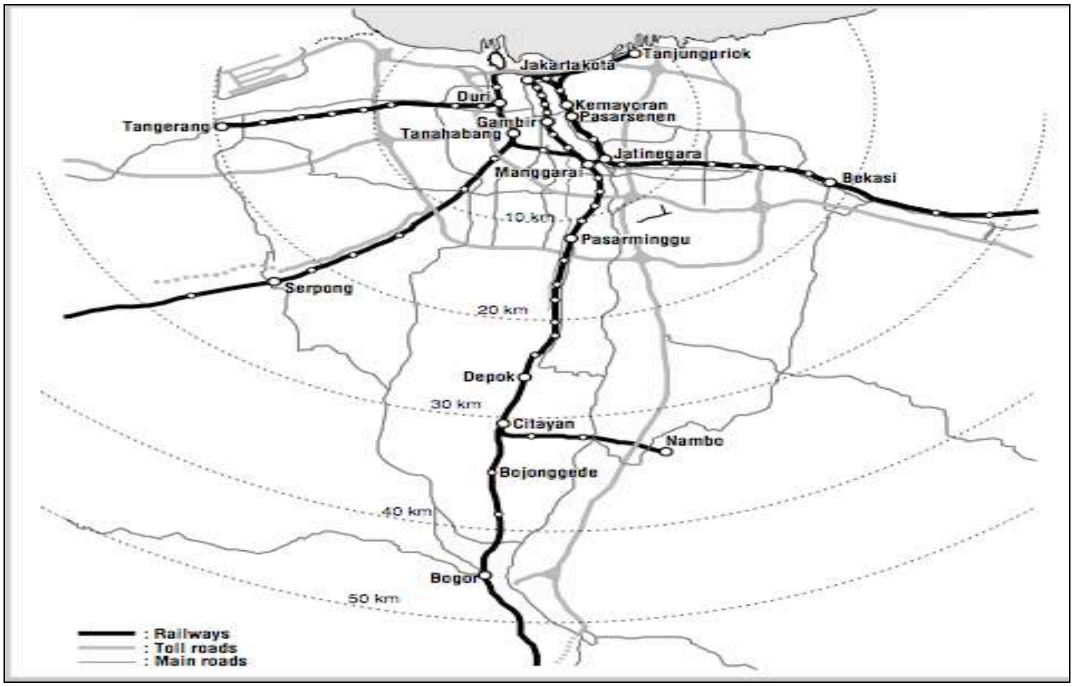


Figure 8: Scheme of BRT, Monorail and Metro for 2010

2.3 The Jabodetabek rail transport

The railway network after the second world's war was mostly used for long-distance rides, the growing road and the extreme pollution in years 1980s, the government decided on 1982 to construct a modern commuter's train integrating the whole existing railway network. The twenty years next saw enormous improvements as double tracking by line, electrification, grade separation, and signalisation improvements, better and more numerous stations, additional rolling stocks depots and workshops, the whole financed by Indonesian government with a support of Japan and France.
In 2003, the railway network became an Express Regional network, and it played an important local part by carrying 400,000 passengers per day with 170 km of lines.
A 1981 Master Plan of Jakarta railway network decided with a Japanese technical assistance to improve the level of performances of the transit system on rail for the suburbs in three stages to be achieved in 2000. The final target was to reach 20 % of the market share.
However, important delays in the project implementation, as well as uncertainties over secured funding inevitably led to a foreseen achieved in 1987 1st stage, only achieved in

1999. In 2003, headways during morning rush hours of trains were between 8 to 15 minutes. Shorter headways foreseen for stage 2 and 3 of the Master Plan were momently setting aside; the 1981 Plan became obsolete in 2003 and had to be completely reviewed.



Source : Tomoyoshi Hata, 2003, « Improvement of railway system in Jakarta Metropolitan Aerea », article in Japan railway & Transport review 35, July 2003

Figure 9: Road and rail networks of Jabotepek

The main result of passengers rapid increase with a growing numbers of trains becoming possible with the double tracking, automatic signalling, station renovation and adaptation and big fleet of EMU[2] rolling stocks: from 137 trains per day in 1992, the number grew to 356 trains in 2001 while the number of carried passengers changed from 130,000 in 1992 to 410,000 in 2001. This is the result of both more trains and transfer of potential demand from other modes to the railway due to its merits of speed, safety, economy, comfort, etc. A Transportation Master Plan for Jabotabek (SITRAMP), which aimed to establish a comprehensive road and railway system to alleviate land transport problems in Jabotabek, was now being implemented based on technical assistance from the Japanese government. The study had two stages: Stage 1 finished in 2002, and Stage 2 in early 2004.

The rail network has separate management of infrastructure and operations: the infrastructures other than station buildings and other offices is owned but the maintenance and operating of the infrastructure are done by PT. KA with the sceme of IMO. Meanwhile train operations are managed by PT Keretaapi Indonesia (PT KAI), which owns and maintains the rolling stock and also maintains the infrastructure under commission from the government.

Two different organizations are involved in Jabotabek railway operations: Jabotabek Division, which was establish in April 1999 solely to focus on commuter business, and manages Jabotabek commuter trains exclusively. Daop 1 Jakarta operates and manages long/middle-distance intercity trains. Having two organizations managing different kinds

[2] EMU : Electrical Multiple Unit

of trains over the same tracks has caused some difficulties, resulting in the future management separation of Jabotabek railways from PT KAI. Commuter trains with economy, business and executive classes mainly operates as suburban services between suburban residential areas and the centre of Jakarta.

Economy-class only train stops at every station, while executive and business-class only trains run directly between the origin and destination terminus stations. However, to provide better services to more passengers, some executive-class only trains stop at some intermediate stations. Northbound trains for Jakartakota run through Bogor, Bonjonggede and Depok and then on the Central line: trains with 8 cars are operating with 2 women-only cars included during the morning and evening rush hours (e.g. Mexico, Tokyo, etc.).

The infrastructure of Jabodetabek railway is describe in the following table :

	Length (km)	Double track	Single track	Electrified	Non-electrified
Central Line (Jakartakota–Manggarai)	9.7	○		○	
Bogor Line (Manggarai–Bogor)	44.9	○		○	
Bekasi Line (Jatinegara–Bekasi)	14.6	○		○	
Eastern Line (Jakartakota–Jatinegara)	11.4	○		○	
(via Pasarsenen)				○	
Western Line (Jakartakota–Jatinegara)	15.6	○		○	
(via Tanahabang)					
Serpong Line (Tanahabang–Serpong)	23.2		○	○	
Tangerang Line (Duri–Tangerang)	19.3	○	○	○	
Tanjungpriok Line (Jakartakota–Tanjungpriok)	9.0	○		○	
(Tanjungpriok–Kemayoran)	9.5			○	
Nambo Line (Citayam–Nambo)	13.0		○		○
Total	170.2				

Source : Tomoyoshi Hata, 2003, « Improvement of railway system in Jakarta Metropolitan Aerea », article in Japan railway & Transport review 35, July 2003, p36 p 44.

Figure 10: Characteristics and length of the railway network lines

Currently Jabodetabek railway infrastructure based on the direction and the service type can be classified by the directions as followed :

1) Loop line consisting of western line and eastern line is the infrastructure forming as inner ring railroad of Jakarta for commuters travelling notable in Jakarta area.
2) Bogor line: the railway for commuters connecting between Jakarta (JakartaKota) and Bogor Municipality through Depok Municipality
3) Bekasi Line: the railway for commuters connecting between Jakarta and Bekasi Municipality, called Eastern Line.
4) Tangerang line: the railway for connecting Jakarta and Tangerang Municipality;
5) Serpong Line: the railway connecting Jakarta and Serpong (Sub center) of Tangerang Municipality;
6) Tanjungpriok Line: the railway as acces to the port of Tanjungpriok;

The Jabodetabek Commuter travel to and from Jakarta through the stations as shown in the figure below :

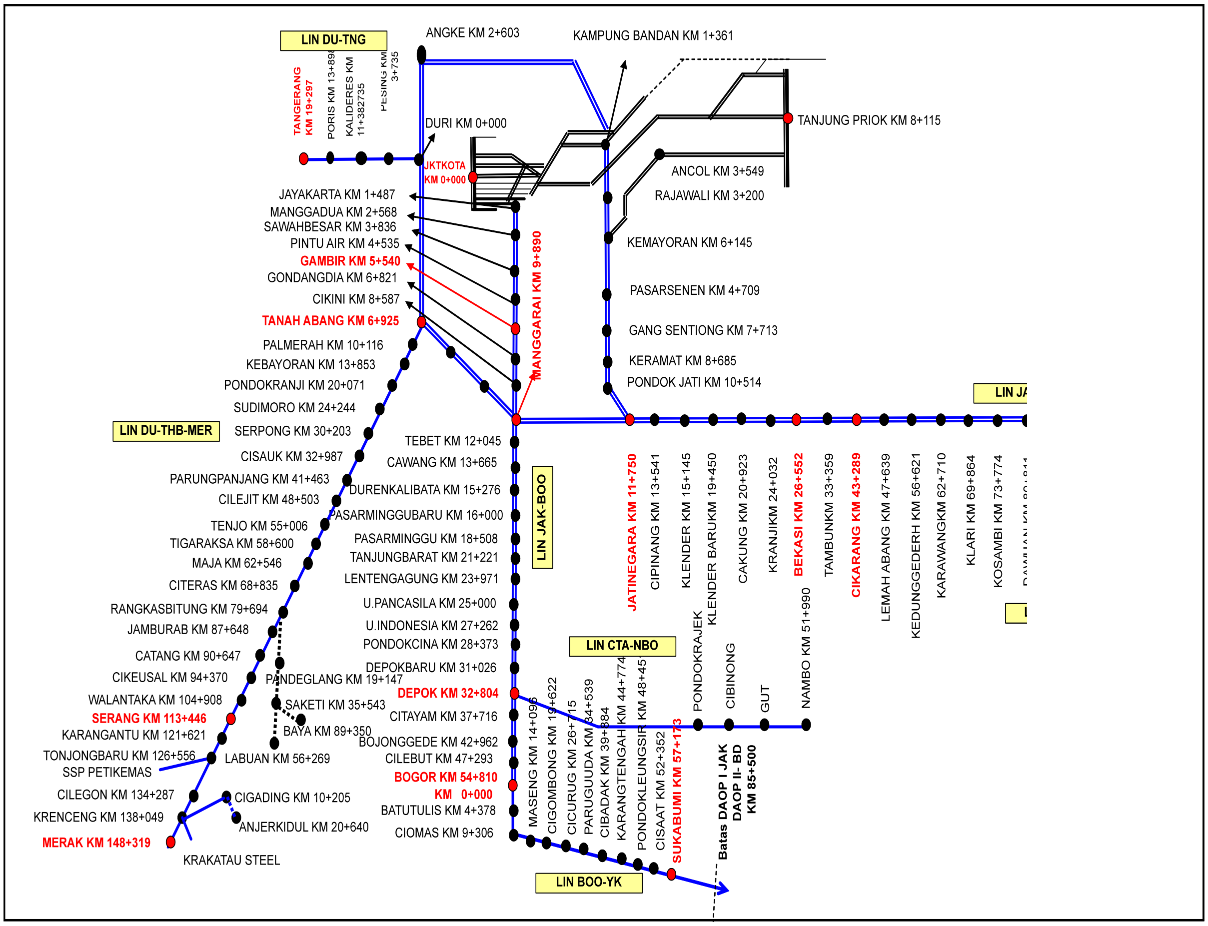


Figure 11: Stations' location in Jabotedabek area

In order to improve the role of railway transportation, the government reforms all the system such as the institutional aspect, regulation aspect, and financial aspect. As the institutional reform, in 2005 the Government separate the organisation of Directorate of Rail Transport from Directorate General of Land Transport and enlarges this organisation to be the Directorate General of Railway (the same level as the Directorate General of Land Transport).

In the same period, the government launched the Revitalisation program and allocated the budget much more than before for railway infrastructure and rolling stock development through the Ministry of transportation. The financial scheme of railway infrastructure consists of IMO (Infrastructure Maintenance and Operation, TAC (Track Access Charge) and PSO (Passenger Service Obligation). The government provide the budget PSO for subside the economic class services which fare is determined by the government as well as the IMO budget due to the status as the owner of the infrastructure. Meanwhile the government get the revenue of the track using called « TAC » or Track Access Charge from user (the train operator). Through the contract of TAC, IMO and PSO, the government commission PT. Kereta Api as the only one railway transport operators in Indonesia, to serve the economic class and operate as well as maintain the infrastructure with the subsidies and the fund coming from the government. In the other hand, PT. Kereta Api has to pay Track Acces Charge to the government.

The evolution of railway financing by the scheme of IMO, TAC and PSO is shown at the following tabel:

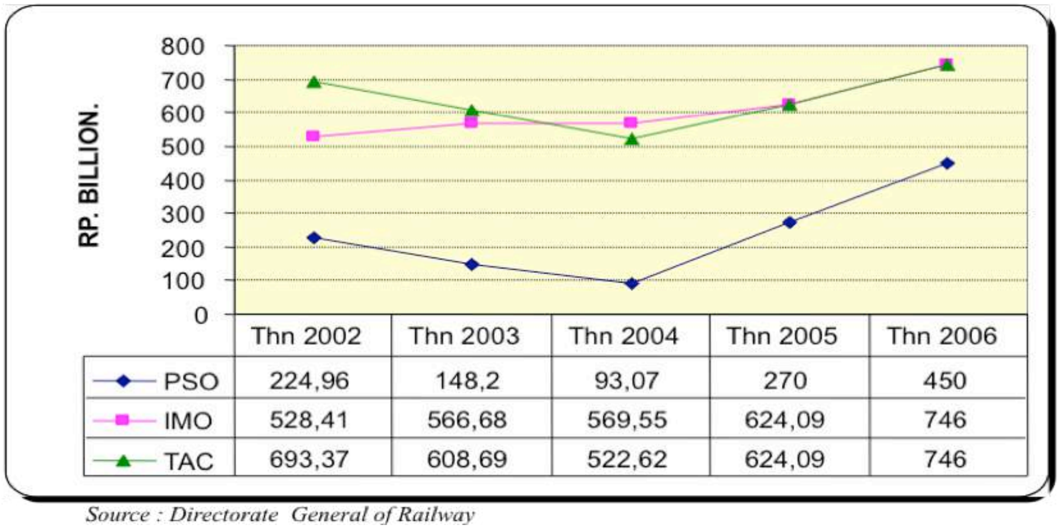


Figure 12: Funding of railway transport (IMO, TA, PSO) in 2004 - 2006

The figure above describes the high growth of both TAC and PSO after railway reform period (2005 and 2006) but the IMO rest growing slowly since years ago. This indicates that the government has been considering the important role of railway transport through the revitalisation program and providing related growing fund.
According to the data resulting from the ticket selling, the volume of Jabodetabek Commuter using the railway transport is predicted 157.858 pax/day or around 52,90 percent of total passenger in railway sector. In 2004 the volume decreases but since 2005 it increases around 0,73 person and in 2007 the demand attaints 287.292 pax/day or growing 74,15 percent of the year before.

Year	2003	2004	2005	2006	2007	Average
2	*3*	*4*	*5*	*6*	*7*	*8*
Non Economic Class (pax)	17,234	22,746	22,132	25,348	34,436	24,379
Economic Class (pax)	157,858	159,012	158,192	164,964	287,292	185,463
Total Jabodetabek (pax)	157,858	159,012	158,192	164,964	287,292	185463
Total Non Jabodetabek (pax)	140,529	135,386	138,408	155,800	17,430	117,511
Total Passengers (pax)	298,387	294,398	296,600	320,764	304,722	302,974
Share Jabodetabek(%)	52.90	54.01	53.34	51.43	94.28	61.19
Jabodetabek Growth (%)		0.73	-0.52	4.28	74.15	19.66
Total Growth (%)		-1.34	0.75	8.15	-5.00	0.64

Source : PT. KA Commuter, 2003-2007.

Figure 13: Volume of Jabodetabek Commute by Rail transport in Jabodetabek (Pax/day) In 2003 – 2007

In 2006 the fleet of electric railcars are 391 sets. Among the fleet there are only 288 sets can be operated (operating ratio is 74 %), 28 set as reserves and the rest were on damaged. The condition of the rolling is shown in the figure below:

CLASS/TYPE		Traction Control	Traction Motor	Made	Fleet	Operated	Reserves	damaged	Operation Ratio
EKONOMIC (NON AC)	REOSTATIK	Rheostatic	DC-Seri	1976	111	98	12	1	88%
	ABB-HYUNDAI	VVVF	AC-Induksi	1992	8	0	0	8	0%
	BN-HOLEC	VVVF	AC-Induksi	1994	112	52	0	5	46%
	HITACHI	VVVF	AC-Induksi	1997	24	20	4	0	83%
JUMLAH 1					255	170	16	14	67%
EXPRESS/SEMI EXPRESS (AC)	HIBAH Seri 6000	Rheostatic	DC-Seri	2000	72	66	0	0	92%
	KRL-I	VVVF	AC-Induksi	2003	8	4	0	4	50%
	JR-103	Rheostatic	DC-Seri	2004	16	16	4	0	100%
	TOKYU Seri 8000	Rheostatic-Chopper	DC-Kompon Kumulatif	2005	16	16	0	0	100%
	TOKYU Seri 8500	Rheostatic-Chopper	DC-Kompon Kumulatif	2006	24	16	8	8	67%
JUMLAH 2					136	118	12	12	87%
JUMLAH (1+2)					391	288	28	26	74%

Source : PT. Kereta Api, 2006

Figure 14: Fleet of Electric Railcars in Jabodetabek in 2006

Since years ago, the railway funding always comes from the public budget and in this case the government meet the limited financial resource. The government considers the important role of other stakeholder participation as well as the opened market in railway transport industry. For that reason the government reform the related regulation. Law Number 23 Year 2007 replacing Law number 13 year 1992 concerning Railway, contains the articles that give the opportunities to private sectors, and local government to invest, provide, operate and maintain either the infrastructure or the rolling stock, or both the infrastructure and the rolling stock, with or without the collaboration. Furthermore the President Decree number 67 of year 2005 regulate the mechanism of infrastructure investment and of the collaboration between the stakeholder.

2.4 Depok Municipality

2.4.1 Geography

Depok municipality lies on 6^{o} 19' 00" to 6^{o} 28' 00" South Altitude and 106^{o} 43' 00" to 106^{o} 55' 30" East Longitude with the area of about 200,29 KM2 (20,029Ha). The condition of Depok generally is the northern region of the lowlands, while the southern region is hilly area with altitude from 50 to 140 meters above sea level with a slope between 2-15 %. Depok is a newest city in the Province of West Java formed with the Law Number 15 Years 1999.

The bounderies of Depok Minicipality is Province of DKI Jakarta and Regency of Tangerang on the north side, Regency of Bogor (Kec.Bojong Gede dan Kec Cibinong Kab. Bogor) on the south side, Regency of Bogor (Kecamatan Gunung Sindur dan Parung) on the west side, and Regency of Bogor (Kecamatan Gunung Putri) and Regency of Bekasi (Kec. Pondok Gede) on the east side.

Depok Municipality is administratively divided into six sub Districts called "Kecamatan", they are: Kecamatan Sawangan, Kecamatan Pancoran Mas, Kecamatan Sukmajaya, Kecamatan Cimanggis, Kecamatan Beji and Kecamatan Limo (see the Map of Depok City)

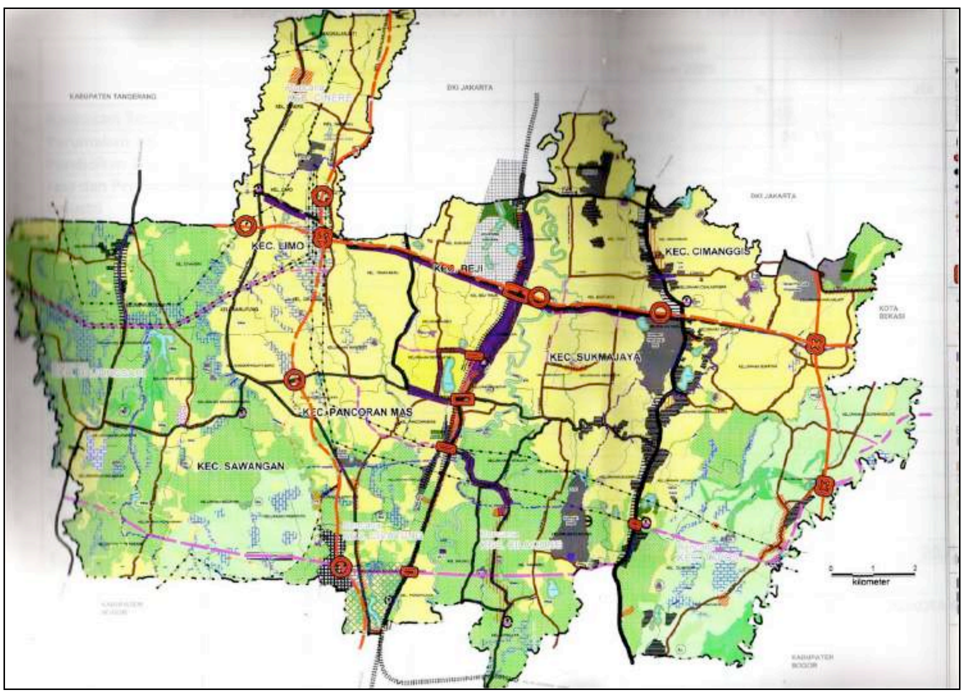


Figure 15: Map of Depok City

The City of Depok is rapidly growing as well as the interconnected transport network regionally to other cities, due to its strategic location between Jakarta and Bogor.

The endemic areas based on slope:
The areas with the slope range between 8 to 15 % are spread out from West to East which is potential for urban and agriculture development.

The areas with the slope more than 15 % potentially are located along the Cikeas River (Ciliwung) and on the southern of Angke River.

Additionally this difference of slope is not only useful for drainage systems but also cause puddles or flooding due to the absence of integrated handling. Depok Muiciality administratively consists of six Subdistricts (called Kecamatan): Pancoranmas, Beji, Cmanggis, Sawangan and Limo.

2.4.2 Population

The average annual growth of the population in years 2001 – 2008 is around 3,2 percent per year. In 2008 the population grows so rapidly (6,4 percent of the population in 2007) that attains 1,503.677 inhabitants. (See figure 16).

No	Years	Population (inhabitants)	Growth (%)
1	2	3	4
1	2001	1,184,045	
2	2002	1,220,817	3.012
3	2003	1,309,995	6.808
4	2004	1,353,249	3.196
5	2005	1,373,860	1.500
6	2006	1,393,568	1.414
7	2007	1,412,772	1.359
8.	2008	1,503,677	6,435

Source : Depok in the futures BPS, 2001-2008

Figure 16: Population of Depok Municipality in Years 2001 - 2008

Among the Subdistrict (Kecamatan) of Depok Municiplaity, Kecamatan Sukmajaya has the highest growth of population with 4,46 percent and Kecamatan Beji is the lowest growth SubDistrict with the gowth of 1,56 percent. (See figure 17).

District	Population of Year				Annual Growth
	2005	2006	2007	2008	
Pancoran Mas	247,622	254,797	269,144	275,103	3.58%
Sukmajaya	307,753	314,147	342,447	350,331	4.46%
Beji	136,899	143,592	139,888	143,190	1.56%
Sawangan	159,543	166,276	166,076	169,727	2.10%
Limo	143,218	149,156	149,410	152,938	2.23%
Cimanggis	379,487	392,512	403,037	412,388	2.81%
Kota Depok	1,374,522	1,420,480	1,470,002	1,503,677	3.04%

Source: Depok in the futures BPS, 2001-2008

Figure 17: The population in each Subdistrict of Depok Municipality in Years 2005 – 2008

In 2008 the density of Depok attains 7.507,50 inhabitants / km^2. Sukmajaya constitute the populous Subdistrict with the density of 10.264,61 inhabitant / km^2. and in the contrary Sawangan is the rarest inhabitant Subdistrict with 3.714,75 inhabitants / km^2..(See figure 18)

Subdistrict	Inhabitants	Area (km2)	Density (Inhabitant/km2)
01 Sawangan	169.727	45,69	3.714,75
02 Pancoran Mas	275.103	29,83	9.222,36
03 Sukmajaya	350.331	34,13	10.264,61
04 Cimanggis	412.388	53,54	7.702,43
05 Beji	143.190	14,30	10.013,29
06 Limo	152.938	22,80	6.707.81
Kota Depok	**1.503.677**	**200,29**	**7.507,50**

Source: Depok in futures, BPS, 2008

Figure 18: Density of each Subdistrict in Depok Municipality

According to the National Labor Survey 2007 (*Depok in figures, BPS, 2008*), The population of Depok consists of 61,3 percent of productive inhabitant containing 53,48 percent as worker and 7,85 percent of jobless, and 38,67 percent unproductive inhabitants including the students by 1,64 percent, the housekeeper by 22,32 percent and the other by 4,71 percent.

2.4.3 Social indicators

According to Nasional Socio-Economic Survey 2007 (*Depok in fiures, BPS, 2008*), there are only 11 percent of inhabitant having the University Diplomas, 52 percents having Junior and Senior High School Certificates, 22 percent have just the Elementary School Certificates and the rest by 12 percent have no formal educational certificate. In the Depok City area there are some Formal Academic Institution by 983 unit with 268.129 Students and 15.094 Teachers/Lecturers (See figure.).

NO	Educational Grade	Number of Institution	Number of Students	Number of Lecturers
1	2	3	4	5
1.	Nursery School	314	14053	954
2.	Elementary School	372	132783	4950
3.	Junior High School	150	46965	3135
4.	Senior High School	139	35233	2622
5.	Diploma III (2006/08)	5	6611	709
6.	Graduate and Post Graduate	3	32484	2724
	Total	**983**	**268129**	**15094**

Source : Kota Depok Dalam Angka, BPS, 2008

Figure 19: Formal Educational Facilities in the Municipal of Depok in 2008

2.4.4 Economy of Depok

Gross Domestic Product in current price of Depok grows annually in the years 2001-2007 by 16,76 percent whilst Gross Domestic Product in constant price based in 2000 increase by 6,67 % percent. (See figure 20)

No	Years	Classified by Basic Price (Rp. Million)			
		Constant Price of 2000	Growth (%)	Current Price	Growth (%)
1	*2*	*3*	*4*	*5*	*6*
1	2001	3.694.722,33		4.118.882,01	
2	2002	3.920.232,26	6,10	4.862.616,01	18,06
3	2003	4.166.626,32	6,29	5.555.669,14	14,25
4	2004	4.436.588,68	6,48	6.314.197,60	13,65
5	2005	4.740.868,66	6,86	7.521.594,61	19,12
6	2006	4.742.901,63	0,04	8.967.606,74	19,22
7	2007	5.418.246,94	14,24	10.426.082,90	16,26
Average			6,67		16,76

Source : BPS, 2008

Figure 20: Gross Domestic Product of Depok

The largest contributing sector (2007) is Industry Sector (37,03%), followed by Trading Sector, Hotel & Restaurant (33,67%). According to the figure above, the growth of GDP by constant price in 2007 attains 14,24 percent of the GDP in 2006.

2.4.5 Conditions of urban transport in Depok

In 2005 Road network infrastructure in Depok consist of 28,5 Km for National road, 26,15 Km for Provincial Road and 328,72 Km for Local Road. The surface condition of the road are 19,35 percent in good condition, 74,45 percent in average and, 2 percent in bad condition. There are still some accessibility problem met in road infrastructure for serving the commuter such as:

- Limited access in North – South corridor.

The existing available main roads are only : Jl Raya Bogor (artery), Jl Margonda Raya (prime collector), Jl Cinere Raya (secondary collector), Jl Tanah Baru Raya (secondary collector)

- Limited access to serve West – East travelling.

The existing available main roads are only Jl Sawangan Raya – Dewi Sartika - Tole Iskandar – Siliwangi (secondary collector), Jl Radar Auri (secondary collector), Jl Ir Juanda (secondary collector), Jl Akses UI (secondary collector)

Other infrastructures available in Depok are one Terminal Type C and five train stations. The terminal Type has the surface of 25.825 m² aith the access at Jalan Margonda Raya (Margonda Avenue) and Jalan Arif Rahman Hakim. In Depok the train will stop and pass through the fives station such as Station of Ponduk Cina, Station of UI, Station of Depok Baru, Station of Depok Lama and Station of Cityam.

Additionally Depok in the only one of surrounded cities, which has a Depot of Electric Railcars.

The Depot has the technical specifications as followed :

- 1,3 Km of total length, 200 of total wide, covering 26 Ha;
- Stabling track for 224 Electric Railcars for daily, monthly and yearly maintenance, inspection, and cleaning services.
- Operationally for serving the existing 288 set of operated railcars in Jabodetabek.

There have been more than 62 companies operating 9.300 buses with the capacity of 121.820 seats for supporting the mobility of Population. There are only 366 buses (less then ten percent) gives the service, but around ninety percent served by mini buses and car. This indicates that urban transport in Depok is served by the inefficient mode of transport. Modes of road public transport are shown in the figure below.

NO	Type of Service	Bus Company	Fleet (unit)				Capacity (Seats)	Type of Fleet
			Depok	bodetabek	Depok-JKT	Non Jabodetabek		
1	2	3	4	5	6	7	8	8
1.	Taxi	26	0	0	4331	0	17324	Car
2.	Urban transport		2880	0	0	0	34560	Minibus
3.	Suburban transport		0	591	3542	0	49596	Minibus
4	Intercity in Province	13	0	62	0	128	5700	Microbus
5.	Inter city Inter Province	23	0	0	366	0	14640	Standard Bus
	Total		2880	653	8239	128	121820	

Figure 21: Road Public transport in Depok in 2008

Depok is also served by Jabodetabek railway with the line of Jakarta – Depok – Bogor. The frequency of trains consists of 12 trains of Depok Express to Jakarta, 3 trains of Semi express To Jakarta and Bogor, 65 trains of Economic class for direction Jakarta to Bogor, as described in figure 22.

The peak hour of road traffic happens in the morning for while commuters depart from Depok to Jakarta and in the afternoon when coming from Jakarta to Depok. According to the data, the composition of the road traffic in general consist of 60%-70% for motorcycles and 10%~30% for private cars, only 5%~15% for public transports, exceptionally on Jl Raya Bogor where public transports are dominant compared to private cars (Tatralok Study, Dishub Depok, 2006).

	TYPE OF SERVICE	LINES			FREQUENCY OF SERVICE PER DAY (ROUND TRIP)
		ORIGIN	-	DESTINATION	
1	EKONOMY CLASS	BOGOR	-	JAKARTA (KOTA)	87
2	EKONOMT CLASS	BOGOR	-	TANAH ABANG	5
3	AC EKONOMY CLASS	BOGOR	-	ANGKE	2
4	AC EKONOMY CLASS	BOGOR	-	MANGGARAI	14
5	AC KOMERSIAL	BOGOR	-	JAKARTA (KOTA)	41
6	AC KOMERSIAL	BOGOR	-	TANAH ABANG	12
7	AC KOMERSIAL	BOGOR	-	MANGGARAI	1

Source : PT. KA Komuter, 2008

Figure 22: Rail Passenger transport in Depok in 2008

The traffic composition of the main roads are described in the figure 23 below :

Road Link	Motor Cycles (%)	Private Cars (%)	Mini buses (%)	Medium buses (%)	Standard buses (%)	Mini Truck	Medium Truck (%)	Big Trucks (%)	Non motorized (%)
Jl. Merawan	56,33	33,54	5,98	0,12	0,01	1,75	1,26	0,05	0,96
Jl. Margonda	69,21	14,84	9,87	3,1	1,23	0,88	0,63	0,03	0,219
Jl. Raya Bogor	70,88	8,4	16,25	1,16	0,19	1,53	1,02	0,26	0,3
Jl. Pangkalan Jati	73,53	13,91	9,93	0,14	0,09	1,49	0,28	0,08	0,55
Jl. Juanda	68,22	22,68	3,13	0,2	0,14	3,31	1,49	0,06	0,77

Figure 23: Composition of the Road Traffic

The performance of some main roads are in densed condition whereas Volume/Capacity Ratio (V/C ratio) over than 0,8; such as Jl Merawan (Cinere-Jakarta) 1.05, Jl Margonda (Depok-Jakarta) 1.09, Jl Cinere (Jakarta-Depok) 1.05,Jl Radar AURI (Tol Jagorawi – Raya Bogor) 1.00, Jl Raya Bogor (Jakarta-Depok) 0.80, and Jl Cinangka (Jakarta – Parung) 0.80.

The performances of the roads are described in detail in the figure 24 below :

No.	Name of Roads	Direction A	Direction B	Road Type	Traffic Volume (PCU)			V/C ratio
					A To B	B To A	Total	
1	Jl. Merawan	Cinere	Jakarta	2/2UD	1216	697	2559	1.05
2	Jl. Margonda	Depok	Jakarta	4/2D	4288	2079	6367	1.09
3	Jl. Raya Bogor	Jakarta	Depok	4/2D	2097	2255	4352	0.80
4	Jl. Raya Bogor	Depok	Cibinong	4/2D	1335	1416	2750	0.46
5	Jl. Citayam	Citayam	Depok	2/2UD	1123	523	1285	0.65
6	Jl. Parung	Jakarta	Bogor	2/2UD	819	1408	2227	0.78
7	Jl. Cinangka	Jakarta	Parung	2/2UD	759	1770	2529	0.80
8	Jl. Bojong Gede	Bojong Gede	Depok	2/2UD	665	500	1165	0.68
9	Jl. Parung Serab	Cibinong	Depok	2/2UD	601	492	1093	0.45
10	Jl. Trace Yogie	Cileungsi	Depok	4/2D	2320	2441	4761	0.77
11	Jl. Pangkalan Jati	Depok	Jakarta	2/2UD	1030	484	1504	0.61
12	Jl. Tanah Baru	Gandul	Sawangan	2/2UD	251	432	683	0.44
13	Jl. Sawangan	Depok	Parung	2/2UD	762	955	1717	0.64
14	Jl. Cinere	Jakarta	Depok	4/2D	766	2036	2802	1.05
15	Jl. Kukusan	Jakarta	Depok	2/2UD	246	488	734	0.55
16	Jl. Nusantara	Kukusan	AR Hakim	2/2UD	631	346	977	0.61
17	Jl. Dewi Sartika	Sawangan	Depok	4/2D	1552	1007	2559	0.52
18	Jl. Ir. Juanda	Raya Bogor	Margonda	4/2D	933	584	1517	0.29
19	Jl. Radar AURI	Tol Jagorawi	Raya Bogor	2/2UD	363	1135	1498	1.00
20	Jl. Putri Tunggal	Jambore	Gas Alam	2/2UD	450	675	1125	0.72
21	Jl. Tole Iskandar	Margonda	Raya Bogor	2/2UD	1292	1431	2723	1.03
22	Jl. AR. Hakim	AR Hakim	Margonda	2/2UD	1615	430	2045	0.79
23	Jl. Kemakmuran	Kemakmuran	Tole Iskandar	2/2UD	614	697	1311	0.50
24	Jl. Jatijajar	Raya Bogor	Cimanggis	2/2UD	677	414	1091	0.46

Figure 24: The Performance of Road Network in Depok

2.5 How to serve the University Campus in Depok by public transport

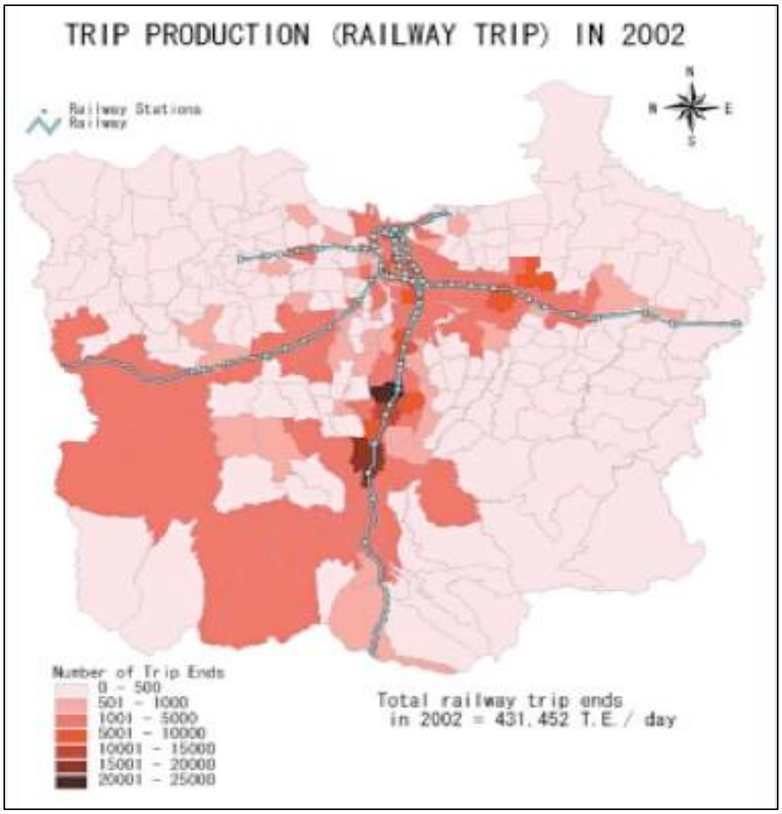
The University's campus in Depok is located in the south of Jakarta in the metropolitan region of Jabotabek, on an area of 302 hectares (that is to say a ray of 1000 meters for a circular area).
This campus where are studying around 40 000 persons (students, teachers and technicians) whose 25 % are living there, is served by private car (1 hour of the Jakarta's centre by normal road or 30 minutes by a toll road), from the airport by taxi (1 hour to 2 hours of ride), by the train of Jabotabek on the line of Bogor and stop in UI station or Pondok Cina station then take a free shuttle which serves all the important buildings of the campus. If we do not take into account people living on the campus, UI begets around 30 000 trips in the morning and 30 000 trips in the evening: we estimate that 70 % of these trips are concentrated during peak hours of morning and evening that is to say 3 hours in the morning and 3 hours in the evening. So, this campus involves a supplementary demand of 7000 passengers / hour / direction during 3 morning peak hours and 3 evening peak hours. If all passengers are going to the centre of Jakarta, there is a supplementary demand of capacity of 7000 spaces at the peak hour, but we can estimate that 25 % of trips are going to south in the direction of Bogor, the passengers will take the train southward to Bogor, or they could go westward and eastward taking bus lines, private cars or rickshaws. The demand could decrease to 5250 spaces per hour at the peak hour.
The railway line of Bogor, serving the campus, increased three times the transit offer between 1990 to 2001. This line carries 80 000 passengers per direction and per day, with 85 trains per direction and per day. The figure 4 behind shows that in front of Pondok Cina station, there are between 10,000 to 15,000 terminal trips per day: if these trips are done in the morning during three hours, we find again our estimation of 5000 trips per hour.
The headway of trains nowadays is between 8 to 12 minutes that is to say 7.5 to 5 trains per hour. At peak hour, a train of 8 cars with 4 passenger standees per m^2 can offer 8 x 160 x 7.5 = 9600 spaces during one hour. If we have to increase this offer of 5250 spaces per hour, we must get 11.6 trains per hour that is to say an headway of 310 seconds or 5.17 minutes. We could also add 2 cars to each train that is to say a total capacity of 160 x 10 = 1600 places, keeping an headway of 8 minutes, the offer become: 1600 x 7.5 = 12000 spaces for a demand of 9600 + 5250 = 14850 spaces. By reducing the headway to 6 minutes that is to say 10 trains per hour, the offer will become 1600 x 10 = 16,000 spaces at the peak hour.
So, by reduction of the headway of 8 minutes to 6.5 minutes that is to say by increasing the number of trains per hour of 7.5 to 9.23 and by increasing the number of cars of 8 to 10 cars (1280 spaces to 1600 spaces), the operator can absorb a supplementary demand of 5250 spaces at the peak hours.

The operator must inject 2 supplementary trains at the peak hour that is to say 6 trains in the morning and 6 trains in the evening that is to say 12 trains per day with 10 cars each.

No	Sation	Number of Passenger
1	Pondok Cina	1.250.220
2	U I	6.564.694
3	Depok Baru	3.411.329
4	Depok Lama	1.919.370
5	Citayam	4.739.724
	J u m l a h	17.885.337

Source : Depok Dalam Angka, 2008, BPS

Figure 25: Volume of passengers in five stations of DEPOK in 2008



Source : Hitoshi Ieda university of Tokyo, Shoshi Mizokami Kumamoto University, Tetsuo Kidokoro University of Tokyo, Seiji Iwakura Shibaura Institute of Technology, 2003, « *Impact study on transportation projects in Jabotabek* », rapport produit par JBIC de février 2003, p 24 à p 33.

Figure 26: Production of terminal trips per day

2.5.1 Demand's analysis

The brief estimation done above in § 2 cannot be the figures of the hypothesis of a feasibility study which has to be done to help for a choice of the future transit system operated to serve the university campus.

A survey managed with a questionnaire to the students, teachers and the staff of University could enlighten the demand by the origin – destination of each person, the mode of transit used by each, and the number of persons to carry.

In front of the high investment of a new guided transit system which will serve the campus, it is necessary to use the system at a level of performances maximum and not to have a pendulous transit system only used at his maximum capacity in the morning and in the evening.

The future system has to be insert in the borough or far away around the campus rather in a direction East – West serving the campus, the railway Pondok Cina station and the borough with settlements around the East and the West of the railway North-South line of Bogor in order to, transit system could be useful for the greater number and that the whole community shares the effort of investment and operation.

2.5.2 Conclusion

If transit demand analysis of the students and staff Campus shows that a demand round 5000 spaces at the peak hour per direction is true between Jakarta centre and Depok, the Regional Express Railway can absorb the demand with the constraint of a reduction of the headway of 1.5 minute and 2 supplementary cars per train: with any doubt a Z track (3^{rd} track) should be construct to have like a provisional terminus in Pondok Cina to return at once to Jakarta.

If the demand is oriented East-West and that the RER Bogor line is not well adapted, the study of a new transit project with bus or ligth rail serving not only the campus but neighbouring quarters with the principal equipment like city hall, schools, hospital, markets, etc. and several stations of the railway Bogor line could be studied in sight of realizing a project by stage which could join the busway network in Jakarta.

A new electrical light rail network on a separate right of way e.g. will alleviate the roads of minibuses, buses, private cars (congestion) and it could be linked to RER in several stations, etc. and will become the heavy axis of different local bus lines used like feeders of this new light rail transit line.

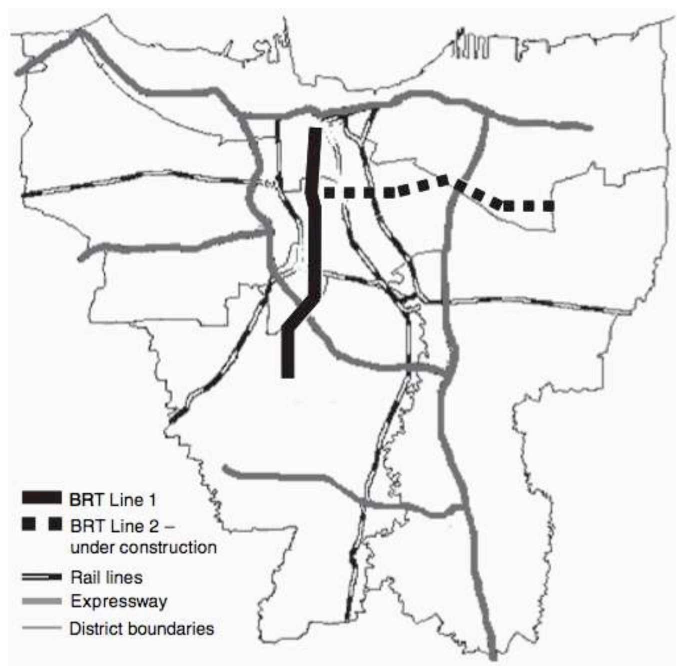


FIGURE 2 Map of Jakarta BRT line and other major transportation facilities (adapted from Jakarta Public Transit Users Association brochure, Pelangi, 2004).

Source: John P. Ernst, 2005, "*Initiating Bus Rapid Transit in Jakarta, Indonesia*", in Transportation Research Record, Journal of the Transportation Research Board N°1903, Washington, p 20 à p 25.

Figure 27: BRT network schematic Plan

Figure 28: UI station

Figure 29: The Jakarta's BRT

Figure 30: Jakarta's congestion

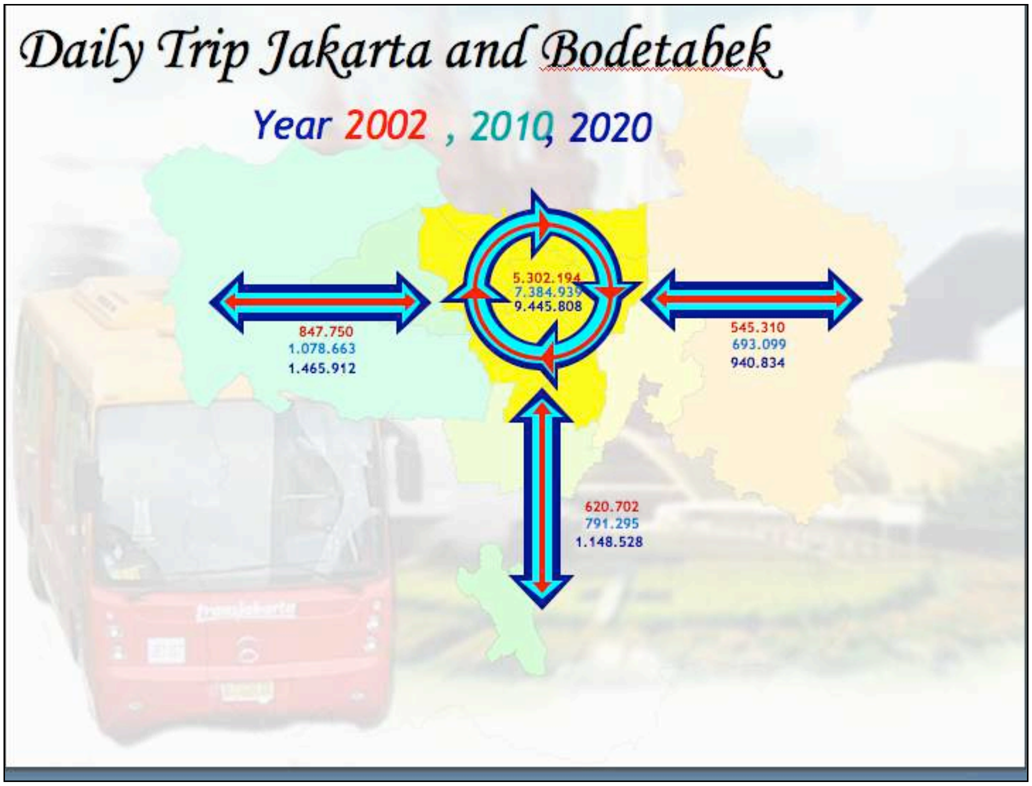
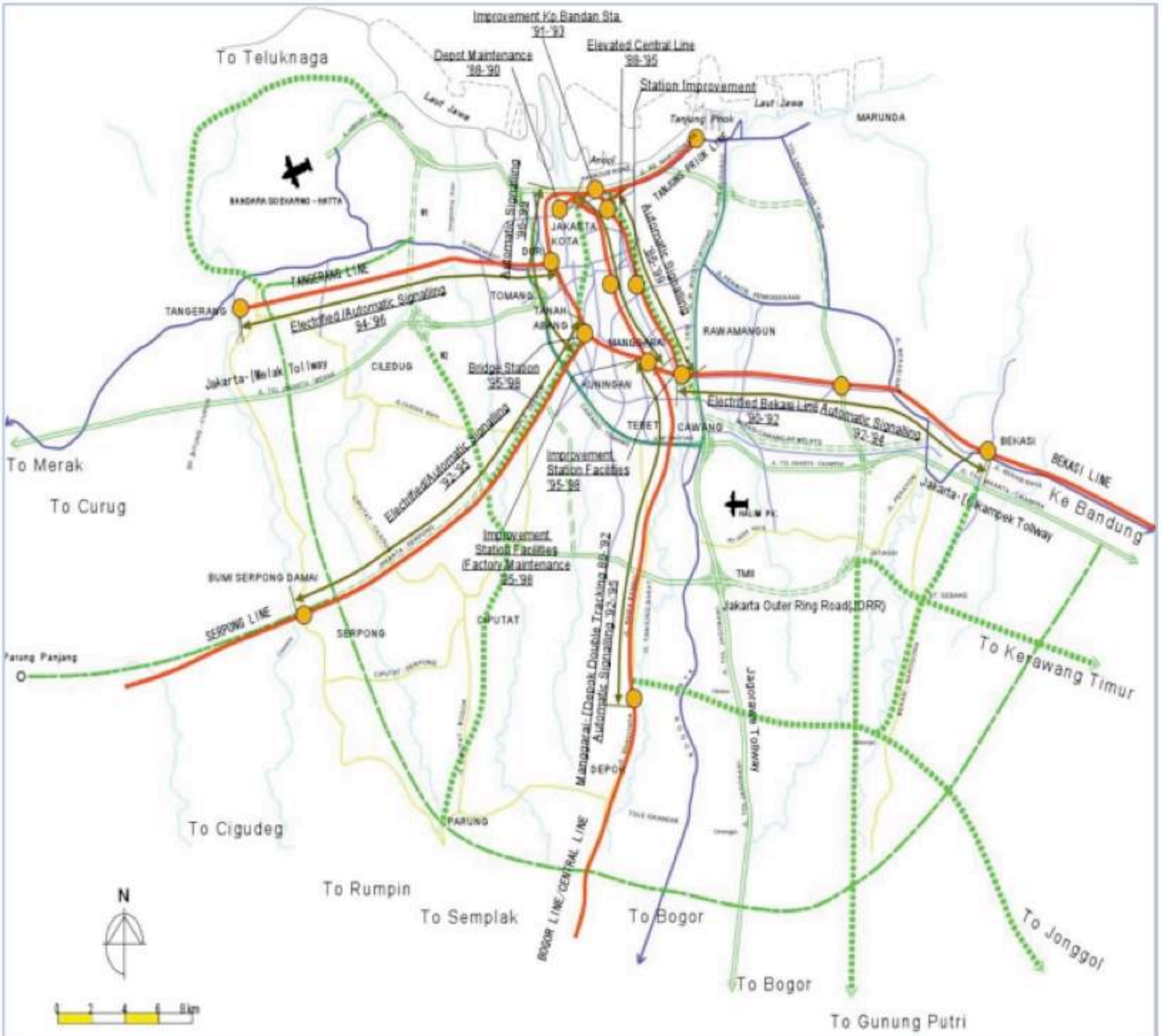
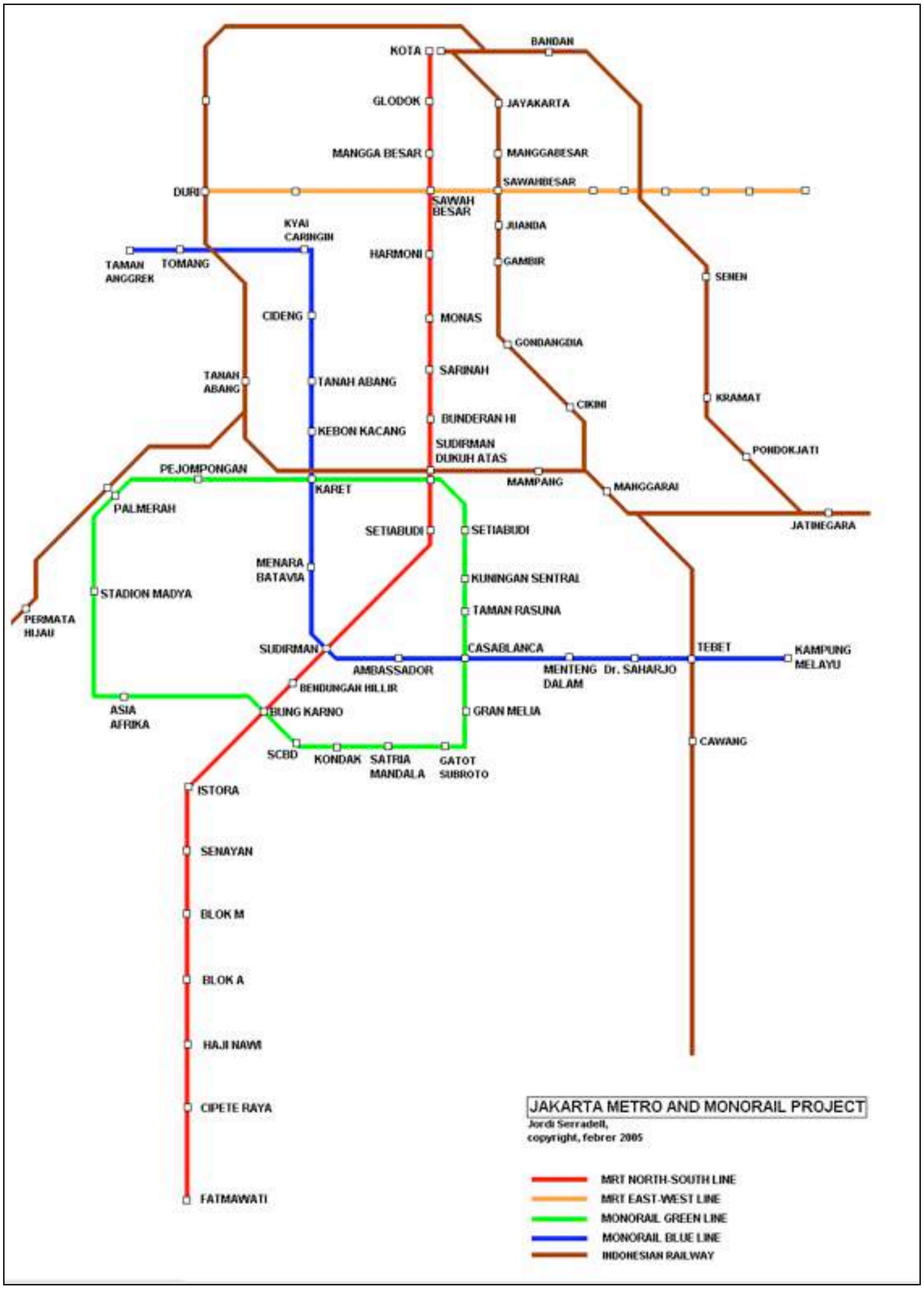


Figure 31: Daily travels in Jabotabek



Source : Hitoshi Ieda university of Tokyo, Shoshi Mizokami Kumamoto University, Tetsuo Kidokoro University of Tokyo, Seiji Iwakura Shibaura Institute of Technology, 2003, « Impact study on transportation projects in Jabotabek », rapport produit par JBIC de février 2003, p 24 à p 33.

Figure 32: The Jabotabek road and regional express railway RER



http://goasia.about.com/gi/dynamic/offsite.htm?zi=1/XJ&sdn=goasia&cdn=travel&tm=55&f=00&su=p531.31.150.ip_p531.29.420.ip_p284.8.150.ip_&tt=2&bt=0&bts=0&zu=http%3A//urbanrail.net/as/jaka/jakarta.GIF

Figure 33: The metro and monorail project

3. Rail-based new transit systems in France

In these chapters below, this report will inform about:

i. TVR and Translohr systems: the background of infrastructure, history and cost of construction for the TVR and Translohr systems, current situation of operation, e.g. capacity, operation cost.
ii. Articulated Bus: current situation of operation, e.g. capacity and operation cost.
iii. Considerations before planning and designing the surface guided transit system for rolling stocks and operating parts and infrastructure.
iv. Key papers and references on the subject.

We give in this report a general description of Translohr and TVR intermediate transit systems and articulated bus systems with geometrical characteristics, axle loads, and infrastructures and estimated general costs. Concerning infrastructure cost, we try to show that the cost of a system is in connection to capacity of a line with the load on the axles and the traffic that is to say the number of axles passing on the track during 30 years, for example. For the aggressiveness and rutting of a track, it is better to have numerous low loaded axles than less vehicles with high loaded axles what is favorable to adopt long vehicle with several axles than shorter vehicles with some high loaded axles. The infrastructure costs given in this report are results of studies ordered by French ministry of transport in the years 1996-97 to compare if the infrastructures of new intermediate systems (TVR, Translohr, Civis..) were cheaper than the infrastructures of French standard tramway TFS of Grenoble and Nantes. Unfortunately the unit cost used in calculation and comparison of tramway TFS, TVR and Translohr given by consultant (Systra, Semaly now Egis, Ratp and some Constructors like Vossloh, etc.) were costs for large quantities and standardized equipments like rail 35 G, sleepers, concrete, etc. The proprietary equipments of the TVR and Translohr tracks were given for little quantities and sometimes only estimate by manufacturers: so our assessment in 96-97[3] could be for some items underestimated. So when we examine the results of the bids given in a table of CERTU for Caen, Nancy and Clermont Ferrand we need an actualization with a present value factor of 4% per year to try to compare with present prices. The low number of answer to bids organized by Transit authority of each city is also an unfavorable factor for standard cost.

The cost of 3 systems announced in the chapter 5 are the fixed costs certified after a bid organized by the transit authority of a city, they are costs for short runs equipment and vehicle: we must wait some years to get an experience of Caen, Nancy, Clermont Ferrand, Padoue, L'Aquila, Venise, soon Sarcelles and Viroflay in the suburbs of Paris to increase the orders of these systems by transit authorities. Then by increasing the number of batches and equipements to produce we can hope to reach a competitive advantage in front of the tramways.

At last, these costs cannot be used outside of these first lines in Europe for example in Korea were the demand of capacities is higher and bids for long runs equipments and vehicles should be in favor of cheaper costs.

[3] See the book of CERTU « Nouveaux systèmes de transport guidés urbain », mars 1999, p.115-116

3.1 The modern tramway or light rail transit

3.1.1 Streetcars

The typical electrical streetcar, from its introduction in the late 1880s up to World War I, was a short, 2-axle, wooden-body vehicle operated by a driver and conductor.

Four-axle vehicles, 12 to 16 m long, made their first appearance during the 1890s, mainly on American interurban lines.

During the 1920s and early 1930s competition from the private automobile began to make a significant impact on streetcar ridership. In addition to diverting passengers, the automobiles created congestion, which impeded streetcar operations. To improve operation in congested streets and to avoid the investment required for track maintenance, transit operators began to convert streetcar lines to bus operation.

The problems of streetcar decline in U.S. cities in the late 1920s were studied by the Electric Railways Presidents' Conference. The Conference concluded that if the streetcar was to retain its important role, it would have to match the comfort, performance, and modern image of its competitors – the bus, trolleybus, and private automobile. In 1930, a Presidents' Conference Committee (PCC) was set up to examine the problem and to supervise a development program for a modern streetcar vehicle that would incorporate the most advanced technology available at the time. This effort products, the PCC car, was in many respects far more advanced than any of its predecessors. An extremely quiet vehicle with soft suspension, it was able to accelerate and brake rapidly, thanks to sophisticated indirect motor control. By 1952 about 6000 PCC cars had been produced in the United States. Modified versions of PCC cars have continued to be produced in Europe (Belgium and Czechoslovakia).

The PCC car did help to improve the competitive position of transit systems vis-à-vis the private automobile and to slow down the conversion of streetcars to buses; but in the absence of other improvements – particularly provision of separate rights of way for which support from city authorities was not available – the PCC car was not able to assure long-term stability for the streetcar mode, nor for transit's role in cities in general.

In many cities it was considered desirable to "mix" transit with auto traffic rather than provide it with priority treatments and maximum possible separation. The conversion of streetcars to bus and trolleybus operations, which began on a large scale during the 1930s, was discontinued by the increased demand for transit services during World War II, and resumed in the late 1940s. By 1960, streetcar systems remained in only about a dozen U.S. cities.

In Great Britain and France, tramway operators faced many of the problems that appeared in U.S. cities: the rising cost of labor and equipment, extravagant road-maintenance requirements, and a diversion of passengers to others modes.

In several other European countries, on the other hand, attitudes toward streetcars were much more positive. Separate streetcar rights - of – way in many German, Dutch, Swiss, Austrian, and other central European cities were preserved and, in many cases, extended.

The decisive progress of streetcar technology and applications came during the 1950s when a German manufacturer (Düsseldorf Wagen DÜWAG) produced a new model of articulated cars, far superior to all earlier articulated cars, including European and U.S. models.

The wide application of these cars and subsequent upgrading of streetcar networks through provision of separated rights-of-way, priority treatments, and other technological and organizational advances resulted in the creation of light rail transit – a rail system that is by its performance more similar to rapid transit than to streetcars operating in mixed street traffic.

3.1.2 The new tramway or light rail transit

In countries where tramways had survived the massive closure of the 50s and 60s, e.g. Germany, Switzerland, Belgium, many remaining systems have been modernised and upgrade and may now be called "light rail systems".
In many other countries, where tramways had disappeared from the streets, completely new systems have been developed since the mid-70s. This was the case in North America, in the Asia-Pacific area and in a few European countries such as the United Kingdom and France.

3.1.2.1 Description

There are many conflicting views of what constitutes a LRT system. As the term implies, LRT usually employs vehicles and track construction, which are less substantial than a full metro.

Some systems, including those in Manila and Istanbul, use lightweight vehicles on a system that has an exclusive track and high platforms similar to many metros. Trams are a basic form of LRT, which have limited RoW, sharing roadspace with ordinary traffic.

A formal definition was adopted in 1989 and placed in the TRB's Urban Public Glossary: "A metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive RoW at ground level, on aerial structures, in subways, or occasionnally, in streets and to board and discharge passengers at track or car floor level." (TRB, 2000)

LRT is designed to accomodate a variety of environments, including streets, freeway medians, railroad RoW (operating or abandoned), pedestrian malls, underground or aerial structures.
Where buses would be impractical or uneconomic and where the high capacity and high cost of the metro cannot be justified, is the major market for tramway systems. Against this background it is regarded as necessary to fulfill the following criteria:

- Vehicles should be able to operate both in street traffic and on their own track at a high average speed.

    - Thanks to this flexibility, costs will be considerably lower than for, for example, a metro.
    - Stop spacing is longer than with older types of tram traffic (500-700m).
    - Maximum speed is 80-90 km/h, and high acceleration / braking rates give a high average speed.
    - Trackwork has a higher standard than earlier suburban lines.
    - Visually, the system should have a modern impact even if it is based on an old tramway network.
    - Lengths of sets can be longer than on old types of tramway - up to 75 m.

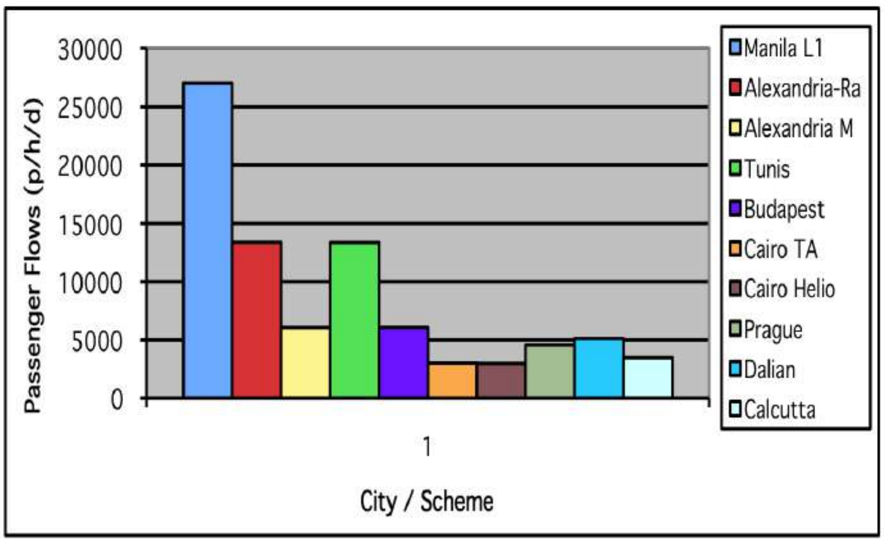
Duo-tramways are a further development of LRT. The system is also referred to as the Karlsruhe model as it was introduced there. The first section was opened in 1992 between Karlsruhe and Bretten and caused a considerable increase in the number of passengers. Unlike traditional trams, duo-trams can operate both on tramways and railways. The cars have the same good acceleration and braking as modern trams, on which they are based. The centre section is fitted with electrical equipment enabling it to run on the line voltage of both modes. The maximum speed is 100 km/h.

3.1.2.2 Performance

a. Capacities

TRL/INRETS 1994 research has questioned the generally accepted idea that LRT has a higher capacity than busways.

In fact the opposite appears to be true. Even in Manila, where the LRT is operating under near-saturated conditions, and where there is full segregation from other traffic, passenger flows are less than on several busways. In order to attain high capacities, LRT needs short, regular headways : the 1994 survey in Manila showed passenger flows of 18900 p/h/d and after upgrading the line 1, in 1998, 27000 p/h/d.



Source : (Gardner, Rutter TRL, Kühn INRETS, 1994)

Nota : For Tunis (Godard, Kühn INRETS, Belaïd & al. SMLT, 2000) ; For Manila survey after upgrading L1 (IRJ, 1994)

Figure 34: LRT & Tram passenger flows

In Tunis the 1994 survey showed passenger flows of 9300 p/h/d, in 2000, the passenger flows have reached 13400 p/h/d. These two last surveys show that LRT requires a level of control and regularity that most developing cities find difficult, especially with on-street operated trams.

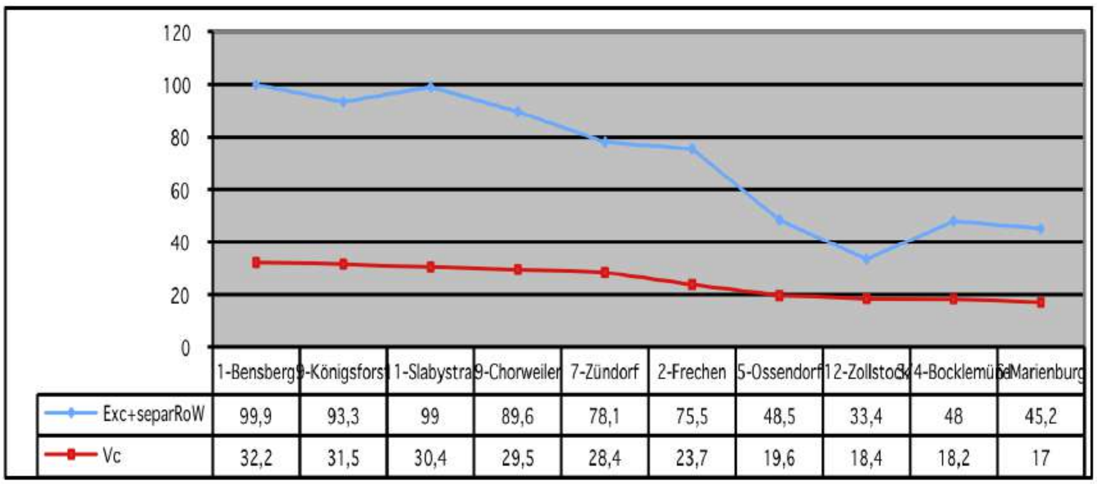
So, investment costs are high, and thus the challenge is to develop the right mode in response to the right transport need. Light rail is the ideal mode for carrying between 3000 to 11000 passengers per hour per direction. Only metros and heavy rail have a higher transport capacity. Intense bus systems as in Latin America could partly reach similar capacity, but with far higher pollution and noise level.

b. 2. Speeds

Tramways are penalized by the perturbations due to general traffic, and they are often blamed for their insufficient commercial speed. This is one of the reasons why many lines and networks have been suppressed during the last fifty years. It is also one of the reasons why the cities having kept their tramway networks try to improve their quality of service:

- by separating as much as possible the tramway tracks from general traffic,
- by giving priority to public transport on the conflict points made up of level junctions with general traffic.

Taking the example of LRT network of Köln see the Figure 7 below and the results of 11 european networks' survey where the general tendency was a considerable increase[4] of commercial speeds between 1966 and 1983, it seems to be clear that the networks having important sections with segregated RoW have commercial speeds superior to those of the networks having important network lengths with shared RoW. (Kühn ,1988)



Source : (Kühn ,1987)

Figure 35: Mean commercial speeds of some LRT lines in Neumarkt (Köln centre) on the Köln LRT network

The commercial speed influences the service that can be provided for customers, but also determines the number of vehicles and drivers that will be needed. The commercial speed is also related to the maximum speed of the vehicle, and to braking and acceleration characteristics. It might thus be expected that electric trains would be significantly faster than buses. In practice, TRL field surveys revealed little difference and research using multiple regression analysis, to allow for factors such as station spacing, suggests that the inherent difference between busways and LRT is not statiscally significant.

LRT achieves high speed by using a signalling system to avoid bunching, and by obtaining priority at traffic signals over other traffic; and it achieves high capacity by having large vehicle which take advantage of the signal cycles. In practice the distance between signals defines the maximum vehicle size, and the need to provide for crossing traffic limits the number of vehicles per hour. However, LRT systems are operationally vulnerable to the everyday events that happen in the centre of developing cities; whether this is junctions being partly blocked, or road maintenance work, or a breakdown, or an accident, while bus systems

[4] This increase in relative values being not, however, directly proportional to the increase of the percentage of segregated RoW realized in the networks.

are often able to get round the problem (they can overtake, leave the busways, etc), LRT is not.

Traffic engineering measures are aimed primarily at optimising traffic's temporal flow.This means that green phases at traffic light signals will switch to green to allow the passage of public transport vehicles. Optimising green phases at intersections often also frees up more green-phase time for motorised individual traffic and other traffic, or allocates existing time more appropriately.

Normally buses tend to have a lower average speed than trams. The average speed of buses in a comparison between 16 LRT networks and 24 bus networks (Hass-Klau et al. 2000) was 16.9 km/h and trams 20.7 km/h, both for mixed traffic. Light rail running on its own RoW and/or in tunnel sections will travel on average about 7 km/h faster than if travelling on street. For example some average speeds of LRT lines in Buffalo, Bremen, Denver, Essen, Blue Line L.A., Green Line L.A., Pittsburgh, San Diego and Stuttgart, are respectively 29.3 km/h, 28 km/h, 23.2 km/h, 28 km/h, 36 km/h, 57 km/h, 26 km/h, 37 km/h and 25.9 km/h.

Average speeds of buses on busway lines in Bergen, Dublin, Malmo, Ottawa, Pittsburgh and Southampton are respectively 25 km/h, 24 km/h, 24 km/h, 50 km/h, 53/37 km/h and 25 km/h.

The extent of grade separation and thus the speed and reliability of light rail systems vary widely. LRT capital costs and line haul trip speeds both increase as the fraction of RoW that is grade separated increases; a completely grade separated light rail system should be able to achieve line-haul speeds that are very close to those of high-performance, heavy rail system. LRT feasibility studies all too often claim the capital costs savings obtainable from limited grade separation and at the same time assume the speed and reliability that can only be obtained in a rail system with complete grade separation. (Kain et al.1987)

Thanks to their high performance, light rail vehicles accelerate quickly and can attain good service speeds. Together with good design features such as segregated right-of-way and priority at crossings and traffic lights, which make light rail congestion-free, these will result in a good average commercial speed (between 20 and 30 km/h) and thus short journey times.

Measures to reduce dwell times at stops (e.g. step less and gapless boarding, wide doors, tickets sold off the vehicle) increase speed and regularity and also improve the accessibility of the system.

3.1.2.3 Infrastructures

a. *Implemented Sites*

The LRT tracks are distributed on four types of sites:

- exclusive RoW corresponding in general to new realisations in city centres on several levels: tunnels or viaducts.

- segregated RoW corresponding to independant tracks in the middle of or along a boulevard or on a former railway track;

- reserved RoW corresponding to lanes of the carriageway in general delimited by paint or using specific surfacing, but not separated physically from general traffic;

- shared RoW composed of lanes of the carriageway used by general traffic: these tracks are found rather in old networks on carriageways with little traffic or on too narrow carriageways on which it is not possible to reserve a suitable space for the tramway. In this last type of site, we can classify the mixed pedestrian-public transport streets or Malls in which the carriageway is used only by pedestrians and passing tramways.

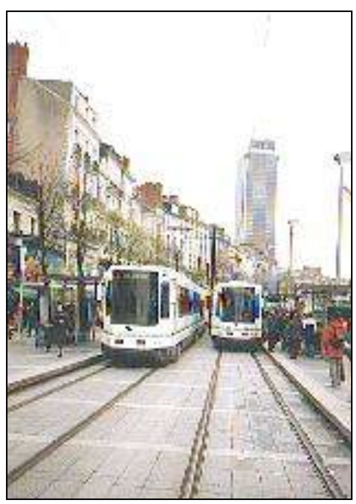
For one and the same line of a given network, we find all the types of sites with, in the best organized networks, a hierarchy going from the exclusive RoW in the city centre, where the urbanization is in general very dense, to the separated tracks in peripheral districts, where road space allows them, a certain number of sections remaining, however, in shared RoW.

b. Evolution of track sites

The trend of the existing networks consists in increasing the parts of exclusive or segregated RoW on their tramway lines. This trend is being confirmed for the new lines, which are generally built in segregated RoW using different types of space: railway tracks, motorway bus lanes or urban streets.

The use of railway tracks allows the access to the city centres without great investments in tunnels: the Tijuana and El Cajon lines San Diego, the Los Angeles-Long Beach line, the Calgary, Edmonton, Portland lines, the Albtalbahn to Karlsruhe, some lines of the Köln, Stuttgart, Göteborg networks are example of this.
In some networks, buses use a separated lane for installing a LRT line if traffic needs it: the realisation in Los Angeles, Sacramento, Portland and San Jose are examples of this.

c. The influence of track sites on commercial speed



Source: Semitan

Figure 36: The separated right of way of tramway in Nantes

Tramways are penalized by the perturbations due to general traffic, and they are often blamed for their insufficient commercial speed. This is one of the reasons why many lines and networks have been suppressed during the last fifty years. It is also one of the reasons why the cities having kept their tramway networks try to improve their quality of service:

- By separating as much as possible the tramway tracks from general traffic,
- By giving priority to public transport on the conflict points made up of level junctions with general traffic.

If we consider the average commercial speeds of the networks visited, between the years 1966 and 1983 (cf. table 3), we can see that the general tendency is a considerable increase of these speeds, this increase in relative values being not, however, directly proportional to the increase of the percentage of segregated RoW realized in the networks.

However, it seems to be clear that the networks having important sections with segregated RoW have commercial speeds superior to those of the networks having important network lengths with shared RoW.

City	In 1966	In 1973	In 1977	In 1983	Remarks
Brussels	14.8 km/h	17 km/h 52 %	17 km/h 40%*	17.17 km/h 45.47 %	* Use of a tramway line by the new metro. On the LRT sections, the speed is 23 km/h, in peripheral areas 26.9 km/h (line 44)
Charleroi	18 km/h 38 %	20 km/h 40 %	21km/h 50 %		Commercial speed in the old network : 19,5 km/h; in the modernized network (80% ST):24,5 km/h
Utrecht			29 km/h 95 %		
Hanover	A-line 18.9 km/h	Network 20.7 km/h 38 %	Network 20.1 km/h 53 %	A-Line 22.1 km/h	In 1983, 68 % of separated tracks with exclusive RoW in the whole network
Cologne	18.6 km/h	22.1 km/h 64 %	22.7 km/h 72 %	23.5 km/h 81.4 %	The highest speed was recorded on the line 13: 45 km/h on a 7.5 long section with exclusive RoW
Stuttgart	17.3 km/h 34 %	19.45 km/h 37 %	19.51 km/h 37 %	20.2 km/h 68.33 %	With the arrival of the new DT8 vehicle, the SSB company thinks it will reach 25 km/h as commercial speed
Zürich	14.2 km/h 15.8 km/h	15.5 km/h 6 %	15 km/h 9 %	13-15 km/h 15.4 %	
Berne	14.14 km/h	14.8 km/h 8 %	14.7 km/h 12 %	16 km/h 15.3 %	
Basle	16.5 km/h	16.3 km/h 29 %	17.71 km/h 40.37 %	12.9 – 26.1 km/h 56.5 %	BVB + BLT networks
Nuremberg	16.1-17.4 km/h	16.9 km/h 30 %	16.7 km/h 46 %	16.5 km/h 37.7 %	
Blackpool		20.9 km/h	20.9 km/h 94.5 %	20.9 km/h 94.5 %	

Sources: UITP Statistics 1968 and 1975. Tramways in Switzerland and the FRG by SODETRANS, 1979.
Notes: - The first figure represents the average commercial speed in the network in km/h.
- The second figure is the percentage of lengths with exclusive and segregated RoW of the whole network.

Figure 37: Evolution of commercial speeds and percentages of separated track lengths during these last years

d. The track

Track construction techniques have made great progress, and there exist detailed regulations as well as numerous specifications especially for geometric, physical and functional characteristics.

Single-track and double-track lines

It is interesting to note that a certain number of LRT lines have been planned for single-track traffic arranging some double-track passing for allowing crossing. This is the case especially in Switzerland with the Neuchâtel network line and the Lausanne line project, in the USA with the network lines in New Orleans, Pittsburgh, Philadelphia, Sacramento and San Diego.

The interest of this configuration is:

- that it allows savings of investments in civil engineering,

- that it can allow the installation of some sections with segregated RoW more easily.

On the other hand, it has the disadvantage of penalizing train frequency on the line; special signs and signals are necessary for ensuring safety, as well as traffic control means for optimizing this train frequency.

Track characteristics

Track construction techniques can be classified into three categories:

- The track sunk into the roadway, generally used with shared RoW, is characterised by the use of a girder rail allowing the access of road vehicles, the passing of pedestrians and cyclists...

- The ballast track is at present the most spread type of separated tracks or tracks with exclusive RoW; it is characterised by the use of the Vignole rail impossible to cross for road vehicles and difficult to cross for cyclists.

- The uncovered track of concrete with use of Vignole rails is the least spread type of track; we find them above all on engineering structures like viaducts, bridges or tunnels. The Köln network promoting this construction type has more than 50 km of this type of track intended for being used each time the track passes over structures of concrete.

The railway gauge varies with countries, in general we find the normal gauge of 1,435 mm (4 feet 8.5 inches), the metric gauge in the old european networks, in Switzerland for instance, the narrow 900 mm gauge in Lisbon, Linz, the broad 1,524 mm (or 5 feet gauge) in Russia and the USA.

3.1.2.4 Tramway's tracks

a. Type of tramway's tracks

The track's layings are considered in relation with the environment of the right of way. Some examples of these layings are following:

- ❖ laying of the standard track (current case),
- ❖ laying of the track ASP (vibration absorption 10 dB),
- ❖ track's laying on floating slab (vibration absorption 20 dB),
- ❖ direct laying of track (bedding on slab),
- ❖ laying of STEDEF track (on bridge principally),
- ❖ specific laying on bridges (reduced floating slab, sticken laying),
- ❖ switches of track belong to the track's laying.

b. Dimensional and comfort constraints

They correspond to the standards defined:

- a minimum ray of curb on line is fixed at 25 meters,
- a minimum ray on a longitudinal profile is fixed at 500 meters (350 m absolute mini) for an hollow and 700 m for a bump. The drawing of the line is constituted of straight alignment and curbs. The plan connections between the straight alignment and circular curb are realized thanks to clothoids which allow linear variation of the curvature, then a linear encreasing of the centrifugal force.

Some curbs are in twist. The twist installing is done by a warping of the track or the right of way in the section with the clothoid. The left is limited to 4mm/m and the twist at 120 mm.

Dynamic constraints
They correspond to the basic data of rolling stocks Citadis 301 and to the rail characteristics:

- The vertical load kept by wheel is 5000 daN,
- The cross effort transmit by the wheel to the rail is estimated to 3500 daN,
- The dynamic ratio kept is 1.5. This dynamic overload takes into account of the incidence of hanging up mass and non-hanging up as well as a degradation of rail-wheel contact.

Climatic constraints
- Temperature (minimal – 20 °C, maximal + 40°C)
- Average daily relative moisture:
  - Minimal 52%
  - Maximal 97%

Constraints linked to energy
Energy of traction delivery for rolling stocks is realized for positive catching with a contact's wire and for the negative polarity with the rails. Dispositions are taken to obtain a rail's correct insulation of the ground to limit propagation stray currents.
To reduce ground-retun circuit resistance of traction current, the 4 rails are parallel connected all 100 meters by cable links. Rails are next connected to the substation.
Constraints linked to noise and vibrations

3.1.2.5 Noise
The noise uttered by the passing trains is the sum of noises of different origins:

- noise of rolling uttured at contact wheel-rail,
- noise beamed by the stocks and boggies,
- noise of auxiliary equipments (blowers, motors, reducer),
- noise reverberated by the trackbed.

The noise of rail squeal appears in curb with a low ray: the origin comes from twisting oscillations, which originate at the time of the slipping of the wheel on the rail. It results a high frequency noise's emission troubling the frontage residents.

3.1.2.6 Vibration
The vibrations: the origin is the dynamic stimulus of the wheel on the rail. The transmission of sollicitations propagate in the ground, to the civil engineering works until the foundations of buildings and brings on nuisance to the frontage residents. There are no rules which could

be directly applied but it is recommended to not exceed 68dB (level of human sensibility corresponding to 0.1 mm/s of vibratory speed (standard ISO 2631/2).
The vibrations of railway origin have generally a high energy between 80 and 85 dB in the 1/3 frequency octave located between 40 and 125 Hz. They weaken with distance.

We admit 1 dB / m damping for surface and volume waves, about 12 to 14 dB for a distance of 12 m. In function of these criteria, it is necessary to adopt technical solutions warranting an environment of vibratory quality, whose energy will be lower to the human sensibility threshold of 68 dB.

Constraints linked to maintenance
The maintenance of the track and the switches must be reducing to minimum. The operations of maintenance such the change of rail or a switch rail must be done without penalize the operation. The drowned tracks cannot be inspected, their conception must warranty in permanence the geometry and the gauge of rails as well as the stability in plan like in profile of the trackbed.

c. *Justification of technical choices*

Recall of the roll of the track
The essential function of the track is to provide the mechanical continuity of the rolling way, which endures the rolling stocks, in maximal safety conditions, of satisfying comfort and optimal duration. We understand by comfort, the vibratory and acoustic comfort as well as for the passenger and for the frontage residents. Besides, the track must ensure the power supply return of the motor rolling stocks and must present therefore a good insulation in relation of the ground.

The track must adapt to requirements of tramway's insertion. It must integrate to the environment and allow creating all the urban landscape of quality. The minimum ray used in plan is 25 meters for a concrete track and 300 meters for a ballasted track with long welded rails. Below 300 m, the rails of the ballasted track must be fished what is excluded. This is why we propose for the less than 300 meters rays to build a concrete track (e.g. in station and by-pass zone).

The track laying on sleepers allows to consider all the range of existing covering (bituminous concrete, paving stones, grass, paves…). The choice of covering is made in relation with the environment but also and above all the trackbed use. The fact that we are on a separate or a mixed right of way or in a junction takes a predominant importance in the choice of surfaces if we want to keep the covering life expectancy in the time.

Rail's choice
The wheel-rail contact becomes rapidly an operator's concern to determine an optimum fretting profile. In order to harmonize the wheel-rail contact of the tramway and avoid abnormal wears, it is recommended for the tracks, drowned in road or concreted or coated, the type 35 GP groove rail with a ray R13. The U 50 Vignole type rail already used for the ballasted track is planned with a concrete laying to allow a sewage continuous laying.

Choice of the track laying type
The types of track laying are implemented all along the line in function of the level of vibration reduction to obtain or the constraints linked to the existing works. Different cut type drawing of these track layings are in the figures below.
The rail is totally welded in straight alignment and in curb.

The standard track equipped with concrete sleepers blocked up with a setting concrete has any anti-vibratile function; its average vibratory level of 80 dB in the third of frequency octave 63-80 Hz. This vibratory energy softens with the ground mass and it is admitted that the level becomes acceptable at right angles with a building located between 10 to 12 meters of the transmitting source.
When the trackbed is between 7 to 12 m near buildings, it is necessary to make use of anti-vibratile layings ASP type[5] or similar, the weakening must be between 10 to 12 dB in the third of frequency octave 63 Hz. In this context, the zone is declared sensitive.
The ASP track consists of a resilient material taken in sandwich between the metallic saddle bearing the rail and the concrete rail supporting block of the sleeper. The principle of the 1st elastic floor being kept, the 2nd floor plays the role of low frequency filter.
When the distance is inferior to 7 meters, the zone is declared very sensitive and the vibratory weakening must be of 20 dB. To reach this target, we must build a floating slab.
This slab is realized by interposing a carpet of polyurethane blunt between the cleanness concrete and the setting concrete.

In the particular case of bridges and parking special layings can be used according the case:

- Direct laying anchored or simply embedded, in the slab, for a weight and height's gain.
- Laying sleepers blocked up with a setting concrete for a weight 's gain
- Laying on floating slab reduced or laying on sleepers with elastomer boot socks for a vibratory protection of the work or a separation track / work in term of deformation.

The surface of the track

The general structure of the trackbed is constituted of a concrete foundation in which the sleepers are inserted. The principle of conception joined up to a independent rail allows to release a 17 cm high space on the whole of the trackbed to implement of surfaces.

The constraints to which the surfaces are subject to are important and of a big complexity:

- Dissipation of railvibratory energy in the surface
- Transmission of horizontal efforts by rail,
- Aggressiveness of road traffic and crossing phenomenon,
- Lack of homogeneity of the surface structure on account of the 4 rails presence,
- Tight link of the rail and the surface allowing defections accepting of the rail without disturbance,
- Treatment of surfaces drainage.

According to the priority agreed to the esthetics or to the functions, the surfaces vary along the line. They belong to the types commonly met on the recent networks of tramways. They are implemented all along the line with a double care of esthetics and functionality:

- paving,
- bituminous concrete,
- concrete,
- deactivated concrete
- grass

[5] ASP: Anti-vibratile, Sylomer, Prestressed

Surface paver or flagstone

It exists two possibilities of implementation. The first is called bedded. It consists in a surface with paver bedded with hydraulic binder to the setting concrete (BC5) of the track, joints between flagstones are also bedded. The rail is made independent by filling the fishplate chamber, the link rail – surface is provided by a polyurethane seam.

The second is permeable. It is a surface in paving laid on a crushed stone with sand-blast seams without binder. The base made by setting concrete is then drained. The rail is made independent by filling the fishplate chamber, the link rail – surface is provided by a polyurethane seam.

Bituminous concrete surfaces

The bituminous layer composed of bituminous concrete thin of 6 cm, settles on hydraulic concrete in under-layer with a metallic plate bed against the filling blunt of fishplate chambers. A polyurethane seam links the rail to the metallic plate.

Grass surfaces

The grass surface laying on a tramway track can be done with two different manners :

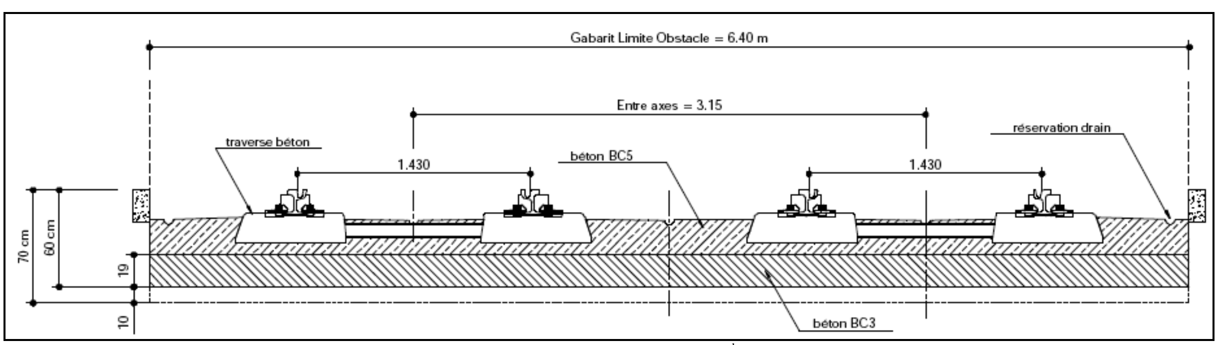
- Standard method coming to sow grass on the trackbed
- Laying called "by plate" to ensure an immediate result,
- In all the cases, the shape bottom is drained and a geotextile holds back the ground.
- A blunt dressing of the fish-plating chambers insulates the rail.
- Automatic watering is implemented on the sides of the trackbed.

Gravel surface

It is constituted of crush stones 10/20 filling up the space between rails and between the tracks. It is levelled at 3cm under the rolling plan of rails. The shape bottom is drained.

The different track's type layings

1. Standard laying and permeable surface

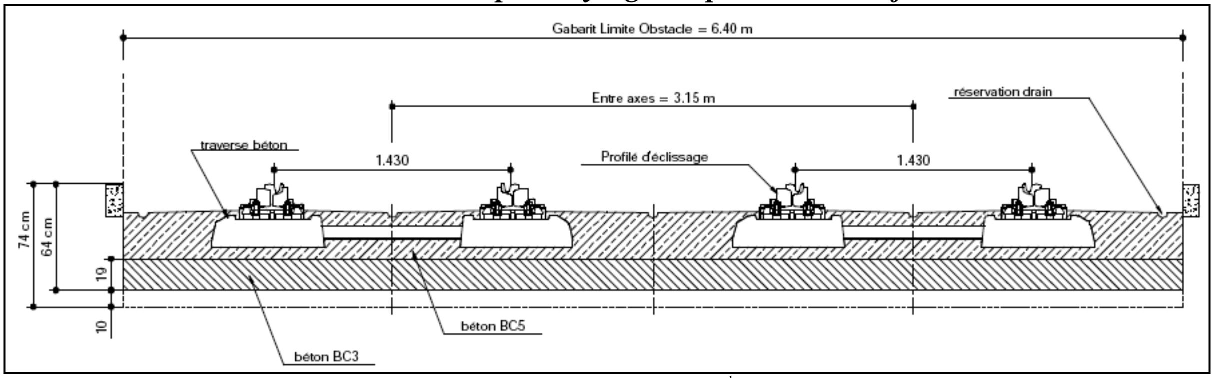


(Source: Egis Rail, Montpellier 3rd line)

(Nota: all the measurements are given in straight alignment; with a DKE of 6.35 m or 6.80 (if catenary'spole in the middle of the RoW) , the depth between the rolling level and the sharp bottom is H= 60 cm if the ground's module EV2 > 35 Mpa; H= 70 cm if the ground's module EV2 > 20 Mpa. Traverse béton = concrete sleeper; béton BC5 = concrete BC5; reservation drain = drain reservation; gabarit d'obstacle GLO = DKE Developed kinematic envelope)

Figure 38: Standard laying of tracks for Citadis tramway

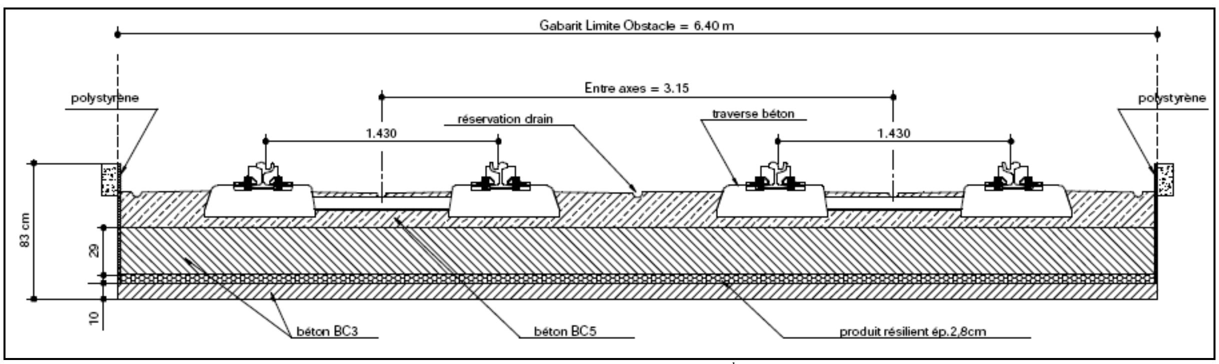
2. *ASP sleepers laying and permeable surface*



(Source: Egis Rail, Montpellier 3rd line)
(Nota: the depth between the rolling level and the sharp bottom is H= 64 cm if the ground's module EV2 > 35 Mpa; H= 74 cm if the ground's module EV2 > 20 Mpa. All the measurements are given in straight alignment; profile d'éclissage = fish-plate profile)

Figure 39: Anti-vibratile, Sylomer, Prestressed ASP laying of tracks for Citadis tramway

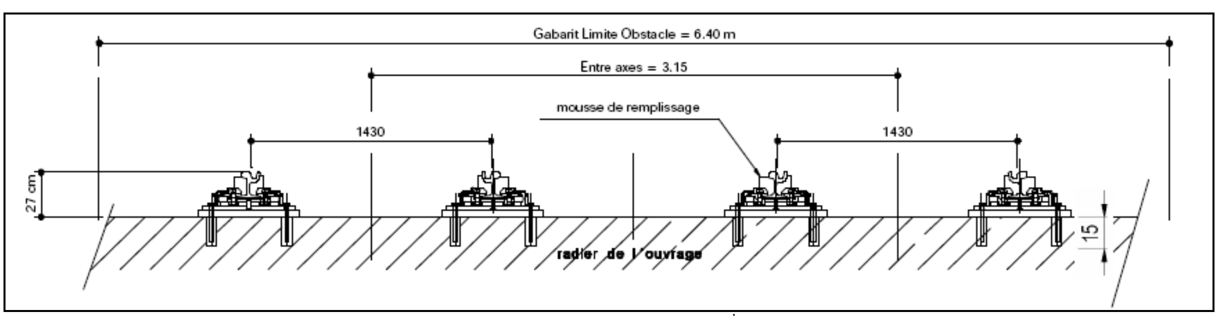
3. *Floating slab laying and permeable surface*



(Source: Egis Rail, Montpellier 3rd line)
(Nota: the depth between the rolling level and the sharp bottom is H= 83 cm if the ground's module EV2 > 20 Mpa. all the measurements are given in straight alignment; traverse béton = concrete sleeper; produit resilient = resilient product)

Figure 40: Floating slab laying for Tramway tracks

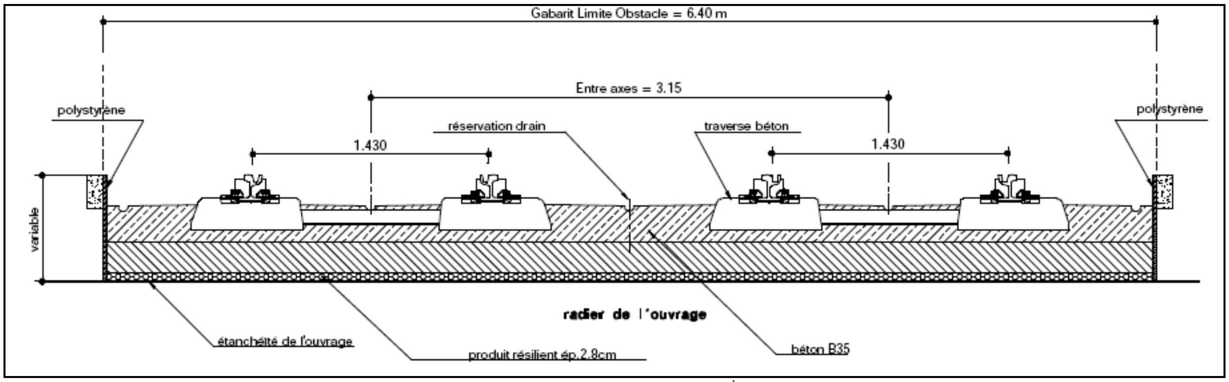
4. *Direct laying on a concrete slab*



(Source: Egis Rail, Montpellier 3rd line)
(Nota: the depth between the rolling level and the level of civil works is H= 27 cm. all the measurements are given in straight alignment. Mousse de remplissage = blunt for filling; radier de l'ouvrage = raft foundation of the work)

Figure 41: Laying of the track antivibratile – sylomer- prestressed

5. Track laying on a reduced floating slab



(Source: Egis Rail, Montpellier 3rd line)
(Nota: all the measurements are given in straight alignment.
Étanchéité de l'ouvrage=tightness of the work; produit resilient=resilient product)

Figure 42: Laying of the track antivibratile – sylomer- prestressed

3.1.2.7 Transit costs

a. Capital cost

LRT capital costs and line haul trip speeds both increase as the fraction of RoW that is grade separated increases. LRT feasibility studies all too often claim the capital costs savings obtainable from limited grade separation and at the same time assume the speed and the reliability that can only be obtained in a rail system with complete grade séparation. Kain et al. (1987) e.g., Manila 1st line completely exclusive RoW on viaduct has a cost/km of 28.23 M US $ (cost escalated to fiscal year 98) compared with Tunis LRT, on a private at-grade RoW whose cost/km is 13 .3 M US $ 98.

Light rail systems reviewed by US GAO (see Fig.2) vary considerably in their capital cost per km. Included in capital costs are the stations, structures, signal systems, power systems, utility relocation, right of way, maintenance facilities, transit vehicles and project oversight. The higher capital costs per km for Light Rail systems compared with Bus Rapid Transit arise from several factors.

First, Light rail systems contain elements not required in BRT. Light Rail systems typically require train signal, communications, and electrical power systems with overhead wires to deliver power to trains.

LRTs reviewed by US GAO vary considerably in their capital cost per km. Included in costs are the stations, structures, signal systems, power systems, utility relocation, RoW, maintenance facilities, transit vehicles and project oversight.

The higher capital costs/km for LRT compared with BRT arise from several factors. LRT typically requires train signal, communications, and electrical power systems with overhead wires to deliver power to trains at an average cost of 3.50 M US $ per double – track km (Pilgrim, 2000).

A consultant's study of 8 Light rail lines in five cities[6] verified by the data of the FTA Index Report[7], found the average costs of these elements to be 1.75 M US $ per km. (Pilgrim, 2000) Light Rail systems also require additional materials needed for the guideway-rail, ties, and track ballast: a ballasted, double-track cross section the average cost is 1.450 M US $ per km. In addition, if a Light Rail maintenance facility does not exist, one must be built and equipped. The need for vehicles will vary for each line or segment depending upon such factors as service frequency, spare ratio, and operating plans : average cost for vehicle and maintenance was 3.3 M US$ per km with a SD[8] 2.4 M US$/ km.

Finally, Light Rail vehicles, while having higher carrying capacity than most buses, also cost more-about 2.5 M US$ each. Another factor that can affect the cost of the systems is the amount and availability of required RoW.
RoW costs are affected by the design requirements of BRT and LRT. A basic busway required a wider RoW than Light Rail. A two-lane busway required a RoW about 7 to10 meters wide for a one-lane per direction busway and 14 to 19 m (without fences) for a two-lanes per direction busway (e.g. Bogota), compared with 6.00 to 7.20 meters wide RoW for respectively a 2.30 and 3.00 m gauge LRT. For the systems reviewed the cost per km for Light rail averaged 21.62 M US$ per km, ranging from 7 to 49.5 M US$ per km (Pilgrim, 2000) These costs appear in Fig. 8 below. They were also detailed line after line in type of RoW: Exclusive (grade separated), Private (at-grade), Street/Highway Median, Reserved Lane/ Mall and Tunnel/Subway.

The definitions of these RoW types are :

- 1. Exclusive with Grade Separations : aerial or surface, such as along a freeway with no grade crossings;
- 2. Private At-Grade : surface on private RoW, such as a railroad line, or adjacent to a city street or highway with at-grade crossings;

- 3. Street / Highway Median : surface with reserved section in medians of streets and highways with at-grade crossings.
- 4. Reserved Lanes / Mall : surface with reserved section in pedestrian malls with at-grade crossings.

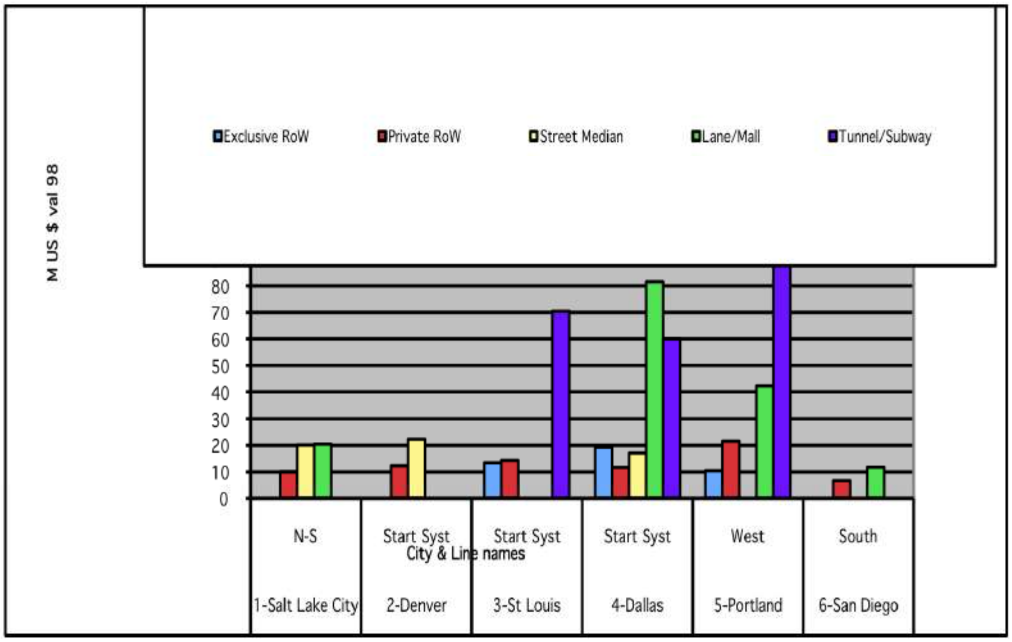
- 5. Tunnel / Subway : below grade in tunnel.We summarize in Fig. 9 the cost per km of each type of RoW for some Lines among the 8 lines of the Pilgrim's study.

RoW Category	Average Cost/ Km in MUS$ 98	Standard Deviation
Exclusive	17.9	0.51
Private, at grade	13.9	21.0
Street/Highway	24.3	10.5
Reser.Lane/Mall	39.1	31.1
Tunnel/Subway	82.9	10.8

Source: BRW, Inc in (Pilgrim, 2000)

Figure 43: LRT total cost by RoW type in M US $ 98

[6] Dallas, St. Louis, Denver, Salt Lake City and Portland ;
[7] Laver R.S. & Schneck D.C. 1995, " The transit Capital Cost Index Study ", FTA Office of Planning, Report n° MD-90-7001-01, July 1995.
[8] SD : Standard Deviation



Source: (Pilgrim, 2000)

Figure 44: Total cost of LRT lines by RoW of 6 lines in 6 cities

The cheaper capital cost of LRT network, is for a private, at grade RoW type, the average cost in 6 US cities is 13.9 M US $ 98. We have another example, it is the Tunis LRT, 5 lines network, 32 km total length of Private, at grade RoW type (200 m tunnel only), a 121 vehicles fleet , the cost is 13.3 M US $ 98 per km.(Godard & al., 2000)

b. Operating cost

We have seen in § 2.4 comparisons between operating BRT and LRT costs in 6 US cities: BRT operating costs are generally lower than LRT operating costs. It is evident that there is a large variation in operating costs, although the major differences reflect whether capital costs are low, reflecting a system built some years ago (e.g.Bern) and nearly fully depreciated and relatively new systems with recent capital costs currently being depreciated.

Operating costs are typically of different systems, and directly comparable figures based on operating experience are subject, in most countries, to commercial confidentiality. In Table 3 below we give operating cost of some French Tram and LRT networks. Costs are not comparable between Nantes, Grenoble, St Etienne because characteristics (length, fleet, density) of networks are different. If we compare the range of op. cost per vehicle revenue km in USA (see Fig.4 above) in the network of Dallas, Denver, San Jose, Los Angeles, Pittsburgh, they are in a range of 7 to 10 US $ lightly higher than French operating costs, San Diego op.costs are out of range with only 2.61 US $ per vehicle. Of course, driver's salaries, electricity, maintenance of vehicles and track system costs are different between France and USA so we stay only in the range's comparison.

	Grenoble 19 km 106 veh.	St Etienne 9 km 35veh.	Lille 22 km 24 veh. *	Nantes 27 km 46 veh	Rouen 18 km 28 veh. **	Tunis 32 km 121 veh.
Cost/veh.km	6.35	4.66	7.04	5.59	4.48	2.50
Cost/trip	0.57	0.46	1.19	0.43	0.475	0.148
Cost/ OSK	0.038	0.035	0.042	0.024	0.026	0.010

Source : (Godard & al. 2000) Nota OSK : Offered Spaces km
1 US $ 98 = 5.87 FF *Op. cost of Lille are 99 costs ** Staff cost of Rouen was estimated and the op. cost of Rouen was given without taxes and managment costs.

Figure 45: Operating costs of 5 LRT networks in France and 1 LRT in Tunisia in US $ 98

Reliability

Congestion-free transport is regular and hence reliable. Thanks to this reliability, high frequency timetables at peak-hours can be designed, obtaining better passenger flows. Light rail can also continue to operate when adverse meteorological road conditions such as snow or ice affect road traffic.

Comfort, accessibility and ease of use

Vehicles with good suspension and well-maintained track together ensure a smooth ride. Low floor vehicles in combination with gapless boarding points offer better accessibility for all categories of passengers. Pleasant and well-designed stations and stops, as well as dynamic passenger information (e.g. in case of service-disruption), also contribute to passenger satisfaction.

Safety

Light rail is many times safer than car travel. Segregated rights of way and priority at traffic lights reduce the risks of accidents with road transport. Input of scientific research in the field of passive safety, results in safer vehicle design (e.g. impact and energy absorption behaviour, distribution of passenger seats). Feelings of insecurity for passengers can be reduced by careful design of stations and stops and other appropriate measures by operators and authorities.

Environment-friendly

With electric traction, light rail produces no emissions at street level. Modern traction equipment allows regeneration of braking energy and consequently considerable energy saving. Light rail is a relatively silent transport mode, and rolling noise and vibration can be attenuated further by good maintenance of vehicles and track. "Green" (grass covered) track reduces noise even more.

Adaptability

Light rail can operate in every possible urban and suburban environment: ideally at ground level but underground or elevated if necessary, in the streets (mixed traffic) or preferably on segregated rights of way. It is an excellent transport mode to serve pedestrian areas in city centres. Light rail vehicles can leave the city-center and run on railway track, even in mixed operation with heavy rail traffic.

Figure 46: Translohr terminus in Clermont-Ferrand

Figure 47: Test track on TVM

Figure 48: GLT under test operation in Rochefort

Figure 49: TVR in Nancy

Figure 50: Translohr STE 4 of Clermont–Ferrand on the test track of Duppighem

3.2 New transit systems using rubber tyres

The concept of rubber-tyred intermediate guided transit system appeared as an attractive means to combine, for the medium importance projects, the qualities of the light rail transit with the economic benefits of the road systems, in order to achieve in some manner a light rail system at the minimum cost. The first assessments of transit contractors promised that it could be possible to realize such a system with 30% lower cost than a standard light rail transit system.

The vehicle gauge becomes more and more crucial in the large conurbations, because of the increasing congestion. As a result, a good choice of public transit system on Separated RoW with a separated surface from general traffic permits to us a better insertion on the permanent road network (especially if it must go through the centre) and a reduction of the nuisances of the public work yards (disruptions to residents).

As for the streetcar, the guidance device of the intermediate guided transit systems on tyres offers several advantages, among which we can note:

i. Make easy, to some degree, the manufacturing of larger capacity vehicles than buses,
ii. Encourage the separate Right-of-Way insertion reducing the land use,
iii. Assure an optimal link between platform and vehicles in the stations.

The guidance device permits the Right-of-Way to stay within the limits of the dynamic gauge of the vehicles adding a protective air space. It facilitates the insertion of the transit system in historic city centers where the space is limited, compared to that of bus Right-of-Way, and also makes better the other uses of the street (parking, sidewalk, bicycle path and etc.) or its embellishment. For example, the guided bus authorizes a reduced Right-of-Way area from 15 to 20% where the buses are operated under a standard traffic, considering the dynamic gauge and the necessary protective air space.

The guidance in station makes it possible not only an easier and faster transfer between the platform and the vehicle, but also the better quality of the service thanks to a reduced gap between the edge of platform and the floor of the vehicle: the disabled persons with reduced mobility and child stroller access becomes easier.

Quality of surface facings can be realized on the tracks like for light rail transit. The track of the intermediate guided system on tyres creates a trace in the city that reinforces the legibility of the system in order to stimulate its use.

Indeed, the railway type guidance device of the intermediate systems (TVR, TRANSLOHR and etc.) can be used for an electric supply avoiding the second trolley line for example in Nancy, non-polluting energy with a high efficiency, like which of light rail type and even to constitute large capacity trains (TRANSLOHR STE version). The vehicles, which are a type of innovation, often personalized and bring silence and riding comfort, show a progress in relation to the very ordinary design of buses.

Under commercial operation two concepts are proposed:

i. The use of the guidance device along the total ride. In this case, the intermediate system operates like " a light rail transit on tyres ". The scheme of Caen GLT has been designed on this principle but keeping a bimodality for bad or inevitable conditions. On the contrary, the Translohr STE did not keep the guidance bimodality. This allows him to choose larger vehicle length and as a result, Translohr STE has a narrower gauge (2.20 m) to facilitate insertion;

ii. A mixed ride along a guided dedicated right-of-way and along a road separate right-of-way, or even along an ordinary road network: the Nancy scheme is designed under this principle.

For the performance, the rubber-tyred intermediate guided systems have some advantages such as higher tyre friction, especially the adhesion that gives them, e.g. the performances superior to iron in emergency braking and in climbing higher slopes.

We recall the inherent qualities of the tyre below according to the tyres manufacturers:

i. Absence of vibrations: the tyre, thanks to its structure and absorption capacities, transmits few vibrations to the environment, contrary to the steel wheel;
ii. Adhesion: thanks to a high coefficient of friction, tyres permit to go elevated slopes (until 13%, the limitation is due to standing passengers comfort) whereas steel wheels vehicles cannot ride on gradient slopes superior to 9% to 11% without motorization of all the axles[9]. The adhesion of the tyre reinforces the users and pedestrians safety, as reducing the emergency braking distances within a very short time if necessary; using magnetic skate on the rail the braking system of light rail system allows also deceleration of 3.5 m/s^2.
iii. Comfort of users, respect of the environment: on straight line and, more again, in curve, the tyre proves to be less noisy than steel wheel. This advantage increases with the vehicle and track oldness, notably in curve where the strident grating of steel wheels on the rails becomes unpleasant for both passengers and residents. If we compare bad maintained tramways under operation with vehicles on tyres in the vicinity generally the noise of streetcars in the curves is superior to the vehicules on tyres: but for another reason, nowadays the people living in the vicinity of rail networks do not bear anymore noisy rail vehicles all day and night long, the operator must maintain the railtrack and the wheels of tramways, the art's rule is a good geometry of rails, round wheels and one oil drop in the good place just entering a curve.
iv. Manoeuverability: with a superior handle capacity compared to the steel wheels vehicle's one, a vehicle on tyre can change direction more easily. Tyre using for tram rolling stocks allows us to reduce from 18 to 12 meters curvature radius. It often permits a better insertion in crowded city center. The terminals can be achieved in loops because of the small necessary area due to the small curvature. The loop terminal allows us to reduce the number of doors to only one front of vehicles and only one cabin. Also, if they are bimodal, the vehicles on tyre can run outside of the tracks and reach the garages and workshops without particular infrastructures;
v. Infrastructure cost saving is also achieved by using the tyre : indeed, it is not necessary when the transit system on tyres is bimodal to stay on its separate right of way, the system could be operated in mixed traffic for some times during public works on the sewage or gas pipes e.g. these pipes staying under the separate platform. The non deviation of gas, water, sewages pipes, telephone and electricity wires was the principal source of savings given by bimodal tramways on tyres manufacturers in 1992 during the bid of Transit Authority of Caen and the choice between tramway on steel wheels and tramways on tyres. But in France all the tramways on tyres project adopted the deviation of all the underground networks

[9] We find 9% slope on the light rail network of Wurzbourg and 10.7% in Neuenkirchen that is closed now.

of electricity, water, gas, sewage, telephone so the transit operator is not obliged to interrupt the operation of the vehicles on the separate right of way and operate the vehicles during some weeks in mixed traffic. But there are not savings on infrastructure investment announced by using bimodal tramways on tyres.

A large part of savings announced by the manufacturers with the arrival of the new intermediate systems on the market depends on the infrastructures. Three types of direct cost reduction can be obtained in the case of the tram on rubber-tyres:

i. First, the most favorable design of structures as regards fatigue, that takes into account the lightness of the axle load and the number of axles passage during the tracks use;
ii. Then, considering the light pavement thickness necessary in front of the calculated traffic, the possibility to keep transverse supply networks under the tracks, but also longitudinal networks if one protects them against leakage currents;
iii. Finally, in some cases, the use of bimodal vehicle allows to go to the depot-workshop, located far enough from the line terminus, along the existing road network, and to use a bus extended depot without putting switches on the tracks and supply catenaries, the vehicles being able to circulate with batteries or a thermal motor foreseen in the bimodal vehicle.

In the case of the light rail transit, the first two factors of cost reduction are possible. The third type is only partially feasible, if it is necessary to construct a railroad track until the garage that could be an extended bus depot in which there are no catenaries. The light tram can be equipped of an autonomy consisting in embarked batteries or other devices, that it will use otherwise if there is a current breakdown; the electric supply design will be able to be calculated thus with this constraint, without redundant electric substations, with an objective of cost savings.

Thanks to vibration lack, it is possible to suppress or to reduce the different elastic levels necessary to absorb noise and vibration in the case of a railroad track passing close to dwellings, hospitals, offices, etc. Otherwise, the reduction of the pavement thickness structure permits us to maintain some supply networks under the track, the cover on these pipes or cables being sufficient during the earthworks and therefore when the Separate RoW Public Transport system is under operation. The absence of vibrations reduces the track maintenance expenses and decreases the mechanical solicitations and the vehicle mechanical ageing.

The road technique used for the Separated RoW Public Transportation System pavements allows us to get some competitive in costs while opening the invitation to tender to the numerous specialized road construction enterprises. It is possible to adopt a more hilly profile and therefore more inclined slopes and shorter curvature radius, which encourages the insertion of the separate Right-of-Way in urbanized areas and reduces the earthworks volumes and pavement construction.

On the other hands, the light rail transit investment cost (20 M€ to 30 M€/km) can appear excessive in the case of projects intended to serve limited passenger volumes (1500 to 3000 p/h/d), what is frequently the case of medium size French conurbations projects. In spite of its savings (6 to 8 M€/km), the busway appears rarely like an alternative. Because the buses always endure a real image deficit and the realization of this system is not considered as a tool permitting to sufficiently improve the urban quality. The elevating urban insertion quality brought by the intermediate system realization is not an extra investment thanks to the contribution, which gives an excellent image to this system encouraging its use.

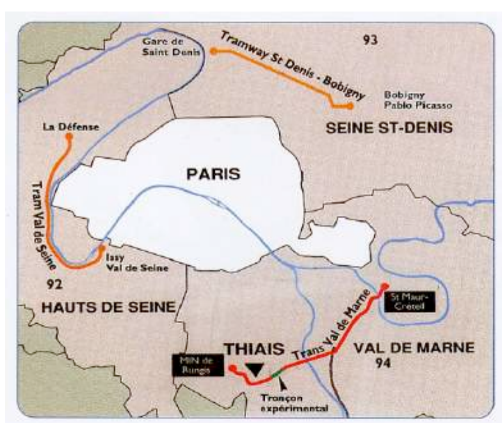
3.2.1 Translohr: Tramway on tyre

The rubber-tyred rail guided vehicle system named TRANSLOHR is developed by the Lohr-Industrie located in Alsace, France. Lohr-Industrie is, for their public transport product segment, associated to Fiat-Ferroviaria[10]. The TRANSLOHR is a rubber-tyred trams range and the TRANSLOHR STE has permanent guidance.

Source: *www.lohr.fr*

Figure 51: TRANSLOHR from the test site of RATP

The first prototype of this system has also been tested since the first quarter of 2001 on RATP's Trans Val-de-Marne site, south of Paris.



Source: http://*www.lohr.fr*

Figure 52: Localisations of Trans Val-de-Marne, test site of 3 systems TVR, TRANSLOHR and CIVIS

[10] Electrical equipment comes from Fiat (now owned by Alstom, which also supplies electrical equipment to CIVIS and TVR.

Clermont-Ferrand has been the first city to employ the system in regular use through the operator SMTC from 2006. In this city the permanent guidance system is chosen with a module vehicle of four cars.

Lohr-Industrie proposes a rubber-tyred guided tram range. The main product is the tram TRANSLOHR STE with permanent guidance, derived from the new small gauge rubber-tyred electric transport system, STEP concept. There are three, four and five bodies' vehicles of 6 ranging in length from 25 m to 39 m. Their body gauge is 2.20 m. These vehicles are easily accessible with 25 cm low floor (above the ride level), always guided, and have an electric traction supplied in electric energy by catenaries and batteries for the circulation in the depot-workshop.

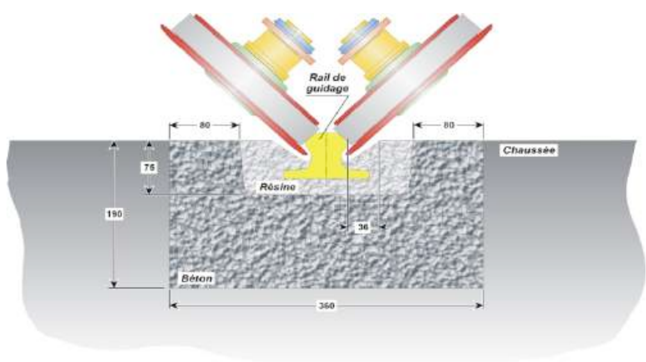
Vehicle aspects	*Descriptions*
Guidance Technology	Mechanical guidance. The vehicle is guided by a single centrally embedded rail on a guideway. Every axle is equipped with a guidance device composed of two rollers in V fixed on a swiveling arm. The guiding system, mounted on all axles, is mechanically locked with the rail, and thus guarantees the precision of the trajectory, the perfect docking at the stations without any effort on the rail. The internal faces of the rollers are covered by rubber. Centre rail has sloping railhead sides. This rail is also useful for the return of the electricity (current), collected by a pantograph. Thus the module is prevented from jumping out of the guidance system. There is no possibility of derailment, even in very slippery conditions. The vehicle is monotrace. 
Bidirectional abilities	Bidirectional modes in the permanent guided version.
Propulsion	Electric traction, with electrical power supply (catenary) and additional gas turbine generator charges batteries for permitting more extensive off- track running like use in public service over the whole bus way.

Figure 53: Vehicles aspects of TRANSLOHR

A bimodal version has also been studied: TRANSLOHR SE (the vehicle is able to leave its rail everywhere as to continue in truck driver mode) for the experiment on the Trans Val-de-Marne site.

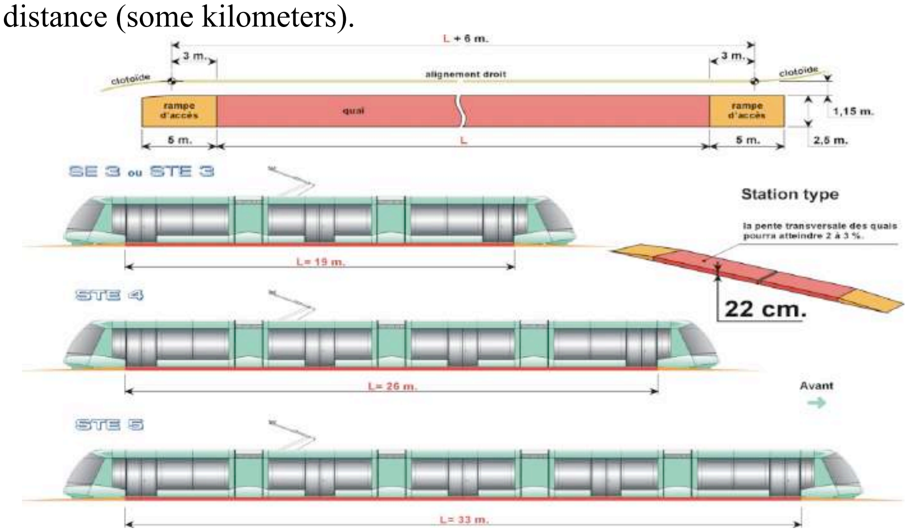
(Source: Lohr-Industrie)

Figure 54: TRANSLOHR SE and the equipment to attach/detach on the rail, the guidance device

3.2.1.1 Geometrical characteristics

Translohr possesses all the characteristics of a modern tramway:

i. Full and permanent guiding by rail, allowing tram architecture and rail accreditations;
ii. Large transportation capacity complete range from 25 to 46 meter long, consisting of 3 to 6 interconnected passenger modules, and a capacity up to 255 persons at 4 p/m^2;
iii. Reversibility: 2 driver cabins at both ends;
iv. Accessibility: integral low floor (25 cm above the track);
v. In option, a pack of batteries on the roof, to ensure electric autonomy for a certain distance (some kilometers).



Source: Lohr-Industrie

Figure 55: TRANSLOHR STE 3, 4, 5 lengths and their respective platform

Source: Lohr·

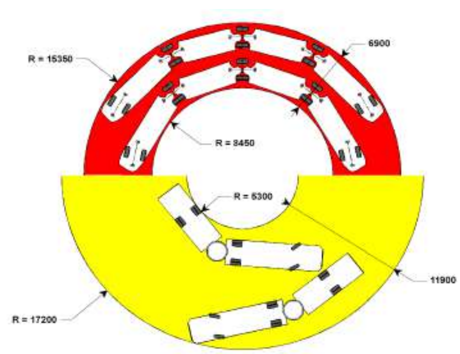


Figure 56: Necessary gauge, radii of Translohr and articulated bus

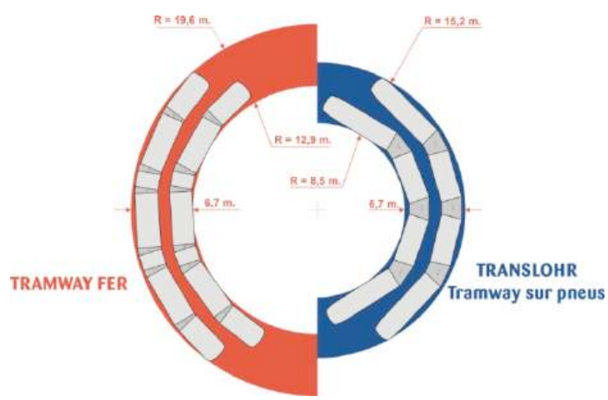


Figure 57: Ground occupancy of Translohr and tramway on steel wheel

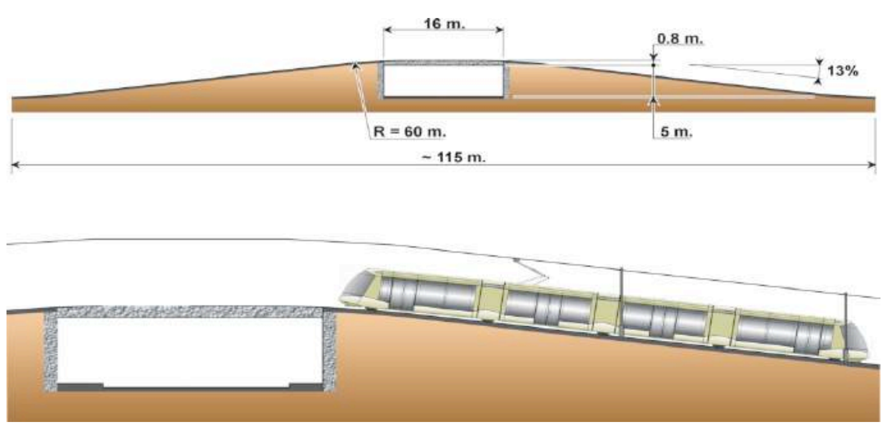


Figure 58: Possibility of the tram on tyres to climb a slope

Model	*Unit*	*STE 3*	*STE 4*	*STE 5*	*STE 6*
Maximum Speed	km/h		70		
Rated power voltage	V		750		
Overall width	m		2.20		
Overall height apart from pantograph	m		2.89		
Floor level	m		0.25		
Overall turning circle	m		10.50 on rail		
Obstacle limit gauge OLG	m		5.40		
Overall length	m	25	32	39	46
Number of passenger modules		3	4	5	6
Number of axles		4	5	6	7
Door (1.3 m x 1.95 m)		2 x 3	2 x 4	2 x 5	2 x 6
Capacities	4 p/m^2	127	170	213	255
	6 p/m^2	178	238	298	345

Source: Lohr-Industrie

Figure 59: Main characteristics of Translohr STE 3, 4 and 5 lengths

3.2.1.2 Differences between steel / tyre wheels tramway

The tyre axle, in replacement of the traditional steel bogie, offers some benefits:

i. Silence of operation (no steel-steel contact): a precise study has to be done about energy consumption between a tramway on steel wheels and a tramway on tyres, indeed generally a vehicle on steel wheels needs between 2 to 3 minus energy than a vehicle on tyres;
ii. High insertion performance: short turning radius (10.5 m at the rail), gradient ability (13%) and small dynamic gauge (5.40 m);
iii. High braking efficiency (disc brakes & ABS installed on all the wheels);
iv. Light infrastructure due to the optimized weight distribution on the axles.

For a middle range of capacity for example between 2,000 and 5,000 p/h/d, the tramway on tyres is an economical one because of:

i. Optimized infrastructure costs;
ii. Reduced ground occupancy (dynamic gauge 2.20 m);
iii. Reduced depot land area;
iv. The underground networks (sewage, gas and water pipes, cables of telephone, television, electricity and etc.) might not be displaced but generally they are displaced in French cities, the public works being paid by concessionary companies that is to say by clients.
v.

3.2.1.3 Different track types

For the guided mode, there are 3 types of track that could be chosen by LCPC[11], we are interested here by 2 types of track:

i. Track in continuous reinforced concrete,
ii. Track constituted by a structure of bituminous concrete with a high module.

Indeed, in order to compare the different intermediate systems, we retain 2 types of track for each constructor, which are the most, adapted to be protected against ruts of bituminous concrete. In fact, under local conditions one constructor could propose a road structure with a thick slab taking all the precautions in relation with this type of work.

3.2.1.4 Case study: the Translohr in Clermont-Ferrand

a. Translohr's first line in France

Following an European invitation to tender on performances, the project "Translohr" of the company Lohr-Industrie was selected in December 2001. It is the bidirectional articulated vehicle of four cars with small gauge (2.20 m in width) and low integral floor (23 cm of the ground) resting on respectively five steering axles. At the extreme parts of vehicles, there are engines (2 x 200 kW on the whole), with an axle load not exceeding 7.9 tons (4 standees/m^2).

As shown in above chapters, in addition to the rubber tyre system, the main difference lies in guidance system, assured by a single central rail gripped by inclined rollers with 45°. This rail is also useful for the return of the electricity (current), collected by a pantograph. In Clermont-Ferrand, the "route" is constructed in a concreted or asphalted track (depends the city's architects constrains), occupying all the width of the platform, in which the rail guides (one per circulation direction) are embedded and bordered by vast ruts allowing the passage rollers. Although being very discrete establishment in urban site, this provision however excludes bus circulation because of the small gauge, just as that of the cars and more particularly of the two-wheeled vehicles (bicycles & motor-cycles) because of the width of the ruts; only the perpendicular crossings or of angle are possible.

b. Actual situation

Tested successfully on the test line of the Lohr manufacturer in Duppigheim in Alsace, the first vehicle arrived in Clermont-Ferrand on December 2nd 2005, and then the 19 others were delivered. After validation of the rolling stock and the line, the drivers formation and the white running tests, the first French line of tyred monorail tram was brought into service on October 14th 2006, from Champratel to the CHU Gabriel Montpied, the section of 10 km long. Actually this line being prolonged, 14 km long for North-South direction, is serving 31 stations of Champratel (where the center of maintenance and depot are) in Pardieu. In downtown area, it takes again an exclusive right of way route for bus done at the beginning of the 80's, and passes through the place of Jaude, the center of Clermont-Ferrand. Far from the south, it takes the central part of a bridge road with a slope of 6.25 % before arriving at the station of CHU Gabriel Montpied, which was provisional terminus on August 25th 2007.

Though the system is generally proved reliable with high accelerations performance and a particularly effective braking system, the technology remains that of a road vehicle - with

[11] LCPC: Central Laboratory of Bridges and Roads

particularly significant jumpings on the concrete pavements - independently of the clean "chuintement" to the guided tyre-vehicles.

c. The extensions

In particular, serving the University Campus and SNCF railway station of Pardieu, the second section was opened into service on August 25th 2007, the overall length being now 14 km. Crossing a not very dense habitat (suburban zone and campus), this prolongation comprises a complex layout with tight curves and strong declivities (up to 8% in Margeride) - for which the tyred vehicles, articulated and with small gauge, are well adapted - and crosses even a national road! For the connection with station TER SNCF, the parking of private cars and buses, the terminal station Pardieu has a multimodal vocation. Since the opening of this extension, the daily traffic passed from 32 000 to 40 000 passengers, frequentation was developed after the re-entry of the many students of the university campus. Unfortunately, this line is not connected to SNCF railway main station of Clermont-Ferrand, this makes the correspondence with the rail network only limited to the station of Pardieu.

d. Total Cost

This first guided tyre line's cost is on the whole 290 M€ (val. 02), that is to say 20.71 M€/km, a price equivalent to the traditional tramways on steel wheels. But as for the majority of the networks, it is necessary to take into account the related installations (independent of the running type), of great quality in Clermont like, for example, in the Place of Jaude which profited a very successful new pedestrians space in prolongation carried out at the bottom of the Cathedral about fifteen years ago. In the north of Clermont, an extension of 2 km is under study to serve the Quartier des Vernes, in order to integrate it in the agglomeration. After a phase of public dialogue, a drafting schedule of conditions, the launching of the invitations to tender and the first construction could start in 2009.

3.2.2 TVR[12]

3.2.2.1 A new guided transit system story: the GLT[13]

For the beginning, a stranger device emerged from the factory of La Brugeoise & Nivelles (BN) in Brugge, Belgium, to be demonstrated initially on a short track in the shadow of the Atomium in Brussel. This was labeled GLT (Guided Light Transit) and was a rubber-tyred vehicle, an articulated bus (3 car bodies) for a duomodal system guided by a central rail. Each vehicle could be coupled in order to form a train of a maximum 3 units, of a length 76m with a capacity 600 passengers (6 standees/m^2). Each of the 4 axles could be put into guiding mode of which the minimum radius is 12.5 m. But with it had a pantograph on its roof, feeding power to electric motors to provide the drive. As well as a steering wheel, at the centre point of the underside of the vehicle a pair of in-line small double-flanged wheels were held down onto a centre slot rail by hydraulic force. When running under electric power from a single overhead wire, these wheels also acted as the current return. An auxiliary diesel motor was fitted to provide power to the electric motors when running away from the guideway and overhead. A longer section of test track was built along some 4km of disused railway between

[12] TVR: Transport sur Voie Réservée, Separate right of way transit
[13] GLT: Guided Light Transit

Jemelle and Rochefort in the Ardennes, and two quite smart prototypes carried out extensive trials, including public operation, in the early 1990s. A third prototype was given bogies and ran trials as a tram in Bruxelles, but these high-floor vehicles were soon rendered obsolete by the arrival of low-floor trams (and later buses). Another significant problem was excessive noise caused by the oscillation of the wheel in the guideway.

In 1989, the Canadian conglomerate Bombardier Transports acquired the Ateliers de Nord de la France (ANF-Industrie) and Brugeoise & Nivelles (Belgium). It was occasions to further develop the Belgian GLT (Guided Light Transit) concept from the 80s, together with Spie-Enertrans. BN was by now part of Bombardier and quite an aggressive campaign in England and France was waged to sell the system as an intermediate mode between tram and bus, with all the kudos of the former at only half the cost. Nothing happened in the UK, but in France the Bombardier salesmen were able to tap into the desire of any French city worth its sale (with Government encouragement) to have its TCSP14 or segregated surface transit system. Most went for trams of course, but it was inevitable that some politicians were going to jump at the opportunity to have a 'half-price tramway'. And it was in the city of Caen that this happened.

The Guided Light Transit[15] or Separated RoW Tramway guided by means of a single central rail has been developed by Bombardier and tested on an experimental site, the Trans-Val-de-Marne, in the southern suburb of Paris, in 1998; it has been chosen for the future Separate RoW Public Transport of Caen and for the Nancy dual-mode trolleybus system substitution where the new system has been under operation from September 2001.

From the choice of this system by the City of Caen, the manufacturers Bombardier - ANF and Spie-Énertrans developed the GLT becoming TVR easily accessible with its low floor, dual-mode diesel-electric, which can be either guided with the central rail or autonomous as rubber tyred vehicle. Under every axle, there is an arm, on which are fixed two vertical rollers and located before and behind the axle, follows the rail and drives the wheels by means of rods. The arm can either be brought down or raised by means of a hydraulic jack. Introducing these vertical rollers on the rail, it is necessary to put the vehicle in an introducing zone, which features a V shape switch or dropping place.

Besides, this vehicle is monotrace. It is not a super trolleybus since its body, born from the new tram 2000 of Brussels, is a rail rolling stock's one; since it is electrically supplied by a pantograph power collector; and since it includes three articulated bodies, with a total 24.5 m length. It can roll to 70 km/h and can climb 13 % maximum gradient, enter in a 12 m minimum curvature radius while the trams enter in 15 to 20 m minimum curvature radiuses according to the track gauge.

3.2.2.2 The TVR (Caen and Nancy)

As mentioned above, the first French city to show an interest in the GLT was Caen. According to its promoters, Caen, like many cities, is too small (200 000 inhabitants) to fully justify the costs of a full tramway system. So the GLT seemed a more realistic proposition. Caen began studies in the late 1980s and by the mid-1990s had settled upon the GLT as their favoured solution to the problems of traffic congestion in the town. A full-scale mock-up of the GLT was produced and remained stationed outside the CTAC depot in Caen for some while.

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[14] TCSP: Transport en Commun en Site Propre , Public Transit on Separate Right of Way

[15] Guided Light Transit presented by Brugeoise & Nivelles during the 1985 UITP Conference in Brussels

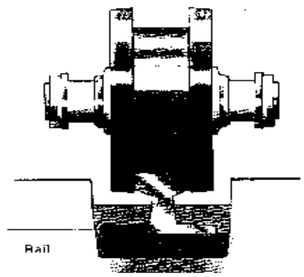
However, the first of new vehicles into service were not in Caen, but in Nancy. Nancy was already famous as having been the only city in France in modern times to build a trolleybus system. This system, which opened in 1982, was operated by a fleet of Renault PER180H articulated diesel-trolleybuses. It served several important suburbs and a major hospital at the top of a steep hill. By the late 1990s the PER180Hs were getting towards the end of their useful lives and were in urgent need of replacement.

Nancy wished to provide a heavy-duty transport solution for their important routes, but it was felt according to the Transit Authority that conventional trams would find it very difficult to climb the steep gradients on the route in all weathers (and even if they did, would not be able to do so without generating significant amounts of noise and disturbance to local residents): they forgot that the first Nancy tramways electrified in 1903 and closed in 1958 used to climb the same slopes. Clearly, Nancy wished to keep the use of the expensive electrical installations put in place for the trolleybus, so an electrically powered mode of transport was desirable. The TVR seemed the ideal solution. Major works were carried out to install guide rails and stations and reorganize traffic flows in the city, and the system was scheduled to open in December 2000. Nancy chose to market the TVR as a 'Tram' presumably in order to sell on the marketing value of trams elsewhere.

With two articulation points and a total length of 24.5 m, GLT vehicles are shorter than most modern trams, but quite long compared to regular buses. They are designed to look much like trams, although they are unidirectional and have bus-like rear-view mirrors. Unlike trams and Translohr vehicles, GLT vehicles have a steering wheel, though it is not used when following a guidance rail. They have 100 % low floors, seat forty passengers, and have standing room for as many as 105.

Figure 60: TVR

(above: TVR in Nancy. below: TVR in autonomous mode On the right, TVR on the test track of Trans Val-de-Marne since 1997 the RATP is using a 1.4 km section of the Trans Val-de-Marne in southeast Paris to test the TVR. The section includes a long ramp with a 5% gradient.)

<table>
<tr><th>Vehicle aspects</th><th>Descriptions</th></tr>
<tr><td>Guidance Technology</td><td>Mechanical guidance. Under every axle there is an arm, on which are fixed two vertical rollers, located before and behind the axle, which follows the rail and drive the wheels by means of rods. The arm can either be brought down or raised by means of an hydraulic jack: to introduce these vertical rollers on the rail, it is necessary to put the vehicle in an introducing zone, that features a V shape switch or dropping place.


</td></tr>
<tr><td>Bimodal abilities</td><td>Yes, a bimodal version under operation in Nancy but not in Caen</td></tr>
<tr><td>Bidirectional abilities</td><td>No bidirectional abilities.</td></tr>
<tr><td>Propulsion</td><td>Electric traction, with electrical power supply (catenary). Auxiliary Diesel engine provides electrical power when running away from the guideway and overhead supply in driver guided mode. Traction motors Alstom 300 kW plus auxiliary 200 kW diesel generator</td></tr>
</table>

Figure 61: Vehicles aspects of Bombardier's TVR (Source: Hans Dahl, "Use and optimization of public transport vehicles: Aspects of bimodal systems in urban areas", International Manager Project an the MBATechnology Manager Program 2004, 50p.)

Nancy's fleet use dual trolley poles to collect and return their electric power, in order to allow the use of existing wires constructed for use by trolleybuses. In Caen, where the central guidance rail has been installed on all sections of the passenger-service route, they follow the model used by trams, collecting their power from a single pantograph and returning it through the central guidance rail, and use their diesel motors and steering wheels only while traveling to and from the depot.

Model	*Unit*	*TVR*
Maximum Speed	Km/h	70
Rated power voltage	V DC	750
Overall width	m	2.5
Overall height apart from pantograph	m	3.22
Floor level	m	
Overall turning circle	m	
Obstacle limit gauge OLG	m	
Overall length	m	25
Number of passenger modules		3
Number of axles		4
Door (1.3 m x 1.95 m)		2 x 4
Capacities	4 p/m2	127
	6 p/m2	178

Figure 62: Main characteristics of Bombardier's TVR (Source: Bombardier)

a. Geometrical characteristics of TVR

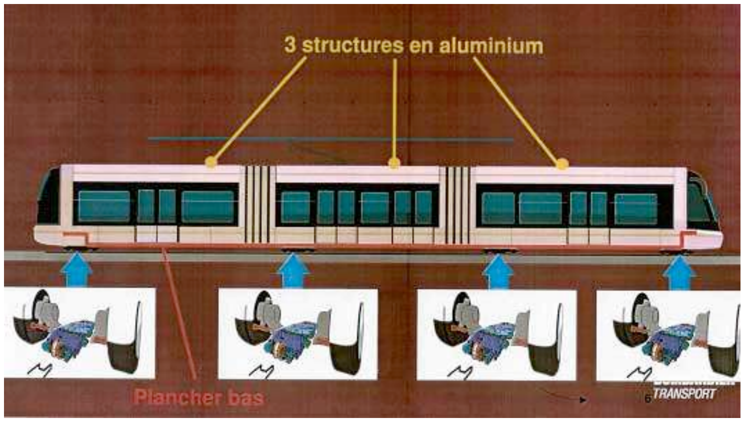


Figure 63: 3 cars rolling stock with 4 guided axles, platform level floor

Source: STRV, STMAC, Transit Authority of Caen

Figure 64: Articulated bus (Tram on tyres, manual conduct) and Classic tramway on rails (Tram on tyres)

In Nancy, TVR system is operated by the Société de Transports de l'Agglomération Nancienne, or STAN. The vehicles follow a guidance rail on about 60% of the route. The system entered service in December 2000, but after several derailment under operation it was closed from March 2001 through March 2002 while Bombardier upgraded the vehicles.

In Caen, the GLT fleet began operation in November 2002, incorporating the changes made to Nancy's vehicles during the upgrade. They are operated by the Compagnie des Transports de l'Agglomération Caennaise under the name Twisto.

b. Different types of TVR track

For the guided mode, there are 3 types of track that could be chosen by LCPC[16], we are interested here by 2 types of track:

i. Track constructed in continuous reinforced concrete,
ii. Track constituted by a structure of bituminous concrete with a high module.

Measurement of track structures

Traffic Hypothesis for the design of pavement structures of Bombardier TVR track is:

[16] LCPC: Central Laboratory of Bridges and Roads

Load on axle	*Passenger number*	*Total load kg*	*Axle 1*	*Axle 2*	*Axle 3*	*Axle 4*
Empty	0	26 000	5 531	5 758	6 032	7 680
Seats	37	27 405	6 084	6 104	6 771	6 447
$2p/m^2$	84	30 456	6 236	7 342	8 119	8 759
$4p/m^2$	131	33 508	6 389	8 579	9 468	9 071
$6p/m^2$	178	36 559	6 541	9 817	10 817	9 383
$8p/m^2$	200	37 993	6 613	10 398	11 451	9 530

Source: Bombardier

Figure 65: Hypothesis of load of each axle of TVR (Nancy and Caen)

With the same traffic's hypothesis than the Translohr of Clermont-Ferrand, we find for the TVR of Caen the thickness of sublayer and layer of bituminous concrete.

c. *Cost of bituminous track of CAEN line*

<u>*Contract's cost*</u>

The Bombardier indicated structure in CAEN is for a track made with bituminous concrete under the conditions of:

i. Geotextile on a PF2 ground surface,
ii. Goundation layer GNT[17] of 0.10 m,
iii. Basis layer of a high modulus asphalt concrete GBHPR of 0.12 m,
iv. Bounding layer of a high modulus asphalt concrete GBHPR[18] of 0.12 m,
v. Wearing course 0.06 m thick, of an antiruting bituminous concrete BBAO[19].

The cost of TVR track implementation of Caen (contracting cost) including earth-work, sublayer, basis layer and surface layer is:

$$458.75 \text{ x } 6.14 \text{ m x } 1 + 474.90 \text{ x } 2 \text{ m} = 3\,766.50 \text{ F/ml}$$

Implementation of rail on reinforced concrete beam:

$$2\,660.77 \text{ F/ml x } 2 \text{ ml} = 5\,321.54 \text{ F/ml}$$

Total amount: 9 088.04 F/ml value 1995

The cost of the track platform 6.14 meters wide for one meter length is, with a present value factor of 4 % per year: 14 541 F/ml double track or

2 271 € value 2007 = 2.217 M€/km double track

The total estimated cost of the double track with duct construction is:

0.70 + 2.217 = <u>**2.92 M€/km double track val. 07**</u>

[17] GNT : Untreated Graded Aggregate
[18] GBHPR : Grave Bitume Haute Performance
[19] BBAO : Béton Bitumineux Anti Orniérant

Estimated cost of a bituminous optimized track

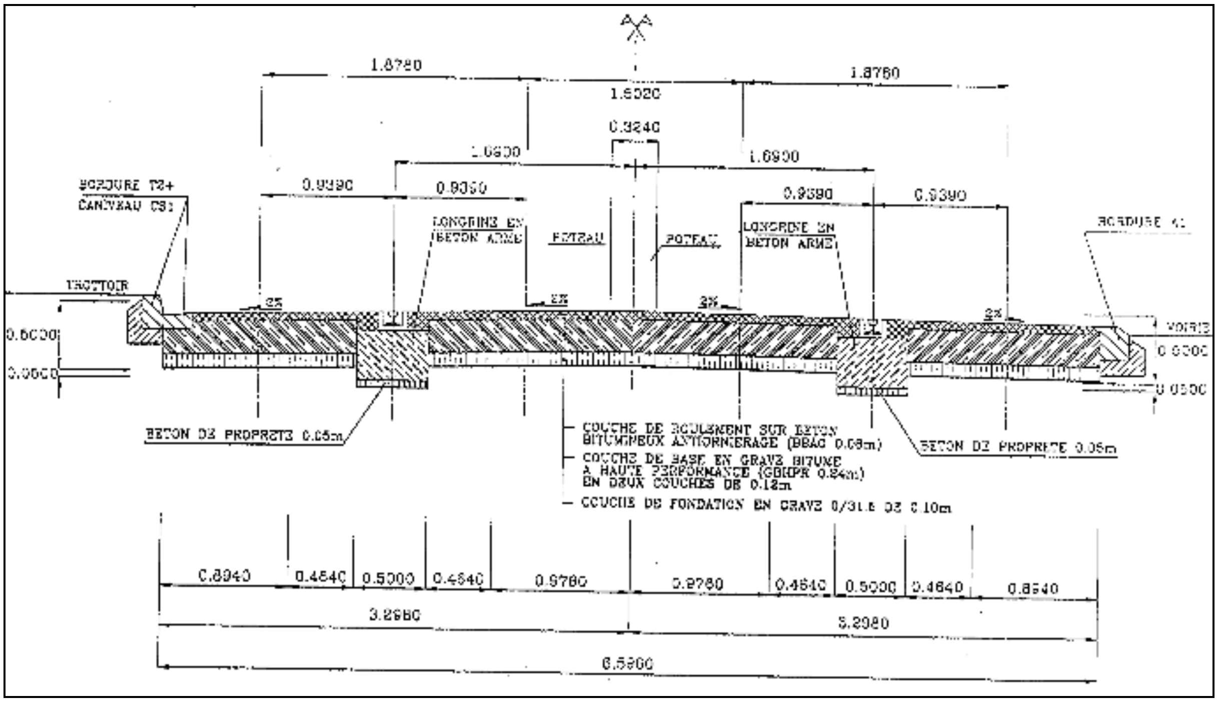


Figure 66: Cut overview of the asphalt pavement track structure with layers thickness
(Source: Bombardier TVR Caen)

3.2.2.3 Case study: TVR in Caen

a. The lines of TVR in Caen: the tramway project

After 12 years of planning and two years of construction, the French town of Caen in Normandy, with 208,000 inhabitants, opened a new tramway at the end of November 2002. It is unusual in having rubber-tyred vehicles, yet is not a trolleybus as it sends the return current through a central rail. But the Caen's Transit Authority said that the new 'tramway' was 40% cheaper than traditional tramways, with a cost of 18 M€/km compared to 25 M€ (val. 07).

Source : TWISTO

Figure 67: Plan de la ligne de tramway sur pneu de Caen

The project has a licensor and two concessionaires in a three-way agreement. Viacités, Syndicat Mixte des Transports en Commun de l'Agglomération Caennaise is the public transport authority for the urban transport region. It is a local authority consisting of 19 districts and the Calvados administrative region. The concessionary company is the company STVR (Société de Transport sur Voie Réservée) responsible for designing the mode of transport, financing, construction of the platform structures, fixed installations, rolling stock and maintenance of equipment. Twisto is the public service concessionaire responsible for the commercial operation of the bus and tram network. The civil engineering work has been carried out by Spie Batignolles TPCI, with ancillary work by SGTE Construction.

b. Actual situation[20]

The scheme opened with two lines, called 'A' and 'B', serving districts in the north and north-east, running through the city centre to the south and south-west of Caen. For the majority of their journey, both routes combine into one, splitting near the terminals. In total there are 34 stops and the total journey time from one end of the system to the other takes 30 minutes. Travel from any of the four terminals into the city centre at Saint-Pierre takes 15 minutes. The route is integrated with 25 existing bus routes, also run by the same franchised operator, Twisto of the group Keolis, that sells combined bus/tram tickets.

Within walking distance of the route, it serves 70,000 residents and 60,000 workers and its opening created 40 new jobs. The system has an on-line journey planner and timetable. Trams run seven days a week from 05:30 to 00:30 at 7 to 10 minutes intervals on each branch, giving a 3.5 to 5 minutes interval service on the main central section.

The tramway is also producing a change in lifestyle for the people of Caen. It is enabling districts to be opened up and revitalized, creating links between central and outer districts, bringing living and working areas closer together and promoting access to public transport for the disabled (a 90cm movable platform has been specially developed to help access for passengers with impaired mobility).

By encouraging mobility and offering rapid transport, the tramway is helping to expand the economy and is revitalizing the city centre and the districts it serves. The tramway service should also encourage companies to set up along its route, promoting the emergence of new business communities in the city centre and its neighbourhood.

c. Infrastructure

The tramway uses a purpose-built reserved street section, designed to also act as a 'buffer' between the pedestrian pavement and road. Cars are banned from using the reserved section. This also allows the trams to average 20km/h during the journey, 30% faster than buses.

The 34 stations are fully wheelchair-accessible, as are the trams, and are spaced about 300m to 400m apart. The maximum gradient allowed by the rubber-tyred system is 13%, which allows trams to reach critical areas of the city centre and the city's old quarters. Construction of the tramway went in hand with an urban transport plan, which saw the existing cycle-route network tripled in size, to encourage environmentally friendly transport.

[20] The principal difference of the TVR in Caen with respect to that of Nancy, that runs only in guided mode. It should not change mode (road or guided). But there are some problems such as the very fast wearing of the tires and rutting problem at certain places.

To broaden its transport services, Viacités expanded its bus network to make it complementary to its tram services. To assist in this intermodal interchange, the new network helps to connect principal modes of transport through the provision of car and cycle parks, 'platform to platform' connections between tram and bus services which reduces walking distances and the sale of a one-price tram/bus ticket.

d. Rolling stock

The rolling stock of TVR of Caen is a hybrid system using a vehicle on rubber tyres but is steered by an arm, which drops into a single centre rail. This arm also provides a return path for the negative traction current.

The trams are Bombardier GLT 'tram-on-tyre' three-car articulated units with a maximum capacity of almost 178 people each (37 seated and 141 standees, 6p/m^2). They are powered by Alstom 300 kW traction motors. An auxiliary 200 kW diesel engine is available for running off route and at the depot, powering the traction motors. The vehicles are single-ended (creating more space for passengers) and are treated as road vehicles under French traffic law, so cannot run in multiple.

e. Signaling / Communications

The system uses conventional tram/traffic lights and there is radio communication from the driver's cabin. The network also provides an online timetable, fares guide and journey planner to encourage integrated multi-mode travel.

f. General Cost

Contrary to Nancy, Caen decided that its TVR would be always in exclusive Right-of-Way and guided by the central rail. Moreover the TVR is powered by a pantograph not such as trolley like that of Nancy. Caen does not have strong slopes as in Nancy but chose the TVR because the tram appeared too expensive for an average city like Caen. It was publicly indicated that the line of TVR of Caen 15.7 km long costs 286 M€ (val. 07), that is to say approximately 18.30 M€/km.

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4. Road-based new transit systems

4.1 The Phileas

4.1.1 Introduction

In 1996, the cities of Eindhoven and Veldhoven approved the project of a “Tram on Tyres” public transport system.

This transport concept was designed for mid-size cities, where the infrastructure for a tram would be too expensive, or where trams are non-existent. An automatic electronic guiding system was claimed to give the vehicle all advantages of a rail vehicle at acceptable costs for the infrastructure.

Responding to these requirements, APTS[21] has developed and produced for the Eindhoven Metropolitan Area a rubber tyred guided transit vehicle, named “Phileas”, which is an important and integral part of an innovative and futuristic High Quality Public Transportation system.

APTS says: “Phileas is an innovative and futuristic vehicle which combines the good characteristics of a tram or metro system with the flexibility, the low capital and operational costs and the infrastructure of a bus system. You can compare for the best the Phileas with a tram on rubber tires, which is following a virtual rail that is stored in the computers of the vehicle”.

The vehicles for the Phileas are built in two versions: 18 m (single articulated, capacity 120 persons), and 24 m (double articulated, 180 persons) and soon a third version 26 m long (double articulated, 200 persons). The companies Berkhof, NedCar, Stork-Fokker, DuvedeC, Traxis, and Frog Systems are co-operating in the development of these vehicles, ordered by APTS.

If we go into detail, the vehicle has a light weight body that has been developed by Fokker SP. The floor is 100% flat over the total length of the vehicle and the modular body system enables us to vary the length and the door positions.

Frog Navigation Systems has developed the automatic guidance system for the vehicle. This enables the vehicle to drive automatically like a personal people mover or semi-automatic like a tram or a train.

The vehicle is also equipped with a parallel hybrid propulsion system of GM Allison and it has all-wheel steering. The automatic guidance in combination with all-wheel steering gives us the possibility to move the Phileas parallel to the bus stop.

4.1.2 Description of the Phileas System

The Phileas vehicle is a kind of guided bus on certain courses. The body consists of reinforced plastic; glass fiber in sandwich structure that flattened over the entire length. All coiled individual suspension can turn easily. The wheels after the first axle are involved each one by an electrical motor. Electrical energy system is installed in addition to an hybrid system. A combustion engine (for gas and gas-oil) with generator generates electrical energy.

[21] APTS: Advanced Public Transport Systems

To ensure the cushioning effect, a powerful battery is put in there additionally. The electronic guidance system is based on permanent magnets installed in the lane; their provision is at random and directed each time to the top, in the direction of the North or South Pole. Moreover there exists a system using the ultrasounds at the stops to ensure the determination of distance, which allows the vehicles to make the exact positioning in diagonal direction.

The Phileas vehicle can be exploited in three modes:

- **In manual mode**, the vehicle functions like a bus.
- **In semi-automatic mode**, the stability of trajectory is carried out by the automatic electronic direction system and the driver is only responsible to acceleration and braking. Moreover in semi-automatic mode, speed in the curves is limited and slowed down automatically at the level of stops, to ensure exact positioning in the direction of wheel.
- **In automatic mode**, the speed regulation is also taken again by an automatic system. In the two automatic modes, the driver always has the possibility of taking again the control of the vehicle.

Figure 68: The biarticulated PHILEAS

The Manual Control System in Eindhoven changes from/into the (semi)automatic control as follows:

- Manual control towards (semi-automatic):
  - The vehicle passed on the magnets and recognizes its position,
  - The vehicle indicates that control can be automatic,
  - The driver pushes on the green button and the vehicle is moving automatically,
  - If the driver wants or must to change into semi-automatic mode, he presses one of the pedals.
- (semi)Automatic Control towards manual:
  - The driver presses the red button and takes again the wheel or
  - The driver takes the wheel, while it runs under the automatic control mode, changes into manual mode.

The Phileas vehicle exploited in Eindhoven has an homologation for the road traffic according to the applicable directives E.C. (category M3, class I) and, in addition, the special regulations relating to the road vehicles of public transport at short distance in the Netherlands.

Figure 69: The PHILEAS vehicles in Eindhoven

Figure 70: The PHILEAS vehicle in Eindhoven

Figure 71: The driver's cabin and electronic equipments

Figure 72: The biarticulated vehicle on the test track

Figure 73: Monitoring of automatic driving

4.1.3 Technical innovations applied in the PHILEAS system

4.1.3.1 Electronic lane assistance and precision docking

The PHILEAS vehicle has an electronic lane assistance and precision docking system, which can be used on routes specifically prepared for this purpose. In these routes, a trail of magnetic reference markers will be laid in the road surface. Electronic lane assistance and precision docking makes it possible to stop with a constant small distance between the door thresholds and the platform edge. The result is a flush step alignment enabling passengers to quickly enter and exit the bus, thus limiting stop times and keeping the average speed as high as possible.

In guided mode the driver does not have to use the steering wheel. The driver is always in control of the speed with acceleration and brake pedals. In guided mode, automatic speed limitation is applied to position the vehicle at each stop very accurately in the driving direction. Because the driver is in control of the speed and there is no obstacle detection the driver must always stay alert. The driver can always switch to manual control with a special control button, or by applying a manual force on the steering wheel.

The guidance system is composed of 3 processors defining its operation. An incident could not take place if two of the three processors stop working at the same time. This same principle is used in aviation for the electronic piloting of the planes. For the homologation of the Phileas system of Douai, APTS must show that the immaterial guidance of the Phileas system offers the same security level as a conventional tram.

4.1.3.2 General requirements for the magnet grid

Without any outside help the vehicle can drive and track its current position over a certain distance. This is realised with artificial intelligence and infrastructure-independent sensors, such as driving encoders in the wheels, steering angle sensors, gyroscopes, etc. Magnetic markers are fitted to the road surface for more accurate positioning. Magnet sensors under the vehicle detect the passage of magnets. Each lane is fitted with a line - grid of magnets. The magnets have a diameter of 15 mm and a length of 30 mm. Usually the magnet grid is laid in a smooth line. The magnet grid must be placed in the road surface in such way that the magnet sensors always are able to detect the magnets under the vehicle while riding.

These magnets are normally installed with the manner below:

- A small hole is bored in the roadway, depth 5 cm, diameter 1.8 cm,
- A magnetic marker with cylindrical diameter 1.5 cm and length 3.5 cm is inserted in the hole,
- A resin is run for filling up to the level of surface road.

In general, the magnet grid is laid in the middle of the lane, both on straight sections and in gentle bends, however:

- The grid line is laid at a minimum of 145 cm and a maximum of 165 cm from the right hand side of the road on straight sections of the road and in gentle bends.
- APTS will determine the path of the magnets in sharper bends or where the ideal route of the grid is not clear.

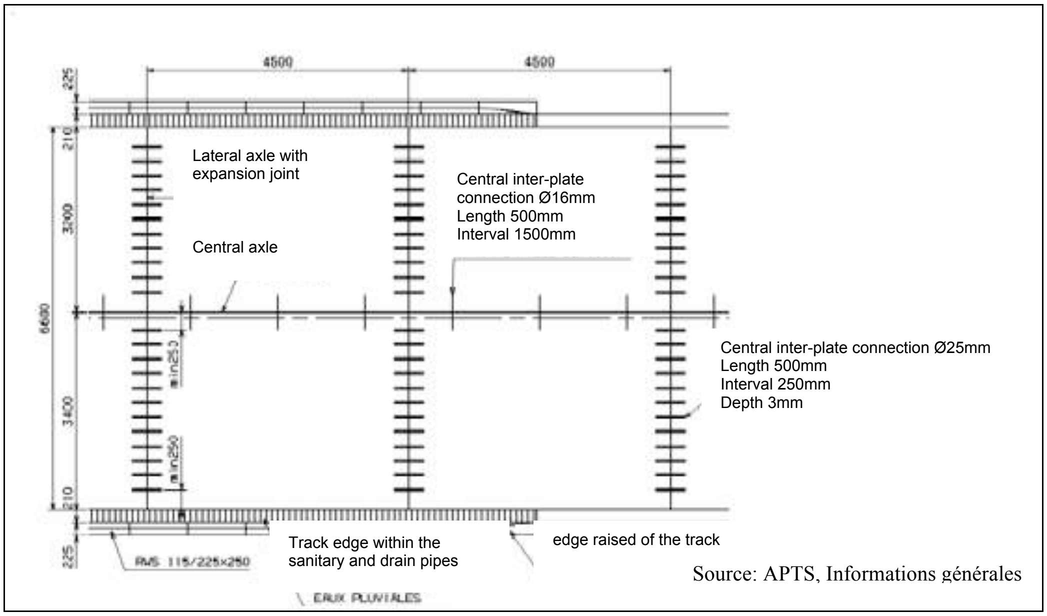


Figure 74: Elements and presentation of the running track

The intermediate distance between the magnets in the longitudinal direction shall be 4.5 m ± 1.0 m. This distance corresponds to the distance separating the centers from two adjacent plates composing along the way. **Furthermore, a minimum distance of 20 cm must be kept from ferromagnetic steel** (e.g. bridge, viaduct, etc.). The reliability, which the information redundancy offers, answers the question of safety preoccupations for the people transported as well as for the other users of the parallel roadway systems.

This dotted line constitutes the way, which follows and knows the vehicle. The information of the time-space type is available and transmitted for the SAEIV (Assistance System for the Operation and Travellers' Information).

4.1.3.3 Functional Blocks of Lane-Assistant Systems

The components needed for implementing lane-assistant and precision docking functionalities depend on the type of application and the level of interactions among drivers, vehicles, and infrastructure. The **Erreur ! Source du renvoi introuvable.** shows the functional block diagram for lane-assistant and precision docking systems. When a vehicle is operating in an open environment, sensors generate signals with noise from the background. The sensor outputs are provided to the algorithms or the processing unit for various purposes, such as diagnostics about the system state, or the determination of vehicle location, or the control command to be sent to the actuator. If equipped, a communication system can transmit and receive information from other systems (vehicles or infrastructure) to the processing unit. The information from the processing unit is then fed into a human-machine interface to alert or indicate to a driver the existing threats. Additionally, the output can be fed into actuators to control the vehicle to follow a desired trajectory. In either case, the actions taken by the actuators or the drivers will alter vehicle dynamics, which is further fed back into the loop for sensing and processing.

Signification of the different modules below:

ABS = Anti Break System
CVE = écran de dialogue PCC/conducteur intégré au tableau de bord
DCS = Driving Control System
GCS = Guidance Control System
MMI = interface SAEIV / comducteur
MMS = Magnet Measurement System
SCS = Special Communication System
TPLC = Informatique de régulation de l'entraînement des roues
VBC = gestion des télécommunications
VCS = Vehicle Control System

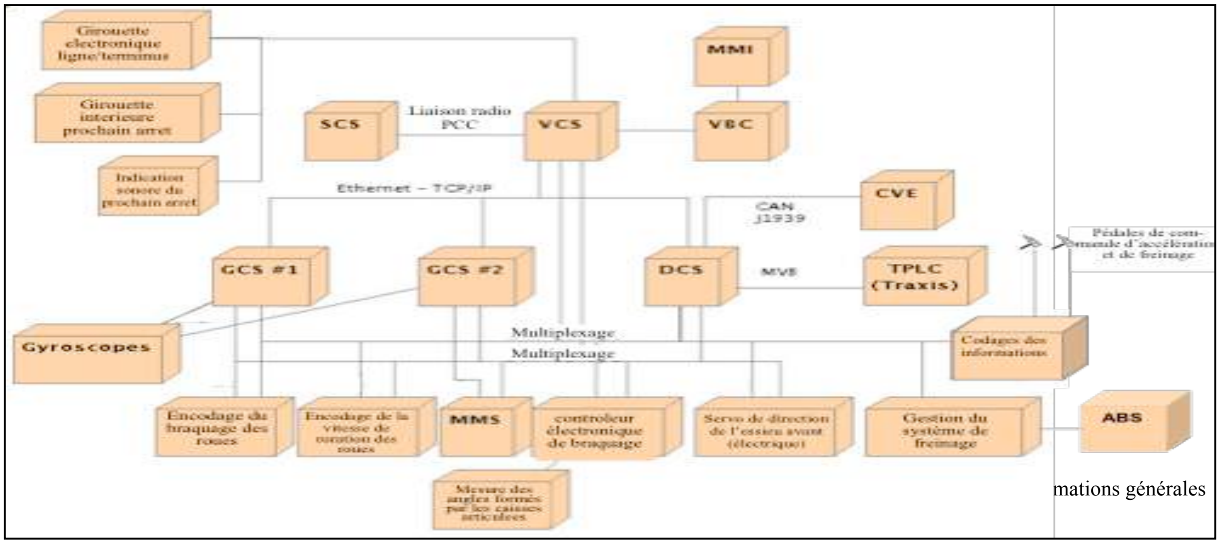


Figure 75: Functional Block Diagram of Lane Assist and Precision Docking Systems

Nota:

Girouette électronique ligne/terminus	Electronic windvane line/termanal
Giroutte interieure prochain arret	Interior windvane of next stop
Indication sonore du prochain arret	Sound indication of the next stop
Encodage du braquage des roues	Steering wheel encoding
Encodage de la vitesse de rotation des roues	Wheel rotation speed encoding
Controleur électronique de braquage	Electronic steering controller
Servo de direction de l'essieu avant(électronique)	Front axle direction Servo
Gestion du système de freinage	Break system control
Mesure des angles formés par les caisses articulées	Measuring angles formed by the articulated cases

Abstractly, in terms of information flows among sub-systems, the system contains the following types of elements:

- Information sources, such as roadway and lane markings, and vehicle motions.
- Information transmitters and receivers (transducers), such as sensors
- Information processors, such as hardware and software for signal processing
- Information representation, such as human-machine displays
- Information executors, such as actuators or operators
- Information channels, such as interfaces among various elements.

Note that both lateral and longitudinal control may exist individually or simultaneously. For example, in the lane-keeping application, drivers may still control the vehicle speed while the lane assistant system is regulating the vehicle trajectory by controlling the steering inputs. In the precision-docking mode, the lane assistant system may be under automated control without driver inputs.

4.1.3.4 Functional Decomposition

Depending on the design features and functional requirements of lane assistant and precision docking systems, there can be significant variations in the selection of sub-systems and components. For an exemplar case study of lane assistant systems, the main functioning blocks are devided into 5 blocks:

Vehicle and lane position sensing: Identifying the location of vehicle relative to the infrastructure

The actual sub-systems for this function are determined by the selection of technology. For example, a computer-vision technical approach will require a camera and image processing with clear lane markings on roadways. A magnetic marker system will require the installation of magnets on the roadways and magnetometers on the vehicles for detection and processing. An approach using global positioning systems (GPS) will demand an on-board Differential GPS unit and a geometric map of the roadway.

On-vehicle sensing and processing: data gathering and processing

The components in this category potentially consist of computers or processors, vehicle inertial navigation systems (INS), networking or communication links between sub-systems, and computations required for generating information for driver assistance or commands for controlling functions.

Actuation

If steering or speed control is part of the lane-assist application, then actuators will be needed. The actuation can be implemented electrically, hydraulically, or pneumatically.

Driver-Vehicle Interface (DVI)

The DVI is the bridge or communication channel between drivers and vehicles. It can serve multiple functions, including diagnostic, driver assistance, or actuation.

Data Communication Networking

The data communication network exchanges data among all functioning blocks and through channels of communication.

Each of the five blocks can be further decomposed by their functions.

Sensing can be separated into:

- Vehicle lateral position sensing
- Vehicle longitudinal location sensing
- Vehicle speed sensing
- Acceleration sensing
- Yaw rate sensing
- Throttle position sensing
- Brake line pressure or brake stroke sensing

Processing can be separated into:

- Vehicle position processing
- Vehicle state and fault detection processing
- Warning and display signal processing
- Acceleration command processing
- Braking command processing
- Steering command processing

DVI can be separated into:

- Monitoring, indicating the state of vehicular systems
- Signal of impeding automated functions, indicating actions or problems
- Control process
- Warning of hazardous situation
- Request for input or intervention by the driver

Actuation can be separated:

- Steering control
- Engine control
- Braking control

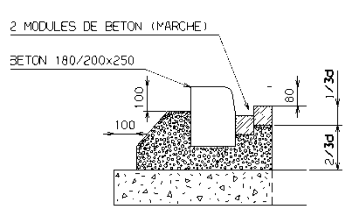
Networking can be separated into:

- Networking between sensors and processor
- Networking between processor and DVI
- Networking between processor and actuator

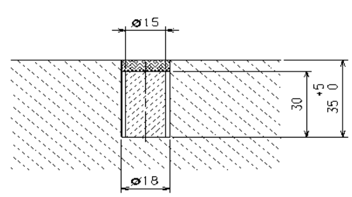
4.1.3.5 Raised platforms for stops

Precision docking makes it possible to stop with a constant minimal distance between the door thresholds and the platform edge. This requires additionally a raised platform, which is optimised for the Phileas system:

- the platforms must have a height of 30 cm above the road surface;
- the cross section of the edge of the platform shall be according to APTS specifications,
- for an articulated vehicle of 18 meters long, the minimum length of the platform is 14 meters: so for the necessary platform length we can diminish of 4 meters the length of the vehicle (18, 24 and 26 meters long)
- the stop platforms must be straight and situated directly next to the bus lane ;
- after a curve the vehicle needs a straight section of at least a vehicle length before a platform



Kerb detail



Magnet marker

Source: APTS, Informations générales

Figure 76: Kerb detail and magnet marker

Figure 77: A magnet protected by an elastomer, above the metro ticket

Light weight body

The vehicle has a modular light weight body which is 40% lighter than a conventional steel construction. The floor and roof panels are made of aluminium sandwich panels. The sidewalls are made of polyester sandwich panels.

Application of sandwich panels has a number of advantages:

- Integration of functions, such as strength and rigidity, isolation and finishing,
- Low weight, offering more payload or compensating for additional equipment,
- No corrosion,
- High flexibility of door placement and interior configuration,
- Large freedom in styling, even for small series.

The monocoque body meets the requirements for rail vehicles regarding to isolation, fire resistance and recycling. Crash tests have proved a superior resistance against side-impact accidents with passenger cars. A service life of at least 20 years is guaranteed for the Phileas vehicle body.

So we observed (cf 1rst consulting report) at once that the load of the empty rolling stock of TVR is heavy if we compare with STE4, which is 33% longer but only 10% heavier. The same for Phileas vehicle 24 meter long, its load is 19.65 metric tons. On the other hand, the TVR loads 26 metric tons, heavier (+ 32 %) for a similar capacity. The load is a real constraint for operating cost (because of the energy consumption) and for the aggressiveness on the track (thickness of layers structure).

When vehicles are carrying passengers at a normal load with 4 standees/m2, the less axle loads are on the STE4 around 7 800 kg for 5 axles and three quarters of the axles of TVR are heavier (8 500, 9 500, 9 000). Though, Phileas 24 m long has only one axle above 7 900 kg at 8 700 kg.

Empty vehicles

Vehicle empty	*Total load kg*	*Axle 1*	*Axle 2*	*Axle 3*	*Axle 4*	*Axle 5*
STE4 32 m	28 500	6600	5200	5200	4900	6600
TVR 24 m	26 000	5 531	5 758	6 032	7 680	0
Phileas 24 m	19 650	3 335	4 690	4 665	6 960	0
Phileas 18 m	15 230	3 270	5 010	6 950		

Loads on empty vehicles

Vehicles with 4 standees/m2

Systems 4p/m²	*Passenger number*	*Total load kg*	*Axle 1*	*Axle 2*	*Axle 3*	*Axle 4*	*Axle 5*
STE4 32 m	162	38 900	7900	7800	7800	7500	7900
TVR 24 m	131	33 508	6 389	8 579	9 468	9 071	
Phileas 24 m	141	29 520	4 910	7 960	7 920	8 730	
Phileas 18 m	104	22 510	4 780	9 025	8 705		

Vehicles with 6 standees/m2

Systems 6p/m²	*Passenger number*	*Total load kg*	*Axle 1*	*Axle 2*	*Axle 3*	*Axle 4*	*Axle 5*
STE4 32 m	222	42600	8400	8700	8700	8400	8400
TVR 24 m	178	36 559	6 541	9 817	10 817	9 383	
Phileas 24 m	185	31 675	5 350	8 875	8 575	8 875	
Phileas 18 m	140	24 820	5 320	10 405	9 095		

Source: Load of each axle of Phileas (APTS ed. 19/11/04), Translohr STE 4 (Lohr-Industrie ed. 26/07/04), TVR (Bombardier ed. 19/11/96)

Figure 78: Axle loads for 4 vehicules; STE4, TVR, Phileas 24 m, and 18 m

4.1.3.6 Hybrid propulsion or trolley

A GM Allison parallel hybrid propulsion system with an Euro-IV diesel engine is standard applied in the Phileas vehicle. Proven on the streets of 26 cities across North America, the GM Allison hybrid EP50 system is the world most advanced parallel hybrid for city buses. Buses equipped with this system have accumulated over 26 million kilometers in the first two years of operation. The working principle of the EP 50 hybrid propulsion system is shown in the figure below:

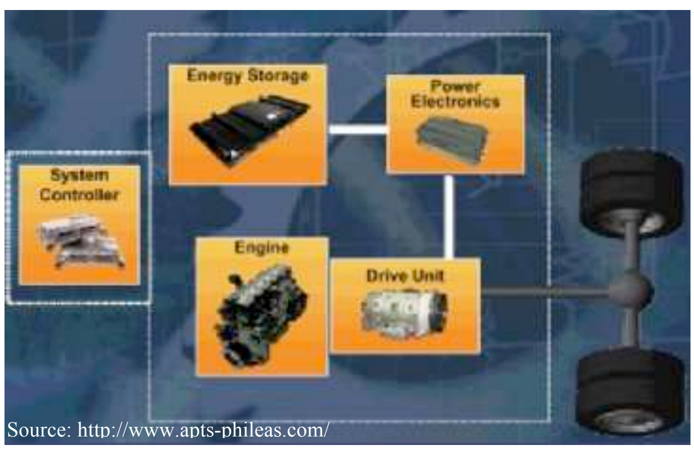


Figure 79: EP 50 hybrid propulsion

Torque from the diesel engine is combined with torque from electric motors to drive the vehicle.

Because the electric motors act as generators when the vehicle brakes, electric braking energy is regenerated and stored in the energy storage system. This is a NiMH battery. A power electronic unit is used to transform AC-power from the electric motors to DC-power for the battery. At cruising speeds the vehicle is propelled mainly with the diesel engine. By using a smaller diesel engine and operating it at its most efficient range the hybrid propulsion system reduces fuel consumption by at least 20 % in comparison with conventional buses. Also it reduces emissions and increases passenger comfort. Optionally the Phileas vehicle is also available with a trolley propulsion system from Vossloh-Kiepe.

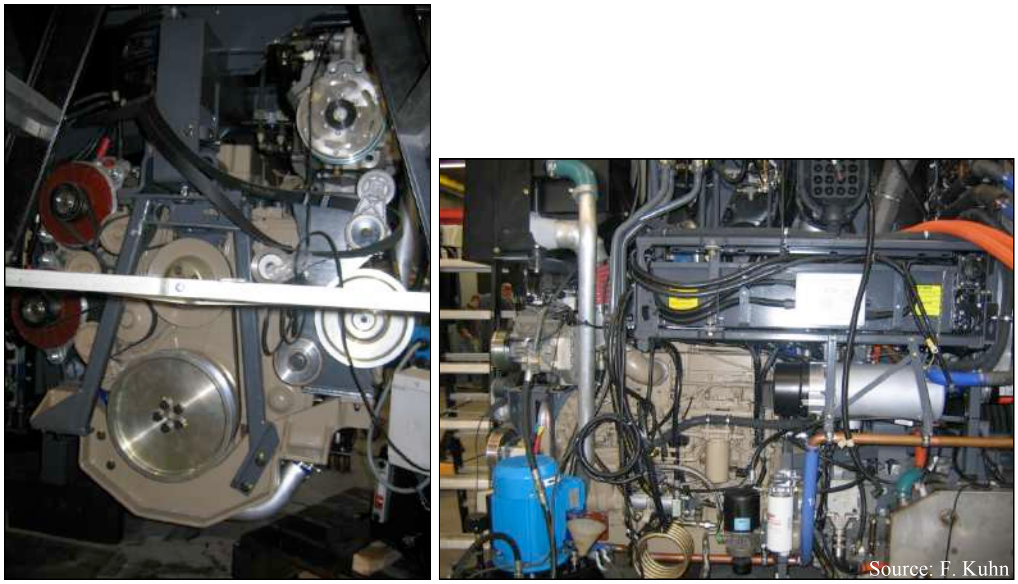
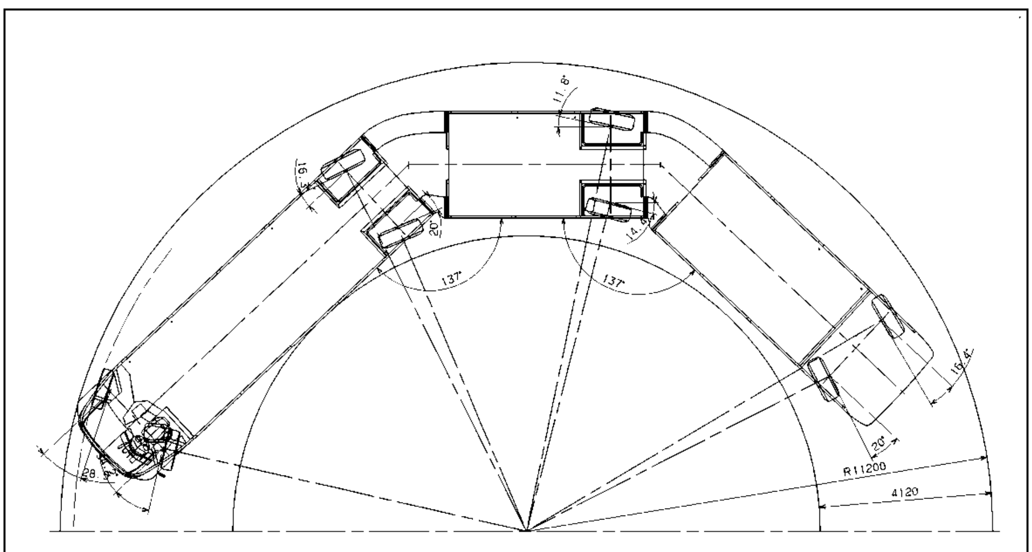


Figure 80: Views of Diesel Cumming motor at the rear of the vehicle

4.1.3.7 All-wheel steering and independent wheel suspension

The combination of all wheels steering with electronic lane assistance makes precision docking possible at each door. This is a unique feature of the Phileas vehicle. During precision docking all wheels are steering in the same direction and the vehicle is moving sideways. The turning radius of the Phileas vehicle is equal to standard buses (12 m), but the swept path in sharp bends is significantly less, only 4.5 m. Also the swing out is always small (<0.50 m).



Source: APTS, Informations générales

Figure 81: Necessary gauge and radii of Phileas double articulated vehicle

In guided mode, the front axle is steered automatically with servo motor. The set points for the servo motors are determined by the guidance system.

In manual mode, the front axle is steered by the driver with he steering wheel. The set-points for the second axle are determined by the front axle and the set-points for the other axles are determined by the articulation angle(s).

Source: APTS, Informations générales

Other radius (meter)	*Inner radius (meter)*	*Swept path (meter)*
12.00	7.76	4.24
12.50	8.33	4.17
18.00	14.37	3.63
25.00	21.69	3.31
50.00	47.08	2.92
100.00	97.27	2.73
150.00	147.33	2.67

Figure 82: Radius of Phileas vehicle

4.1.3.8 Doors at both sides with automatic side selection

The vehicle is standard equipped with power operated service doors at the right side of the vehicle. Doors are applied at the right side of the vehicle. Optionally doors can be applied at the left side of the vehicle or both sides (e.g. in Douai project). In historic cities it's not always possible to locate stops consequently at the right side of the lane. For example, by application of a central stop platform in the middle of a two-directional bus lane the required total width can be limited significantly. However, if doors are applied at both sides it must be prevented that passengers get off the vehicle at the wrong side. **In manual mode**, the driver has to select the side at which the doors shall be activated at the next stop. **In guided mode**, the guidance system knows the position of the vehicle and is used to determine the side at which the doors will be activated at the next stop.

4.1.3.9 Phileas vehicle types: product range

Figure 83: Phileas 18 m vehicle (left) and 24.5 m vehicle in Eindhoven

The Phileas vehicle types are in the table below:

Source: http://www.apts-phileas.com/

Type	*Seats*	*Standing (4 / 6 p/m²)*	*Total (4 / 6 p/m²)*
Single articulated 18.5 m	29 / 29	74 / 111	103 / 140
Double articulated 24.5 m	46 / 46	83 / 125	129 / 171
Double articulated 26.0 m	52 / 52	89 / 133	141 / 185

Figure 84: The Phileas vehicle types

4.1.3.10 Technical specifications

The technical specifications of the three types of vehicle Phileas are given in the table below:

Source: www.apts-phileas.com

PHILEAS Model	*Unit*	*Articulated*	*Bi-articulated*	*Bi-articulated*
Type		18 m	24 m	26 m
Measures				
Length	m	18.44	24.45	25.97
Width	m	2.55	2.55	2.55
Height	m	3.20	3.20	3.20
Accessibility				
Kneeling	mm	- 70	- 70	- 70
Floor-height	mm	340	340	340
Interior-height	mm	2.25	2.25	2.25
Aisle width mini	mm	755-950	755-950	755-950
Doors		Flexible (both sides) 1.20*2.00	Flexible (both sides) 1.20*2.00	Flexible (both sides) 1.20*2.00
Drivability				
Turning radius	m	12.50	12.50	12.50
Swept-path	m	4.40	4.40	4.40
Track-width (double lane)	m	6.60	6.60	6.60
Guidance (whole line)				
Principle		Magnetic	Magnetic	Magnetic
Distance gap (door-stop)	mm	50	50	50
Max speed	km/h	60	60	60
Material body		Composite/Al	Composite / Al	Composite / Al
Tyres		275/70R22.5 385/65R22.5	275/70R22.5 385/65R22.5	275/70R22.5 385/65R22.5
Seats/Disabled/ Standees		Adaptable	Adaptable	Adaptable
4p/m²		29/1/74	46/1/83	52/1/89
Total		103	129	141
6p/m²		29/1/111	46/2/125	52/1/133
Total		140	171	185
Weight				

Empty	kg	16,650	21,600	21,600
$4p/m^2$	kg	23,350	30,000	30,700
$6p/m^2$	kg	25,800	32,700	33,600
Traction		Parallel hybrid	Parallel hybrid	Parallel hybrid
Powersource				
Diesel		ok	ok	ok
Overheadwire/Trolley		ok	ok	ok
Topspeed	km/h	96	96	96
Max acceleration	m/s/s	1.4	1.4	1.4
Grade	%	> 13	> 13	> 13

Figure 85: Technical specifications of the Phileas

4.1.4 Infrastructure requirements of Phileas system

The minimum infrastructure requirements for Phileas are:

i- Free bus lanes as much as possible, with a design speed of at least 50 km/h;
ii- A minimum of curves, or curves with a design speed of at least 50 km/h;
iii- An average distance between the stops of at least 500 meters;
iv- Total priority at intersections as much as possible, controlled with traffic lights or barriers;
v- Stop platforms have an height of 30 cm, with cross-section according to APTS specifications;
vi- A magnet grid for lane assistance and precision docking over the complete length of the routes;
vii- Road surfaces made from concrete to prevent deformation and ruts.

The requirements n°1 to n°4 also apply to conventional bus rapid transport systems (BRT). The requirements n°5 to n°7 are specific for Phileas vehicules. APTS also has more detailed requirements for the minimum lane width, for vertical alignment of Phileas routes, for construction materials, for traffic calming measures and bus gates, for the magnet grid and for the Phileas stop platforms. Rails and overhead lines for electric power are not necessary, the required investments in the infrastructure are relatively low.

The single articulated vehicle meets all legal requirements for urban city buses and has unlimited access to the public road. The double articulated vehicle also meets all the legal requirements for urban city buses, except for the length. In the European Community a permanent permission is required for the double articulated vehicles for specific routes.

4.1.5 Vertical alignment of Phileas system routes

As Phileas vehicles are low floor vehicles, special attention is required for vertical alignment of the vehicles routes. Although the Phileas vehicle can drive at different heights, it normally drives with a small ground clearance of 0.18 m under the rolling stock. Only with this height a step free entrance is realized at the raised stop platforms. Due to the long distance between axles (up to 7.7 m) and the small ground clearance, the radius at the top of a bridge or hill shall be at least 50 m. Also the radius at the bottom of hills shall be at least 52.5 m. In both cases the vehicle will have to drive with 5 km/h to prevent damage. With a larger radius the vehicle will be able to drive at higher speeds. The hang over at the front and at the rear of the vehicle allows for inclination angles up to 12.5 % (1:8). In case of a climbing slope just after a descending slope a distance of at least 9 meters is required between the end of the descending slope and the beginning of the climbing slope.

4.1.6 Construction materials for dedicated lanes

Due to guided vehicles always using the same track, APTS advices to use reinforced concrete or equally stable materials for Phileas system routes. With softer materials like asphalt deformation (ruts) will occur within a few months. This will increase the maintenance costs for the infrastructure significantly. Steel reinforcements in concrete constructions may be applied if necessary. Especially the field from vertical steel reinforcements is difficult to distinguish from the magnetic field of the magnets. Vertical steel reinforcements are used in columns to support bridges and fly-overs. Therefore, the magnetic markers have to be positioned as far away as possible from vertical steel reinforcements and also from steel lids of wells (sewage). Several fly-overs have been applied which are reinforced concrete constructions in Eindhoven and Douai. The infrastructure was designed in close consultation with APTS, the reinforcements are no problem for the guidance system.

According to APTS, the magnets can be installed in all the kinds of infrastructures. If it is about reinforced concrete, APTS advises to envisage a zone of 40 x 40 cm without steels in order to put the magnet in there. If there isn't any vertical steel frame, the disturbance of the magnetic field is minimal; this kind of steel frame is used only for some civil engineering works for exemple, bridges and tunnels. Moreover, with the FROG system, it is possible to filter this influence. But the fitting of the guidance system will take a little more time in this case.

4.1.7 Phileas vehicle envelop: DKE

In the Netherlands, there exists a directive to define the width of the infrastructure for bus based on practical experiments. It recommends using a width of 3.30 m for a single way and of 7.10 m for a double way at speeds of 50 km/h. For 70 km/h, the widths become 3.50 m and 7.50 m.

In Eindhoven the width is 6.60 m for a double way, and the Phileas vehicle can roll up to 55 km/h over this way.

In the Netherlands, the automatic guidance control is regarded as "cruise control" or like extra helps for the driver. This kind of equipments is not under the control if the two proofs are confirmed: the function can be only activated by an intentional act of the driver and by the least logical action of the driver the function is deactivated. The guidance system of Eindhoven must be fail-safe and all controls are based on this aspect.

In France, the legislation being different, the Phileas system must fulfill the requirements imposed by the SRMTG: the Departmental Management of Equipment (DDE) and the BIRMTG recognized the guidance system used by APTS on February 10, 2005. It becomes apparant that the principle of guidance perhaps approved in France.

The following step in the process of homologation will examine the infrastructure in Douai and compare these data with the characteristics of the vehicle and its guidance in different speeds. This comparison will lead to critical situations on the level of safety at certain places. At these places an adaptation of the DKE or a maximum speed will be forced to minimize the risks on the level of safety: making modifications of the vehicle or the infrastructure will be possible.

4.2 Évéole: The Douai's urban transit project

The city of Douai expects an increase of 50 % in (car) trips by the year 2015. This would likely lead to (massive) congestion of the city centre and an aggrevation of parking difficulties, unless a frequent, fast and pleasant collective transport mode is implemented: a tram.

The public transport Authority of Douai Metropole, the "Syndicat Mixte des Transports du Douaisis" SMTD, studied various options and finally selected a tram on rubber tires: Phileas. This selection was based on the premise that the electronic guidance avoids the installation of expensive rail, while the concept still ensures similar quality and punctuality of travel as a tram.

Consequently, Douai, city of North of France near Valenciennes and Lille has choosen the less expensive project of tramway on tyres or BRT the Phileas system instead of Translohr or Civis systems.

A contract was signed on 7 July 2005 between APTS and SMTD from the Douai agglomeration. In Douai the Phileas project is called "Tram 2007". The contract consists of the delivery of 12 articulated vehicles 18 m long and the approval of the Phileas tram including the guidance system for the french market. The vehicle for Douai is delivered with a diesel hybrid propulsion system and with doors at both sides. The vehicles were delivered at the end of 2007 and operation was planned to start in 2008. The order for APTS involves an amount of 17 M Euros. The total costs of the project including the infrastructure are 117 M Euros. The objectives for the Tram 2007 project for Douai are:

- 18 000 passengers per day,
- Commercial speed of 23.6 km/h.

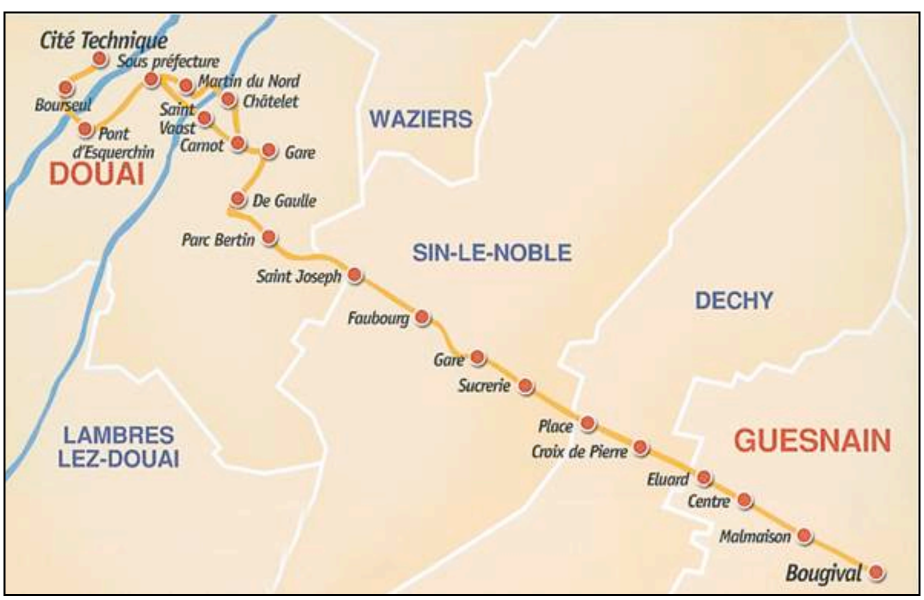


Figure 86: Line of the Phileas project in Douai

The Douai region is realizing a public transport network with dedicated infrastructure. The total length of the lines will be 34 km. The Douai project implies the first phase of this network, with a line of 12 km from Douai, via Guesnain to Lewarde. Other places near the line are Waziers, Sin Le Noble, Dechy and Lambres lez Douai. 39 stop platforms are realized along the line with an average distance between the stops of 400 meters. A number of stops are placed at the right side of each lane. Central stops between both lanes will be placed at locations with limited space at the right side. This requires a vehicle with doors at both sides.

Figure 87: Phileas articulated vehicule in the center of Douai

The area between the central train station and the Place Carnot was completely reconstructed. A single directional bus lane was applied here. Other traffic will pass the station square with a tunnel. The rest of the line is a two-directional concrete bus lane. At place Charles De Gaulle in Douai, which was also reconstructed, passengers will be able to step over to conventional buses. At the national road RN 45 the line is in the middle of the road. In the city of Sin le Noble, the line branch off from the RN 45 and use an old road and bridge, that was renovated. The terminal is in Guesnain, in a next stage the line will be extended to Masny and to Aniche.

4.2.1 Phileas line in Douai: Évéole

The layout of the Phileas is entirely in exclusive right of way, except for the crossroads at the Fleurquin quay (shared right of way) and in the section located in front of the technical city of Douai (terminals, divided road tram/drunk/cycles, pedestrians with access control on both sides of the site for the motorized vehicles).

The insertion of the roadway is done globally according to 2 types of installation:

- **Axial:** the platform of the TCSP[22] is established into the axle of the roadway system. The road traffic tooks place on separated ways with one direction to one way,
- **Lateral:** the platform is established on one side of the roads. The outlets of the transverse road or the number of the accesses for the residents are restricted to avoid

[22] TCSP: Public Transit System on seperated right of way

the intersections with the platform of the TCSP and to guarantee a good commercial speed.

However certain part of the TCSP roads is not installed near the roadways.

4.2.2 Impact of the insertion of the TCSP on circulation

The installation of an exclusive right of way on the shoulders leads to an overall reflection of the space organisation to various circulations:

- Maximum priority of the TCSP at the crossroads,
- Setting one-way traffic and reorganisation of circulations,
- Reduction of the width and speed,
- Installation of mixed traffic roads.

Within the framework of the PDU[23], traffic organizations are elaborated by taking account of the TCSP project in the related cities. These plans are thus used as a basis in the restitutions or the modifications to be made to existing circulations.

4.2.2.1 Fixed and dynamic signalling system

A specific signalling system to the TCSP is installed in each crossroads to link with the road and pedestrian traffic. On the whole line, the TCSP profits a maximum priority of right of way in crossroads. The implementation of this priority system will make it possible to reach the commercial speed of 23.6 km/h.

4.2.2.2 Traffic light of TCSP

The TCSP chosen for the project of Douai is guided throughout the commercial line in nominal mode of operation. The Phileas vehicle can be regarded as a tram. It has the signallling system R17 (signals of tram).

4.2.2.3 The TCSP detection

To obtain the priority, it is necessary to detect the arrival of the TCSP from the upstream in order to guarantee minimum necessary safety times to the other transit modes before authorizing its crossing.

The detection of the vehicles is done by selective and magnetic type of system. The TCSP is detected using a transmitter located under the car body in front of the vehicle (the codes emitted by these transmitters are different according to the circulation direction), a magnetic loop and a detector being used as receiver, located in the crossroads controller.

The maximum priority is guaranteed by an optimal and reliable knowledge of the Phileas vehicle positionning. The option selected in Douai is to put the sensors over the entire length of the exclusive right of way in order to make it possible to follow the progression of the vehicle of TCSP. The standard type of driving is demonstrated by running periods, stops at the stations, and stops before the traffic lights.

According to the configuration of the TCSP, the detection of the vehicles is realized by 2, 3 or 4 inductive loops installed in the platform:

- A loop is systematically located at the level of each station. This loop gives the arrival information in station by intensifying the information of selective detection. It also

[23] PDU Plan de Déplacement Urbain, Urban traffic plan

gives the departure information of station by reducing of passive information (metal mass).

- ➢ Another loop is systematically placed at the bottom of traffic light poles. This detection makes it possible to manage a defunct call by intensifying of the information of selective detection. It also gives the information of departure by reducing of passive detection (metal mass).
- ➢ One or two other loops "of retiming" can also be installed if necessary (for example, if the station is too far from the crossroads or if several crossroads are located between 2 stations).

4.2.3 The structure of the road

The structure of the roadway of the TCSP is a concrete pavement, which allows the fixing of the magnetic guidance sensors. It is made up of 25 cm discontinuous concrete and 24 cm lean-mixed concrete.

Cross-section

By taking into account dimensions of the vehicle and constraints related to the dynamic gauge and the fixing tolerances of the various equipment, the land required of the influence zones for the TCSP is:

- ➢ 6.60 m (separating borders of 0.25 m included) for two-ways TCSP,
- ➢ 3.25 m (separating borders of 0.25 m included) for one-way TCSP.

In curve, the envelope described by the projections of the material could require more extra widths according to the radius of curvature. These extra widths are taken into account using an integral gyration programme for each curve: the radius of curvature of the layout, the dimensioning of rolling stock as well as the operating speed.

The land required of the influence zones of the TCSP is isolated from general circulation by separators located on both sides of the platform. According to adjacent spaces at the platform, 2 types of protection of the exclusive right of way are selected. Along a sidewalk, the platform is elevated of 2 cm. Along the road, the platform is elevated of 6 cm.

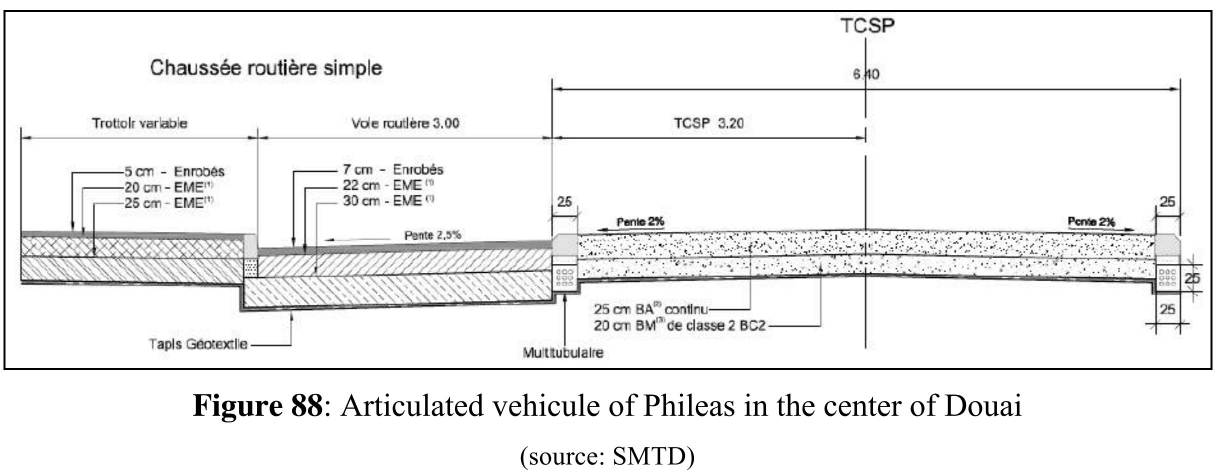


Figure 88: Articulated vehicule of Phileas in the center of Douai

(source: SMTD)

Nota: enrobés : bituminous concrete ; EME Enrobés à Module Elevé : High modulus bituminous concrete ; BA continu : continuous reinforced concrete ; BM : lean mixed concrete ;

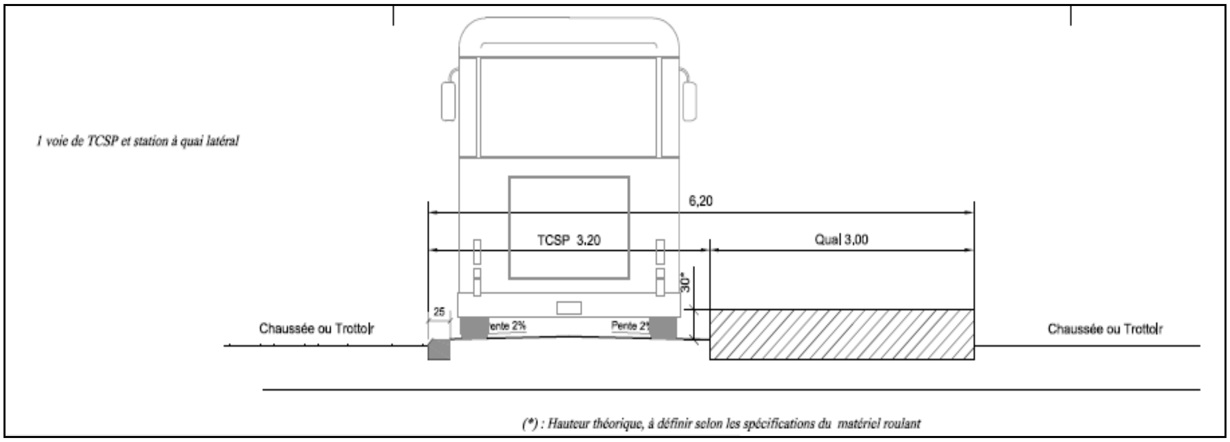


Figure 89: Vehicule of Phileas stopping along a platform station: dimensions of the track and platform

(Source: SMTD)

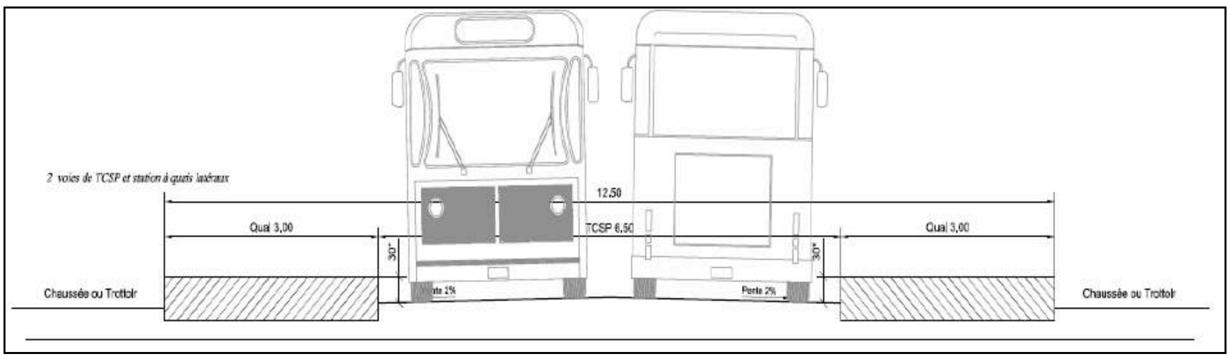


Figure 90: Section type n°9 with the right of way and the station's platforms

(Source: SMTD)

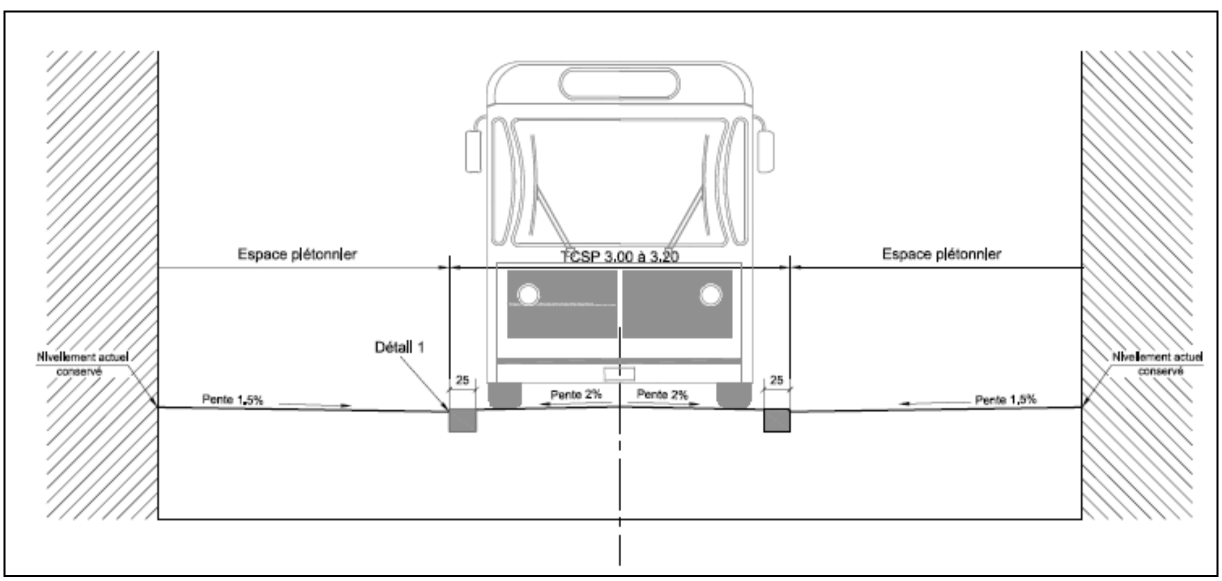


Figure 91: Section type n°8 of the transit and pedestrian right of way

(Source: SMTD)

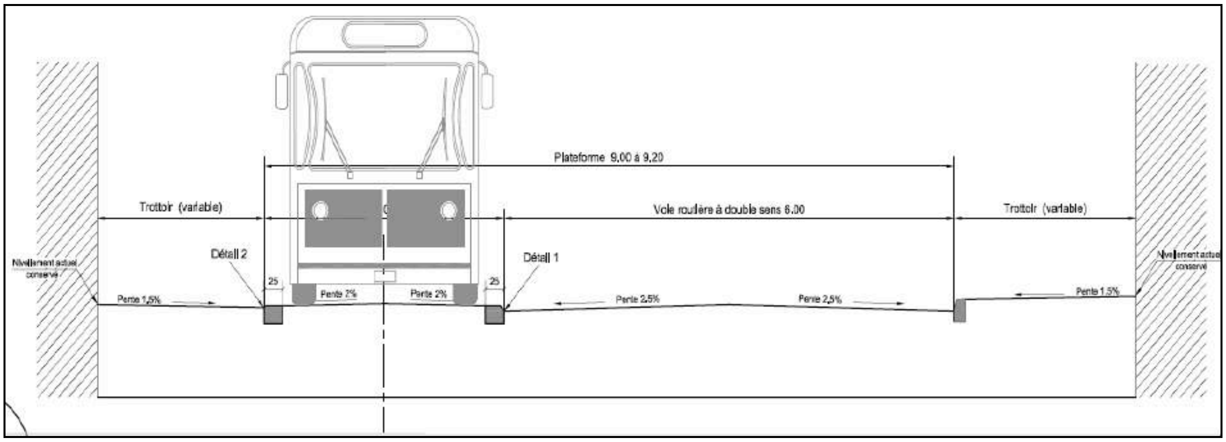


Figure 92: Section type n°6 the transit right of way and a 2 ways road

(Source: SMTD)

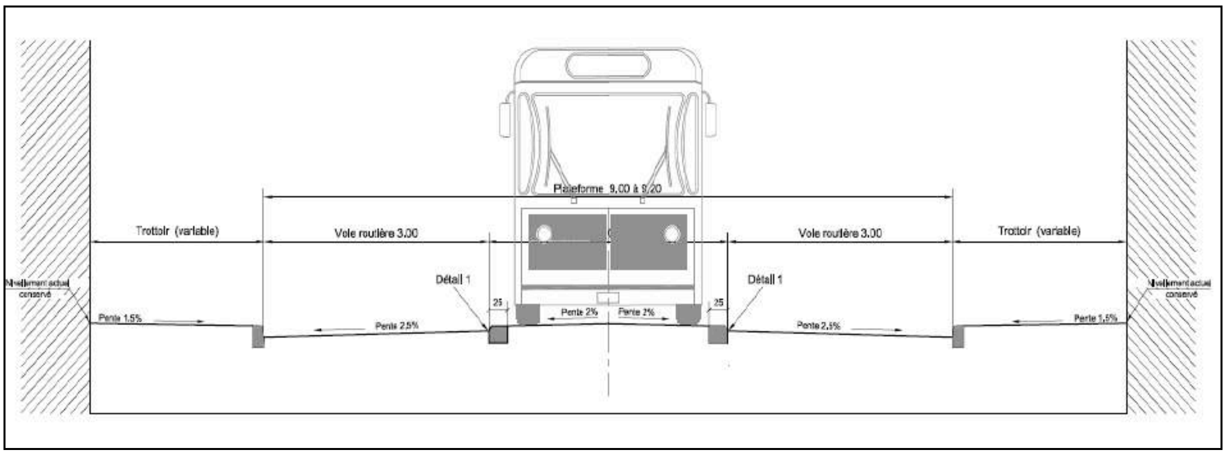


Figure 93: Section type n°5 the transit right of way and a 2 roadside lanes

(Source: SMTD)

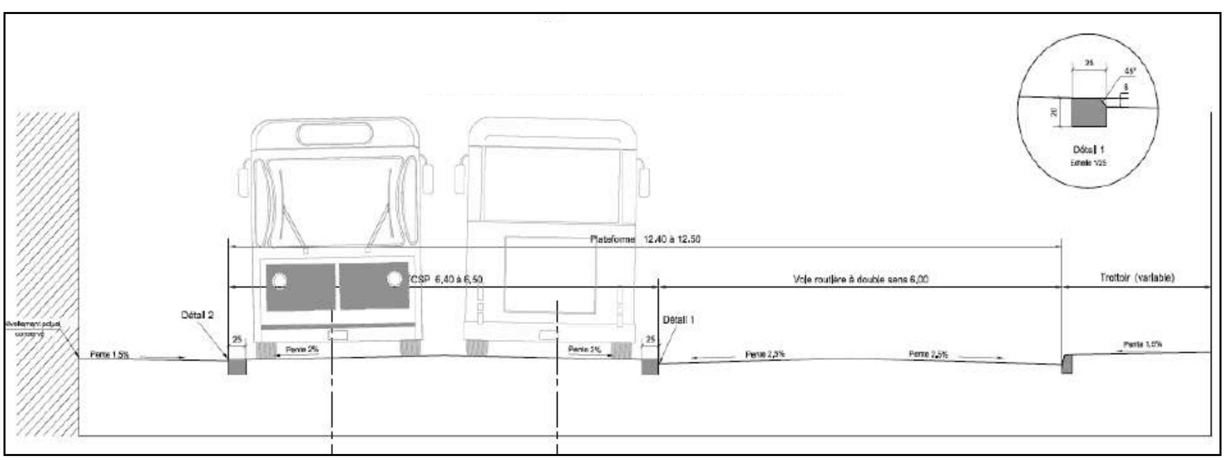


Figure 94: Section type n°4 the transit right of way and a two-way road

(Source: SMTD)

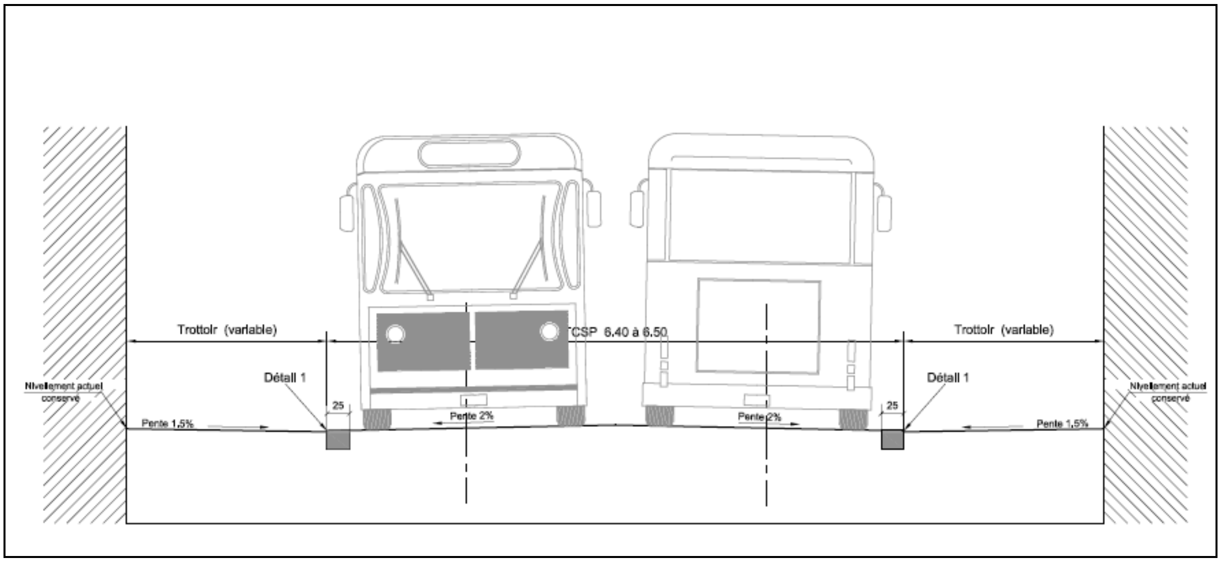


Figure 95: Section type n°3 the transit right of way and a two pedestrian's pavements

(Source: SMTD)

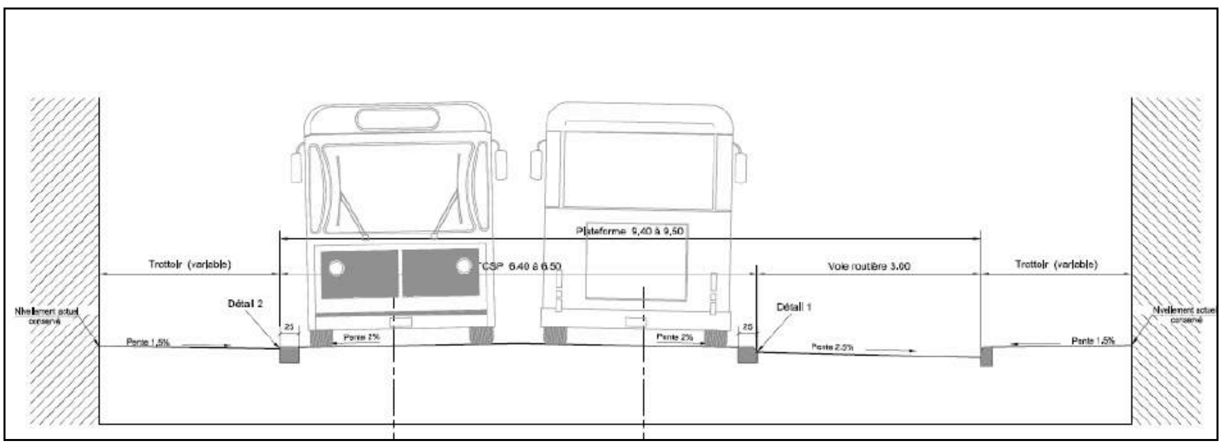


Figure 96: Section type n°2 the transit right of way and a road side lane

(Source: SMTD)

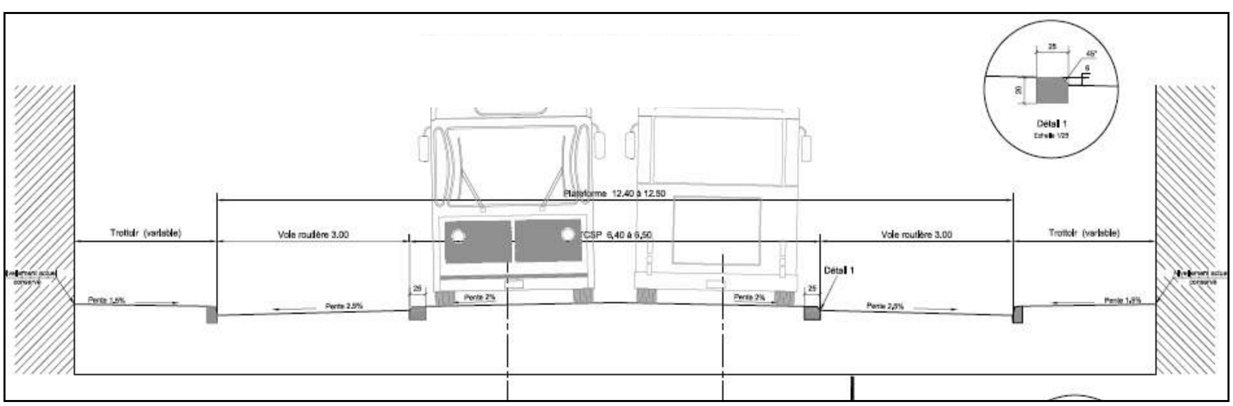


Figure 97: Section type n°1 the two-way transit right of way and two road side lanes

(Source: SMTD)

4.2.4 The rolling stock

4.2.4.1 Propulsion

The vehicle has an internal combustion engine (ICE) coupled to a generatrix.

In phase of acceleration at the starting between 0 and 16 km/h, the power and the torque are given by electromotors. In phase of acceleration between 16 and 60 km/h a mixed working is operating: internal combustion engine and electromotors,

In constant speed phase between 16 and 60 km/h, the power is given by internal combustion engine and batteries are charging equally.

4.2.4.2 Braking system

The braking system is composed of three types of brakes, which are driven to:

- guidance system : change detection of path sets and overspeed ,
- at brake pedal : like a bus, the driver can everytime brake the vehicle with the intermediate of the brake pedal,
- to the dead man's handle : vigilance device.

We consider 3 types of braking:

- Normal braking service (FNS) from 1 to 1.3 m/s2 acting on the guidance in cas of « admissible » sets (sets between 10 to 15 cm according to speed), in case of overspeed and during the station docking,
- Safety brake (FS), parameterizable linked to the guidance system of 3 m/s2 acting on the guidance in case of sets « no-admissible » (sets superior to 15 cm), in case of forced action by the driver on the steering wheel, automatic surveillance and in case of temporary door opening,
- Emergency braking (FU) between 6.2 and 7.3 m/s2 according to the standard EEG 71/320 coming from the driver action on the brake pedal.

Figure 98: Evéole vehicle

The normal braking service acts on electromotors until 1 m/s2. Beyond 1.3 m/s2, all the brakes function together on electromotors and on the pneumatic braking system.

On the other side, the vehicle also has a parking brake (FP) and a stop brake (FI).

	FNS	***FU***	***FS***	***FI***	***FP***
Empty Deceleration (m/s2)	1.1 to 1.3	> 6.2	> 3	Keeping stopped for slope < 18%	Keeping stopped for slope < 18%
Deceleration for 6 pas/m2 (m/s2)	1.1 to 1.3	> 6.2	> 3	Keeping stopped for slope < 18%	Keeping stopped for slope < 18%

Figure 99: Summary of decelerations

4.2.4.3 Fire / smoke

The Phileas vehicle is classified in the category A1 in terms of the standards NF F 16101, NF F 16102, NF F 16102, NF F 16103 and respects the attached specifications.

4.2.4.4 Sweep guard

The Phileas vehicle system having a tramway type reference owns a sweep guard: the height comparing to the riding level is superior or equal to 7cm.

4.2.4.5 Data saving

Data saving system allows us to keep during a sufficient period the informations about:

- Guidance system: variations, braking, itinary, mode change,
- safety and emergency braking,
- accomplished distances, the time, the speeds and the decelerations,
- forced actions on the steering wheel,
- release of automatic surveillance.

Figure 100: Driver's cabin and the doors of the Evéole

4.2.4.6 Wheel riding system

The entire wheel can turn and their orientation is permanently checked by the guidance system. Axles pass in the same trace (layout).

In case of a non checked axle, the guidance system releases the safety braking. In case of a tire pressure losing, the guidance system tries to maintain the vehicle on the immaterial rail as always as possible, helping the driver. In case of a flat tyre, an alarm is sent to the driver who must keep the vehicle resting.

4.2.4.7 Driver's surveillance detector

The driver's vigilance is checked when the TCSP is moving by actionning and releasing with predefined intervals of one action of the hand upon a manual command or a pedal.A sounding tone and a safety braking will be automatically released if these conditions are not respected.

4.2.5 Estimation capital cost of Douai's transit system

Items Transit system	*Capital cost in €*
General public works	53 336 171
Bridges	12 178 437
Connected arrangements	15 730 463
Operating central System	6 173 222
Total HT (value December 2002)	87 418 293

Figure 101: Estimation capital cost of Douai

(Source: SMTD, estimation projet)

The public transit sytem cost of Douai without rolling stocks is 87.42 M€(value December 2002) that is to say 87.42 x 1.22 = 106.36 M€ value 2007

Estimation of Rolling stocks 12 x 1.1 = 13.2 M € 2007

Total amount = 119.56 M€

Or 10 M€/km

4.2.6 Investigation of road certification for immaterial guidance

The Evéole project consists in:

- The line of 9 km mainly in exclusive right of way
- 21 stations(stops)
- 12 vehicles
- permanent guidance from terminal to terminal in nominal mode

The participants in the project are:

- the Transport Authority : SMTD
- manufacturers of the bus and the guidance system
- the Master of works: Ingérop / Reichen & Robert except guidance system
- the RATP for the drafting safety documents
- EOQA Certifer and Cété Méditerranée

The differences between Evéole and Phileas are:

- Guidance system
  - safety structure modified in order to adapt the security level requested by the Transit Authority
- Hardware and software equipment

  - diesel-electric parallel hybrid propulsion and not LPG-electric series
  - doors for travellers on each side of the bus and system of selection
  - addition of a device of driver surveillance
  - software versions of power supply management of the batteries treating the bugs which happened in Eindhoven.

- Safety demonstration
  - methodology developed according to the standards EN 50126, 50128 and 50129
  - security level of the guidance system, requested by the Douai's TA
- Operating: propulsion and braking ordered by the driver

The administrative procedures is been working with the explications below:

- STPG[24] decree
  - favorable opinion on the DDS[25]
  - complements of the DPS[26] before decision of completeness and technical instruction
  - strong link between the width of the Platform and the guidance system
- Road Certification
  - instruction in progress
  - 4 necessary deviations (battery main switch, cubicle with fuse, doors, numbers of spaces)

In conclusion, the selected approche is like this:

- On the project as a whole
  - work on archive projects before official sending
  - regular meeting with the TA and the participants
- On urban insertion
  - regular meeting among TA, Master of works and EOQA IU[27]
- On the guidance system
  - regular meeting with the manufacturers in the respect of the scheduling of the responsibilities : Constructors/EOQA/State (STRMTG-BIRMTG)
    - to exceed the difficulties as regards confidentiality
    - characteristics of function and the structure of guidance safety
    - expediting of the approach of general safety (APR, APD of system level)
    - expediting of the approach of safety of the guidance system (allowance of the safety levels to the safety factors, analysis of the type FMEA[28], etc)

[24] STPG :Guided Public Transit Service
[25] DDS : Safety Definition Document
[26] DPS : Preliminary Safety Document
[27] IU : Urban Insertion
[28] FMEA : Failure Mode and Effect Analysis

4.2.7 Conclusion on Douai

One of the challenges of urban development, in addition to the limited building spaces, is the excess traffic and its problems to be resolved. To rectify this situation, the promotion of public transport and the reorganisation of traffic flow, coupled with an had hoc policy of improving available sites, are the main goals of public and private partners involved in the Phileas project for high-quality public transport.

The Phileas vehicles themselves combine an ultramodern design and great comfort with:

- Accessibility
  - Accurate docking at every stops
  - same access for handicapped & valid passengers
- Increase of comfort
  - Easy access by level boarding
  - Optimization of trajectories for comfort
- Increase of safety
  - No collision between vehicles and platforms
  - Better working conditions for the drivers, higher availability of the driver to watch the environment
  - Safety gauge defined for high safety level
- Increase of average speed
  - Reduced dwell time due to easier boarding
  - No need for ramp maneuver, no ramp failure
- Better identity of the bus line
  - Enhanced image of the transportation system
  - Better respect of the dedicated lane by car users

In addition to our research, A SWOT[29] analysis made for the CIVIS system by an operator of BRT, VEOLIA TRANSPORT and a transit sytem constructor SIEMENS, and presented during Veolia Bus Rapid Transit Seminar in Rouen 19th, 2007 sums up the position of Phileas system in the range of BRT existing systems in the tables below:

Source: *VEOLIA Bus Rapid Transit Seminar Optiguide Rouen, October 19th, 2007*

Strengths	***Weaknesses***
Investment cost for a guided system	System approach implies complex marketing towards Authorities, operating companies and bus manufacturers
Flexible operation	
Ahead of competition, references and backlog	Regulatory constraints (safety)
Opportunities	***Threats***
BRT growing trend, and in particular revival of bus image (design, low emission)	**Phileas market entry with an ambitious product**
Tramway is not affordable for all cities or lines	BRT without guidance: improved design + better docking capabilities could make guidance less attractive

Figure 102: SWOT Analysis

[29] SWOT : Strengths, Weaknesses, Opportunities, Threats

4.3 The Bus rapid transit (BRT)

4.3.1 Description

The concept of a bus-lane is well-known, being an area of road space reserved for buses only by the use of paint and signs. This gives buses priority over other vehicles, leading to fewer delays. A busway includes some form of physical segregation. A BRT system might have many of the attributes of a metro; that is fixed routes (which are clearly named, e.g. 'central line', 'green line', etc.), dedicated named station/stop, a corporate image for vehicles (e.g.Transmilenio), timetables, and publicity material. Gardner & Kühn (1992)

Conceived as an integrated, well-defined system, BRT would provide for significantly faster operating speeds, greater service reliability, and increased convenience, matching the quality of rail transit when implemented in appropriate settings. The following features as bus lanes, bus streets and busways, bus signal preference and preemption, traffic management improvements, have to be included to improve bus service. Two other features as integration of transit development with land use policy and improved facilities and amenities, must be taken into account.

4.3.2 Busway performance

4.3.2.1 Capacities

The maximum line-haul passenger throughput recorded nowadays is 36,000 phd[i] on Caracas Avenue busway in Bogota, with a 2-lane each-way. The São Paulo busways also achieved a high throughput with 20,300 phd, and Assis Brasil busway, Porto Alegre, 26,100 phd. Latin american busways are well designed and operated: more basic busways in Turkey and Côte d'Ivoire carry flows in the region of 7,500 to 19,000 phd (Gardner et al. 1991).

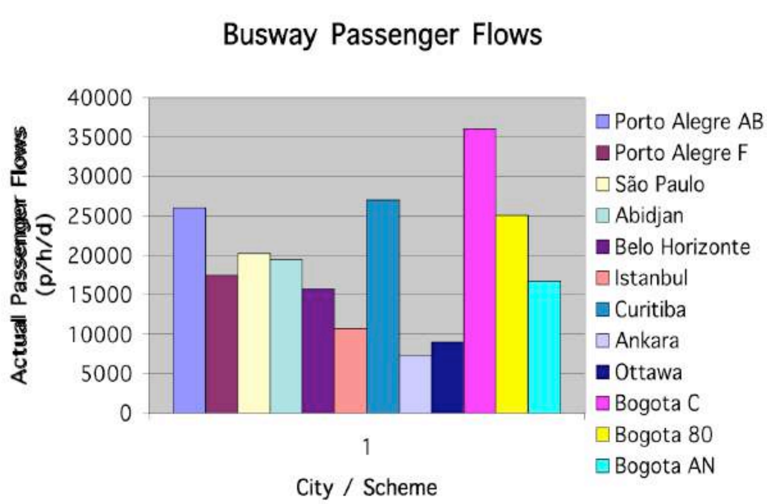


Figure 103: Busway passenger flows

Source : (Gardner et al.1991), pour Bogota (Transmilenio, 2001) Nota : For Bogota there are three busways, Avenida Caracas C, Calle 80 and Autopista Norte ; for Curitiba this is a maximum flow (TCRP, 1999)

4.3.2.2 Speeds

Average bus commercial speeds along the case study busways ranged from 12.0 to 24.6 kmph during the morning peak. (Gardner et al. 1991) Bus stop and intersection spacing, and the provision of special operating features, would appear to be the main influence on bus speeds. All bus stops surveyed which had overtaking facilities had lower overall delay times than those without. Overtaking also permits the introduction of limited-stop and express services, making overtaking bays at stops one of the most cost-effective measures to improve capacity and commercial bus speeds under normal circumstances. Nowadays, the average operating speed is 20 kmph on the Bogota, Curitiba, Porto Alegre and Quito busways, 18 kmph in São Paulo for omnibus bus services. Express bus services have an average operating speed around 30-32 kmph in Bogota and Curitiba (see Table 2 below "Performance & cost of some BRT).

The essence of BRT is that bus operating speed and reliability on arterial streets can be improved by reducing or eliminating the various types of delay. Among several types of delay we have delay due to traffic signals and due to passenger stops.

Priority treatment of buses at intersections holds the potential to reduce a significant source of delay in bus operations. Bus operating speeds may also improve if traffic signal cycles are coordinated to the time required for passenger service,i.e. the red phase occurs during the time needed for passenger boarding and fare collection. Delay due to passenger stops includes passenger boarding time, collection of fares, etc.

Boarding time can be reduced by improvement of the fare collection process, e.g. pre-payment of fares, self-service fare collection, greater use of passes, smart cards, etc. and by easing the boarding process with low-floor buses together with high platforms. Delay can also be reduced if stop spacing is increased and the number of stops are reduced. There is a trade-off between stop spacing and convenience to passengers.

4.3.3 Infrastructures

4.3.3.1 Segregated RoW[ii] (Busway)

Busways typically provide a two-way roadway in a segregated RoW designated for the exclusive use of buses. Maximum operating speeds are typically in the 70-80 km/h range. Stations are provided for passenger service. Very frequent bus service on the Transitway is accomodated by dividing the bus routes between a number of stops at each station (e.g. Avenida Caracas, Bogota). While most of the Transitway is fully segregated from other traffic, the downtown segment consists of reserved lanes on a one-way couplet. This section tends to be slow and congested.

4.3.3.2 Exclusive Reserved Lanes (Bus lanes)

Roadway lanes –either on arterial streets or freeways- reserved for the exclusive use of buses are a form of high-occupancy vehicle (HOV) lane distinguished by a highly restrictive occupancy policy. Exclusive lanes can be provided in the same direction as general traffic (concurrent flow) or in the opposite direction as a contraflow lane.

The line haul services of BRT operate on predominantly bus only track. Most busways tracks have been created by the reallocation of existing road space. The busway track itself is of normal road formation but using design standards that account for the tracking of vehicles (unlike a standard traffic lane, buses will always fllow the same path in a busway) and ensure that the road surface is well engineering to ensure a smooth ride. Busways operate best with the maximum practical segregation of buses and traffic. Segregation may be made up of islands, or kerbs or heavy weight road studs depending on available road width; a combination of segregation measures is feasible to account for the constraints in cross section likely to be encountered along a route.

4.3.3.3 Right of Way Characteristics

The standard and minimum desirable widths of lanes on which standard buses operate are, respectively, 12 and 10 ft (3.66 and 3.05) in America, 3.50 and 3.00 m in most European countries. Operation on narrower lanes is possible, but only with reduced speed and safety. Two-lane roadways for buses traveling at moderate speeds should be 7.50 m wide (e;g; Av Caracas in Bogota two-lanes per direction are 15 m wide); high-speed (freeway-type) operation exceeding 70 km/h requires a median separation or a physical divider such as a guardrail and 5.50 m width for one lane and a shoulder on each side. Station length is determined by the number of bus stopping points required (e.g. Av. Caracas 6 stops make a station 190 m long). Both diesel buses and trolleybuses can operate on extremely steep streets in areas (until 19 %) and 6 to 8 %with snow and ice.

4.3.4 Busway costs

4.3.4.1 Capital cost

Bus systems provide a versatile form of public transportation with the flexibility to serve a variety of access needs and an unlimited range of locations throughout a metropolitan area. Because buses normally travel on urban road ways, infrastructure investments needed for bus service can be implemented cost effectively along corridors where ridership may not be sufficient, or where the capital investment may not be available, to construct rail systems.

Low-cost investments in infrastructure, equipment, operational improvements, and technology can provide the foundation for Bus Rapid Transit systems that substantially upgrade bus system performance. Conceived as an integrated, well-defined system, BRT would provide for significantly faster operating speeds, greater service reliability, and increased convenience, often matching the quality of rail transit when implemented in appropriate settings.

In order to improve performance of bus services, and to cope with heavy demand along major commuter corridors, a number of intermediate and great cities (mainly in Brazil but also in Ecuador, Colombia, Turkey and Côte d'Ivoire) have introduced busways. These are segregated traffic lanes for the exclusive use of buses. Busway transit comprises a system of busways, generally using high capacity buses, with some form of management or control organisation. Various means of collecting and distributing passengers beyond the busway facility may be employed. With special operational measures, busway transit can provide a highly efficient and cost effective system of mass transit.

Source: (World Bank, 2001), (Ceneviva, 1999), (Montezuma, 2001) H.P. High Platform

Characteristics	Bogota 1°ph	Curitiba	Porto Alegre	Quito	São Paulo
Length in km	38	56	27	16.1	250
Bus Fleet	470 art.dies. Trunkal	108 biart &art.dies.	1,600 dies.	113 trolleys	11,000 dies & 600 trols
Ridership in M/day	0.8	1.3	1	0.25	3.2 *
Segregation	At grade	At grade	At grade,	At grade,	At grade
Operational Measures	T- Feeder	T-Feeder	Bus Ordering	T-Feeder	T-Feeder
Capital Cost	388	264.3	25**	137	N.A.
Capital Cost / km	10.2	4.7	1**	8.5	N.A.
Infras Cost / km	5.76	1.35	1**	3.54***	3
Vehicles Cost / km	4.45	3.37	N.A.	4.97(4)	N.A.
Max. Cap.phd	35,000	22,000	20,000	15,000	20,000
Ave. Speed kph	20-30 expr.	20 –32 expr	20	20	18
Busway Width (6) in meters	Median HP T=15	Median T=9.6	Median T=9.7	Median T = 10	Median HP* T=10

Figure 104: Performance & cost of some BRT systems

Source: US General Accounting Office, sept.2001 1-Dallas, 2-Denver, 3-Los Angeles, 4-Pittsburgh, 5-San Diego, 6-San José.

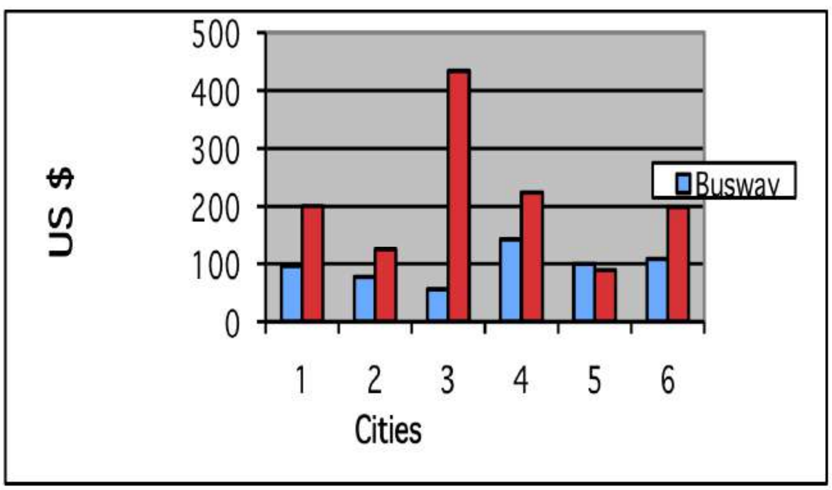


Figure 105: Capital Costs Comparison between recent LRT and BRT project in USA in M US $ per km

Nota : Cost escalated to fiscal year 2000 US$. 1 US$ (2000) = 7 FF/1.067€ . Average LRT capital costs are for 13 cities that built 18 LR lines since 1980. Busway capital costs are for nine busways built in four cities. Capital costs for buses using HOV lanes are for eight HOV facilities in five cities, and using arterial streets are for three lines in two cities.

BRT is not a single type of transit system; rather it encompasses a variety of approaches, including buses using exclusive busways or HOV[iii] lanes with other vehicles, and improving bus service on city arterial streets.

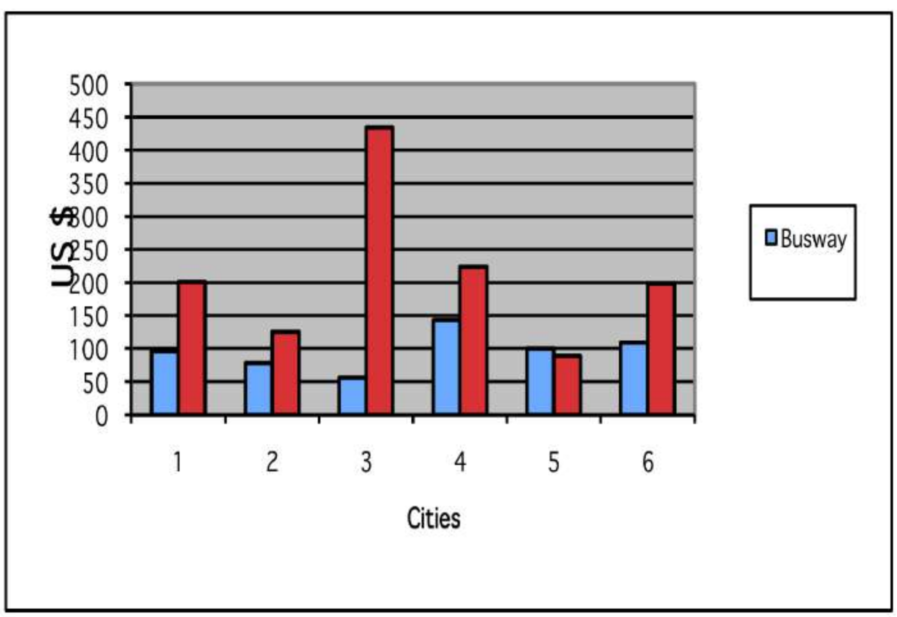
The BRT systems generally had lower capital costs per kilometer than the LRT systems in the cities reviewed by US GAO, although neither system had a clear advantage in operating costs. The capital costs for various types of BRT systems in cities like Houston,TX; Los Angeles,CA; Miami,FL; Pittsburgh,PA, for busways, Dallas TX; Denver,CO; Houston,TX; Seattle,WA; san Diego, CA, for BRT using HOV lanes and Los Angeles,CA and Orlando,FL for BRT on arterial streets, appear in figure 2. Capital costs per km decrease from 21.62 US M$ for LRT to 0.42 US M$ for BRT on arterial streets. Costs of BRT projects include the cost of the roadway busways or bus lanes, station structures, park and ride facilities, communications and improved traffic signal systems, and vehicles, if additional or special buses are needed for the project.

4.3.4.2 Operating cost

The key components of operating a transit system are labour, energy and replacement of materials. However, operating costs over the entire lifetime of a rail project can still be less than the capital costs: operating costs alone is not a good indicator of the real costs for a city.

The US GAO report, comparing the operating costs for BRT and LRT in each of the cities that operated both types of systems[iv], found mixed results. Three measures were examined : cost per vehicle revenue hour, cost per vehicle revenue km, and cost per passenger trip

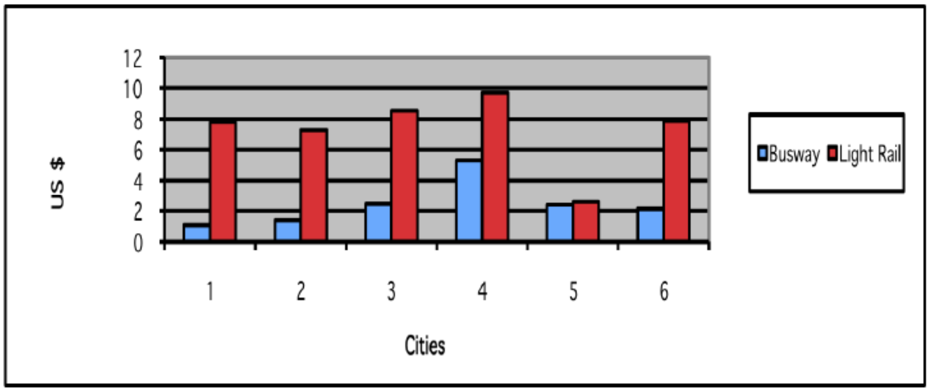
In a Figure 3 below representing operating cost per vehicle hour in 1999, BRT had lower costs in five cities and LRT in one.



Source:National Transit database and 6 transit agencies

Figure 106: Operating costs per vehicle x hour in US $ 99

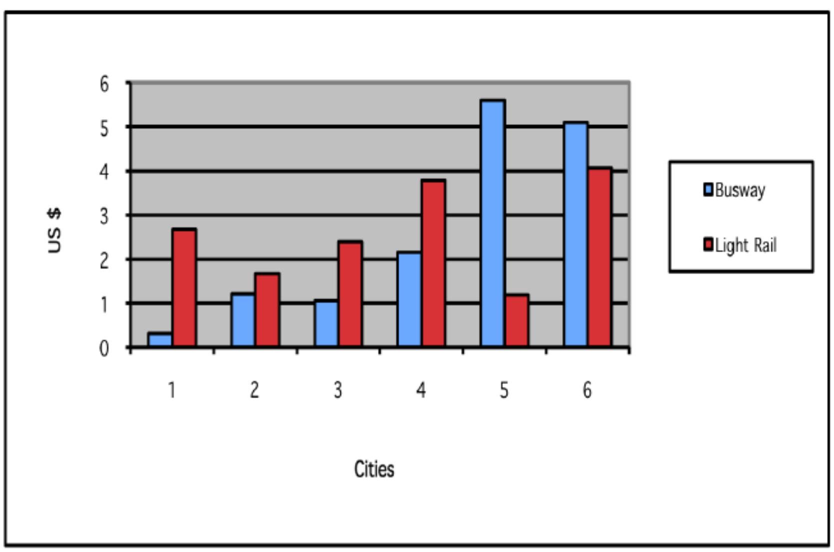
In Figure 107 below representing operating cost per vehicle revenue km in 1999, all six cities' BRT systems showed lower costs per vehicle km than LRT routes. According the GAO report and one transit expert:" BRT lines often run only during the busiest rush hour periods while LR systems typically offer all-day service, which may in part explain this result."



Source : National Transit database and 6 transit agencies

Figure 107: Operating cost of veh x km (LRT & BRT) in US $ 99

In Figure 108 below representing operating cost per unlinked passenger trip in 1999, four of six BRT routes had lower operating costs per passenger trip than did LR systems.



Source: National Transit database and 6 transit agencies

Figure 108: Operating cost per trip (LRT & BRT) in US $ 99

The wide disparities in operating costs and ridership levels are likely due to the variety of BRT and LR systems, the US GAO reviewed. The GAO report added : "For example in Los Angeles, the BRT service on the Wilshire-Whittier line has very high ridership : high ridership generally reduces the cost per rider.

In contrast, both San Diego and San Jose have lower BRT ridership, which contributes to higher costs per rider". In addition, vehicle sizes and passenger capacity can vary greatly between Light Rail and bus vehicles, which can affect vehicle-based comparisons.

4.3.5 Main characteristics of exclusive Right-of-Way

4.3.5.1 Regularity

The exclusive Right-of-Way for bus highly increases the performances of this mode of transport. The commercial speed depends only on the operation characteristics: distance between stations, duration of the stops, and performance of the rolling stock.

4.3.5.2 Capacity

We estimates that, an integral exclusive Right-of-Way and for a circulation without stop, the maximum vehicle capacity should be around 700 pcu[30]/h/d. Circulation in non-protected site implies a very strong fall of the possible traffic flow, circulation speed of around 10 km/h at the peak hours, i.e. a capacity from 100 to 150 pcu/h/d.

The observations confirm these various elements. Thus on the anti-directional reserved way on the motorway I 495 in New York without stop, we reduced the maximum traffic flows to 597 pcu/h/lane and on traditional motorway to 175 pcu/h/lane (Michigan AV, Chicago).

The unit capacity of the standard buses with 70 passengers and 160 passengers on the articulated buses (6 standees / m^2), the passengers capacity can reach of 15 000 spaces/h/lane to more than 25 000 spaces/h/lane in integral exclusive Right-of-Way without stop.

The maximum capacity of transport and the level of vehicle regularity are highly related, we must define what is the acceptable capacity in term of speed and regularity.

Two cases are to be considered:

i. If the exclusive Right-of-Way has only one lane per direction, three levels of traffic flow and three levels of service exist:
    a. with a traffic flow lower than 30 veh/h/d the crossing of the crossroads can be done with priority by the traffic signal control; regularity and speed are maximum;
    b. with a traffic flow ranging between 30 and 60 veh/h/d: the operation of circulation signal cannot give the priority any more to all the vehicles because the capacity of the cross-sections would be very reduced, but the buses still profit the regularity offered by the reserved way;
    c. with a traffic flow ranging between 60 and 120 veh/h/d, the formation of queue is unavoidable; it is necessary to envisage several stations with the stops; the stops at the crossroads and common obstruct generated by buses involve a diminution of speed and regularity: beyond 120 veh/h/d, the advantages of the exclusive Right-of-Way are extremely attenuated;

ii. If the exclusive Right-of-Way has two lanes per direction, or without stations avoiding the access and discharge tracks and having a sufficient number of stops,

[30] pcu : private car unit

we can reach much higher capacity, by 300 veh/h/d (ex: COMONOR In Sao Paulo).

The table below indicates the theoretical time capacities by direction of the exclusive Right-of-Way operated by standard, articulated buses and megabus (standard Bordeaux and Curitiba):

Bus Type	*Unit Capacity in passenger*[31]	*Excellent speed and regularity, signal priority (p/h/d)*		*Suitable speed and regularity (p/h/d)*		*Limited Case: diminished speed and regularity*	
		1 lane/d	*2 lanes/d*[32]	*1 lane/d*	*2 lanes/d*	*1 lane/d*	*2 lanes/d*
Standard	*97*	*2 910*	*7 275*	*5 820*	*14 550*	*11 640*	*29 100*
Articulated	*148*	*4 440*	*11 100*	*8 880*	*22 200*	*14 800*	*37 000*
Megabus Bordeaux	*215*	*6 450*	*16 125*	*12 900*	*25 800*	*21 500*	*43 000*
Megabus Curitiba	*270*	*8 100*	*20 250*	*16 200*	*32 400*	*27 000*	*54 000*

Figure 109: Capacity of 4 types of bus

The capacities shown above represent physical limits, which always do not answer the economic optimum and are thus then unrealistic.

4.3.6 Great capacity Bus

The great capacity bus is justified when the traffic increases and exceeds a certain threshold. The two types of vehicles of this family generally met in the world are the articulated bus (100 to 150 places) and the double deck bus. Some operators estimate, in front of the traffic increasing on some lines strongly loaded, that it is preferable to use articulated buses offering a better comfort and more easily absorbing the traffic at peak hours, without increasing waiting time at stops or stations.

4.3.6.1 Rolling stock

The vehicle is the dominant part of a bus transit system. Since the beginning of the car's era, all the attention was related to its development like means of transport. It was characterized for a long time by a high technical, operational and economic development.

[31] 8p/m^2
[32] It is two lanes per direction or one lane without stops or one lane with stations for separated lanes

4.3.6.2 Costs

a. *Investment costs*

The rolling stock

With regard to the rolling stock, we can give an approximate cost of the vehicles knowing that this cost depends on several parameters, specially the size of the series and the degree of complexity of the equipment (low floor, options, etc.).

Bus Types	*Unit cost in MF HT 94*	*Actualized cost in M€ HT 07*
Standard	1.1	0.268
Articulated	1.8	0.439
Megabus	3	0.732
Standard Trolley	2.4	0.585
Bimodal Articulated Trolley	4	0.975

Figure 110: Cost of rolling stock buses

(Source: F. Kuhn 1995, "Un système de transports collectifs : l'autobus en site propre", Séminaire sur les sites propres pour autobus à Tunis le 20 juin 1995, 19 p., catalogue des matériels roulants du CETUR.)

The infrastructure

The realization of an exclusive Right-of-Way requires reinstallations of roadway system: kerbs, separators, repair of roadway and pavements, modification of the sewage system, deviations of postal and telecommunication networks, etc., pulling up the trees and plantations, modification of luminous signalization. The cost of a project depends, first of all, on the nature of the system ('transport' project or 'urbanism' project, also of the importance of the public works. A cost-comparative analysis of BRT carried out in these last years in Montpellier, Clermont Ferrand and Dijon in France, makes it possible to give an average cost of the infrastructures:

i. The cost of the project of the exclusive Right-of-Way including its platform, coating, the roadway system of re-establishment, urban the equipment, signalization and the stations is: **2.44 M €/ km val.07**

ii. By taking account of the land acquisitions, of the network deviations, the public works and the induced works, this cost becomes: **5.61 M €/ km val.07**

iii. The infrastructures of the Trans Val-de-Marne in the Parisian suburbs had a cost of: **11.22 M €/ km val.07**

These costs reveal the diversity of the actual situations. The more important cost of the infrastructures of the TVM is due to the bridges necessary to traverse the cross-section on motorway and trunk roads.

b. *Operating costs*

The operating cost depends directly on the personal costs and the principle of amortization applied by the operator. Insofar as the use of great capacity vehicles makes it possible to reduce the relative personal cost (of 60 to 70% of the total operating cost), the importance of the transported traffic is thus in direct relationship to "the financial efficiency" of the transportation mode (3 000 to 6 000 p/h for the articulated bus in Europe). The installation of exclusive Right-of-Way improves the bus rotation speed and thus brings operating advantages.

The intentional effort for the productivity profits allowed a increasing kilometric offer almost 7% more with practically stable train crews in France in 1984 to 1988, while the other manpower dropped of more than 2.3% thanks to the diminution of external services. A commercial speed improvement allows, with the same number of drivers and rolling stocks, to increase the daily operating number without practically any financial influence except energy consumption (6.7% of the operating cost) and thus to reduce the average kilometric cost.

c. The amortization

The choice of vehicle type (standard bus or articulated bus) or transportation mode (bus, trolley bus, tram, etc.) is consistent to annual amortization cost per differentiated offered place (except the costs related to the fixed installations and the infrastructures).

The commercial speed, which determines the average running kilometer for each vehicle category, influences directly the amortization cost per offered kilometric places:

Type	*Capacity* [33]	*Estimated life cycle*	*Purchasing cost in MF 94*	*Actualized cost in M€ 07*	*Average km/year*	*Annual Amortization (in € 07)*	
						per km	*per PKO*
Standard	100	10 yrs	1.1	0.268	38 000	0.70	0.007
Articulated	150	10 yrs	1.8	0.439	38 000	1.16	0.0078
Megabus	215	10 yrs	3	0.732	38 000	1.92	0.0089
Standard Trolley	100	15 yrs	2.4	0.585	38 000	1.03	0.010
Bimodal Articulated Trolley	150	15 yrs	4	0.975	38 000	1.712	0.0114

Figure 111: Amortization

(Source:F. Kuhn 1995, « Un système de transports collectifs : l'autobus en site propre », Séminaire sur les sites propres pour autobus à Tunis le 20 juin 1995, 19 p., catalogue des matériels roulants du CETUR.)

From the obtained results on the line 7 and 8 of Bordeaux, we can note that the operating cost per km (without tax and general cost) of an articulated bus is about 30.52 F/km (F 94) 7.44 (€ 07), the cost including amortization would be 34.47 F/km 8.4 (€ 07) for 38 000 annual kilometers.

With the hypothesis that the commercial speed would pass from 13 km/h (currently on this line) to 22 km/h on an exclusive Right-of-Way (64 000 annual kilometer), the operating

[33] Capacity calculated as 8 pers/m^2

cost per km would be 20 F/km or 4.88 (€ 07)(52% profit) and the amortization 2.81 F/km 0.68 (€ 07) (69% profit), i.e. kilometric cost of articulated bus 22.81 F/Km 5.56 (€ 07) (or 53% profit).

If we always suppose, in the case of the line 7 and 8 of Bordeaux, carrying out an exclusive Right-of-Way at the average realization cost of 20 MF/km 4.87 M€, i.e. 140 MF 34 M€ for 7 km double direction route on which would be accomplished 880 000 veh x km, the investment could be returned in 14 years (1st estimation without the financial costs, etc.).

In the following table, we give the average cost noted as vehicle x km (except material amortization, but including the general costs of the companies:

Type or mode	*Operating cost veh x km F 94*	*Operating cost veh x km € 07*
Standard	20 to 26	4.87 to 6.34
Articulated	22.5 to 30	5.49 to 7.32
Megabus	25.3 to 34	6.17 to 8.29
Standard Trolley	22 to 28.6	5.37 to 6.97
Bimodal Articulated Trolley	27 to 36	6.58 to 8.78

Figure 112: Operating costs **(Source: Catalogue des Matériels Français, CETUR)**

4.3.7 Case study: the Trans Val-de-Marne TVM

In the "Schéma Directeur d'Aménagement et d'Urbanisme" (SDAU) of the Île-de-France region, the Authorities envisaged, since 1976, a regional connection of public transportation around Paris.

The Trans Val-de-Marne (TVM) is a by-pass line on exclusive Right-of-Way located at the southern east region of Île-de-France, which connects Chevilly Larue (Rungis International Market) to St-Maur des Fossés (the RER station of St-Maur Creteil) passing by the cities of Thiais, Choisy-le-Roi and Créteil, and constitutes the first realization phase of the southern by-pass linking Versailles to Marne-la-Vallée.

4.3.7.1 Targets

The objectives of the TVM are:

i. Creation of major axis of public transportation,
ii. Increasing of the public transportation activity for suburban moving,
iii. Upgrading of the network linkage easing the transfer with the radial lines (4 railway lines, 20 lines of bus).

4.3.7.2 Description of project

The TVM is 12.5 km length; it takes the trunk road N.186 on 9.5 km (whose traffic was strongly reduced by the realization of motorway A86) and the common roadway on 3 km. The TVM consists in 23 stations separated by around 600 m having a platform 40 m length (up to 21 cm more) and from 2.5 to 3 m width, equipped of urban specific fittings.

The table below summarized the installations with the percentage of exclusive bus Right-of-way, i.e. 80.4% of the service line.

Station	*Type of site*	*Line*	*Total %*	*Remarks*
Rungis	banal	800 m	6.4 %	6 bus lines with transfer
Porte de Thiais à Alouettes	Lateral RoW	2 100 m	16.8 %	No near inhabitants
Pont d' Espagne	Reserved for TVM			A86 and N186
Viaduc des Alouettes				lamb jumping
Victor Basch - Pompadour	Axial RoW	5 700 m	45.6%	width 6.5 to 7 m
Viaduc Pompadour		253 m	2 %	width 10.24 m with 8 piles, 2 walls
Pompadour-Créteil University	Axial RoW with central TP	14 00 m	11.2 %	viaduct piles of RN 186
Eglise de Créteil - Pt de Créteil	Banal site and RoW near the cross section	1 650 m	13.2 %	trees and parking
Pt de Créteil - St Maur Créteil	Axial RoW with central TP	600 m	4.8 %	

Figure 113: Service lines

(F. Kuhn 1995, « Un système de transports collectifs: l'autobus en site propre », Séminaire sur les sites propres pour autobus à Tunis le 20 juin 1995, 19 p., catalogue des matériels roulants du CETUR.)

The investment represents 580 MF val.Jan.94 or with actualization of 4% per year 141.5 (M€ 07) for the infrastructures whose financing was ensured by the government for 50% and the region for 50%. For the rolling stock, it costs 33 MF, 8 M (€ 07) financed by the RATP.

4.3.7.3 Operation

a. *Offer*

The operating of the TVM requires 19 articulated buses in service, of unit capacity 101 places (4p/m^2) including 47 seating places. The service range is from 5 a.m. to midnight with intervals of 5 minutes at the peak hours and 10 minutes at the off-peak hours. The two major advantages of the TVM are its speed and its regularity; in addition, a special effort was made out for the traveler information. For this, an operation helping system and traveler information system (SAEIV) were set up.

b. Speed

It was shown that 80.4 % of the itinerary is in exclusive Right-of-Way, in the International Market of Rungis, and that it doesn't exist the problem of traffic and the crossing of Créteil having the partial installations for a experimental period. To amplify the effect of Right-of-Way, the buses profit on their course the successive green light stalled on the theoretical progression of the buses (table of walk). The traffic flows of the RN 186 are also regulated on this green light. Finally, the SAE of TVM is connected to the centralized light command system of the Department of the Marne-la-Vallée (PARCIVAL). According to the position of bus compared to the table of walk, a priority request to the central computer can be required and granted by green time lengthening, or reduction of the red light time on the line, if general traffic is favourable. The average speed is 22 km/h for an average 600 m long interstation.

c. Regularity

Thanks to the knowledge of real time position of the bus and vehicle load estimation, the conroller can optimize the regularity and punctuality on bringing out correct measurements to theoretical time (suppression or addition of a service, modification of a mission, permutation of the buses, introduction of derives on total path). The drivers are informed about the measurements in the form of a desirable passage hour at the next point of regulation, showing on their desk and about bus before and after localization.

d. Interesting points of the project

The TVM serves 57 000 inhabitants and 30 000 employments located at less than 500 m of a station. The daily traffic is 43 000 p/day with a traffic flow 1 600 p/h/d at the peak hours the annual traffic is 11.7 million passengers. The time saving on a way is evaluated to 16 minutes, i.e. 1.2 million hours saved by the entire users. Compared to the traffic of line 392 which significantly took the same way, the TVM has its traffic 25% more in the weekdays and 90% on Sunday.

4.3.8 Operating Cost of bus networks in Nantes and Rouen

A synthetic calculation of operating cost had to be made during the assessment of Tunis metro for the World Bank in 2000.

Year 1998	***Nantes 98 Francs***	***Nantes (actualised €07)***	***Rouen 98 Francs***	***Rouen (actualised €07)***
Operating expenses	382 575 x 10^3		313 745 x 10^3	
For Tramway	86 100 x 10^3		37 604 x 10^3	
For Bus	296 475 x 10^3		276 141 x 10^3	
Total OSK[34]	2 001 133 x 10^3		1 416 535 x 10^3	

[34] OSK Offered Spaces Kilometer

OSK Tramway	619 815 x 10^3		248 000 x 10^3	
OSK Bus	1 381 318 x 10^3		1 168 535 x 10^3	
Total veh x km	18 940 x 10^3		12 668 x 10^3	
Train x km Tramway	2 626 x 10^3		1 430 x 10^3	
Vehicle x km Bus	16 314 x 10^3		11 238 x 10^3	
Tram x km cost	32.78 F	7.09	26.29 F	5.69
OSK Tram cost	0.139 F	0.03	0.152 F	0.033
Bus x km cost	18.17 F	**3.93**	24.57 F	**5.32**
OSK Bus cost	0.215	**0.046**	0.236 F	**0.051**

Figure 114[35]: Bus km and offered spaces kilometer, bus of Nantes and Rouen in the year 98 actualized for 2007

The bus x km cost, which appears in the table 24 above, is for Nantes 3.93 € and for Rouen 5.32 €: this cost is a mean between standard buses (75%) and articulated buses (25%).

We can compute the mean cost of bus x km cost in Nantes and Rouen knowing that there are 75% of standard buses and 25% of articulated buses. In the table 22 Operating costs the bus x km cost of a standard bus is comprise between 4.87 and 6.34 €, those of an articulated bus is comprised between 5.49 € and 7.32 €.

After calculation the cost of the mean bus x km of Nantes seems to be located between: 5.02 to 6.58 €.

The association of French Public Transit Authorities GART in its report "Quand le tramway sort de la Ville" gives the cost of the vehicle x km of 17 Francs val. 97:

Year 1997	*Cost val. 97 in F*	*% Cost*	*Cost val. 07 in €*
- Energy traction	1	5.88	0.226
- Driving	10	58.86	2.26
- Regulation, control	For the record		
Rolling stocks maintenance	2	11.76	0.45
Equipments maintenance	1.5	8.8	0.334
Overheads & miscellaneous expenses	2.5	14.7	0.56
Bus x km cost	17	100	3.83

Figure 115: Actualization with a present value factor of 4% per year (148%)
(Source: GART in the report "Quand le tramway sort de la Ville", 1998.)

[35] Nota : With a present value factor of 4 % per year (142%); in Rouen the bus fleet is 25 % of articulated buses. In Nantes the bus fleet is also 25 % of articulated buses. Source : F. Kuhn & Al, "Evaluation a posteriori du Métro léger de Tunis", report for WB, 2000. Et Annuaire statistique 1999, DTT & CERTU.

4.4 Summary

One of the advantages of bus with respect to the other modes of public transportation is to be able to use the urban roadway system with the other vehicles, i.e. a very great flexibility of utilization, but it generates more and more traffic jam.

This traffic jam decays the bus operating conditions and can generates three policies:

i. To give up its public transportation by limiting the financial importance, that is with saving by reducing the service,
ii. To act fully on the circulation of the private cars in order to make the traffic fluid by limiting the parking possibilities in the center of the cities (ex: Basle and Zürich),
iii. To try to withdraw bus from the risks of circulation by giving him a privileged utilization in a part of the road, by reserving the lanes for him on a separate right of way.

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Caractéristique	Autobus standard ou articulé	Trolleybus Cristalis standard ou articulé	Phileas	CIVIS	TVR	Translohr	Tramway
Fiabilité	forte	forte	A confirmer	moyenne	A confirmer	A confirmer	forte
Système de guidage	aucun	aucun	magnétique	optique (en station)	Rail central	Rail central	Rails
Longueur du véhicule	12 m ou 18 m	12 ou 18 m	18 ou 24 m	18.5 m	24.5 m	25 à 39 m	20 à 50 m
Largeur du véhicule	2.50 à 2.55 m	2.55 m	2.54 m	2.55 m	2.50 m	2.20 m	2.30 à 2.65 m
Charge max à l'essieu en charge normale	13 t	-	< autobus articulé	13 t	11.7 t	7.2 t	9 t
Type de traction	Thermique	Bi-mode electr. thermique	Hybride	Thermique ou électrique	Bi-mode electr. (750V)-thermique	Electr.750 V	Electr.750 V
Vitesse maximale	65 – 90 km/h	80 km/h	80 km/h	80 km/h	70 km/h - 55 km/h en guidé	70 km/h	70 km/h
Plancher bas	oui	oui	Oui	oui	oui	oui	oui
Confort voyageur (bruit, vibration, accostage)	Faible	Moyen	Moyen	Moyen	Bon	Bon	Bon
Nombre total de places (4p/m²)	80 ou 120	70 ou 100	90 ou 120	110	150	120 à 200	100 à 350
Gamme de trafic correspondante (en voyageur / sens / heure)	< 2500	< 2500	< 2500	< 2500	2000 à 3500	2000 à 4000	3000 à 7000
Infrastructures							
Véhicule Monotrace	non	non	Oui	non	oui en guidé	oui	oui
Emprise en section courante	6.50 (20 km/h) à 7.50m	6.50 à 7.50 m	6.60 à 7 m	6.70 (20 km/h) à 7.30 m	6.20 m[1]	5.40 m[1]	5.60 à 6.30 m[1] selon la largeur
Emprise en courbe de 25 m	> 9 m	> 9 m	> 8 m	> 9 m	6.8 m guidé, > 9 m sinon	6.1 m	6.9 à 7.7 m
Rayon minimum en tracé	11 à 12 m	11 à 12 m	12 m	12 m en non guidé 25 m en guidé	12 m	10.5 m	25 m
Pente maximum	13 %	13 %	12 %	13 %	13 %	13 %	6-8 %
Choix de revêtement	limité	limité	Limité	limité	limité	assez limité	varié
Coûts							
Investissement total moyen au km	4 à 8 M€	4 à 10M€	Non connu	~ 8 M€	15 M€	20 M€	20 M€ (25 à Bordeaux)
Prix d'un véhicule	0.2 à 0.3 M€	0.5 à 0.8 M€	1.1 à 1.4 M€	0.8 à 1 M€	1.9 M€	2.35 M€ (STE4)	1.7 à 2.5 M€
Prix d'un véhicule ramené à la place	2 500 €	7 500 €	10 000 €	7 000 €	12 500 €	14 500 €	9000 €
Coût d'exploitation au km parcouru	3 €	3.1 à 3.6 €	> bus	> bus	6.5 €	= tramway	6 €

[1] Hors poteaux caténaires

Source: Systra, EREA Août 2004 in Etude de faisabilité des extensions du réseau communautaire de TCSP à Bordeaux

5. The choice of new surface transit system

5.1 Different systems in the race

We present elements to choose a transit system being able to equip a 3rd stage of "TCSP" Public Transport on Separate Right of Way of a French middle size city, Bordeaux: the first and second stages of TCSP are operated with a standard tramway.
We take into account:

- the road no guided systems like Bus and trolleybus,
- the intangible guided systems on tyres like Civis and Phileas,
- the material guided systems on tyres like TVR and Translohr,
- the standard tramway.

For each identified line and inside each corridor, the choice of the transit system must constitute the outcome of a reflection taking into account various parameters, among which the potential of the waited for frequentation, insertion's constraints and the costs. The frequentation will be a decisive element of the system's choice.
At the same time as this reflection, an essential question will be to know what transit systems could be really considered, taking into account the position of the market and the technological risks of "innovating" systems located between bus systems and classic tramway, but also and above all taking into account the existence of the classic tramway in the first and second stages of the metropolitan urban transit network.

5.2 The classic tramway on rail

5.2.1 Main characteristics

The tramway is operated in Bordeaux metropolitan area on 3 main lines: it is the Citadis of Alstom with 2 models (33 and 43 m).

Modern tramways satisfy the following functions: safety, comfort, and accessibility to all, transit capacity, while giving a reassuring and innovative image. Manufacturers have developed ranges of products designed on the assembly of basic modules making up a vehicle and in this way offer modularity allowing us to adapt each offer to the specific needs of built up areas.

5.2.2 Guidance system

The guidance system of classic tramways is based on the wheel-rail contact which has the advantage to limit the level of strength necessary to movement's transmission (frictions very weak) and as a drawback laying a limited grip in the transmission of this strength.

5.2.3 Rolling Stocks

The characteristics of rolling stocks operated on the line A, B and C of the Bordeaux's network are given below:

	Citadis 30 m	**Citadis 40 m**
Traction Guidance type	Electrical – 750 V Rails for rolling	
Number of bodies	3	5
Length	32,9m	44m
Width	2.4	
Higth	3.27	
Floor Level/rail rolling level	0.32	
Maximum speed	70 km/h	
Acceleration	1.3 m/s^2	
Deceleration	1.3 m/s^2	
Emergency brake	3 m/s^2	
Bidirectional	Yes	
Life duration	30 years	
Multi unit possibility	Yes	
Total number of spaces (4sp/ m^2) within seats	220 48	300 70
Flow per hour with an headway of 4 minutes (each direction) (4sp/ m^2)	3300	4500

Figure 116: Tramways in Bordeaux

Generally, minimum width proposed by different constructors of tramways is around 2.30 meters, other standard width being 2.40, 2.50 and 2.65 meters.
Urban tramway market development led manufacturers to study vehicles whose general concept is based on the following principles: low floor with multiple articulations, modular design, customization possibility, and evolving transit capacity. This last can indeed be increased during the vehicle's life without diminishing performances.
Accessibility is an aspect, which has much evolved these last years, for the tramways of new generation. To answer to the new regulations linked to the persons with a reduced mobility, the height of access threshold were lowered, the gap between platform and the door's threshold were reduced and we can obtain gap values of 32 mm in vertical and 25 mm in horizontal.
The tramway rolling stocks are designed for 30 years life duration, duration that can be increased easily with renovation's operation and technical level reconditioning.

5.2.4 Separate right of way, Track, and surface processing

The right of way consists of rails with laying adapted to the site, pipes and a specific surface covering to take into account the rails and the tramway traffic. Possibilities of covering are wide (grass, paving stones, asphalt, ballast, concrete...).

5.2.5 Energy supply

- Classical supply by OCW:
    - Energy supply is made classically with sub-stations dispatched along the line and the overhead contact wire hung at 6.2 meters high. In this case, the current return carries out by the rails. The overhead line is brought by cross hanging equipment, either fixed to box hooks sealed to façade buildings either to central or side poles integrated to the right of way.
- Supply from the ground SFG:
    - In Bordeaux, an innovative system of energy supply from the ground has been built on some sections of tramway lines (10 km on 1st stage), 3km on a 2nd stage. Developed by Innorail, this system allows to the tramway to be free of an overhead contact wire and its poles, reducing so the width of the separate right of way and a notable interest for passing through a bridge.
- Two systems comparison:
    - The same performances of the vehicles are obtained from energy supply coming from either the overhead contact wire either the supply from the ground. The real advantage of the supply from the ground in front of the overhead contact wire is the energy supply has no more need of structures as poles and overhead wires on the tramway's right of way. On the other hand, its cost is three times higher than, those of the OCW.

5.2.6 Insertion's technical characteristics

The classical tramway is a system entirely mono – track. The right of way for a double track on a straight alignment depends on the vehicle's width, of the existing or no and the catenaries' poles.
For example, in straight alignment, without catenaries' poles, the width of the right of way is for double track:

- 5.80 meters for a 2.40 meters wide vehicle, (i.e. Bordeaux's network),
- 6.30 meters for a 2.65 meters wide vehicle, (i.e. Montpellier's network).

With central catenaries' poles, these widths are increased of 0.40 meter.
In a curve, the width of the right of way increases. This one's depends on the architecture or the rolling stocks (bogies and articulations between the bodies arrangement). For a 25 meters curve, the right of way can vary between 6.90 and 7.70 meters for a 2.40 meters wide vehicle.
25 meters curves could be accepted but it is not recommended to adopt it, in reason of the low speed (but possible to lower the noise and the strengths).
The slope theoretically acceptable is 8%, but generally it is admitted to not go over 6%.

RoW in a curve of 90° between two streets of 11 m wide	Right of way in current section

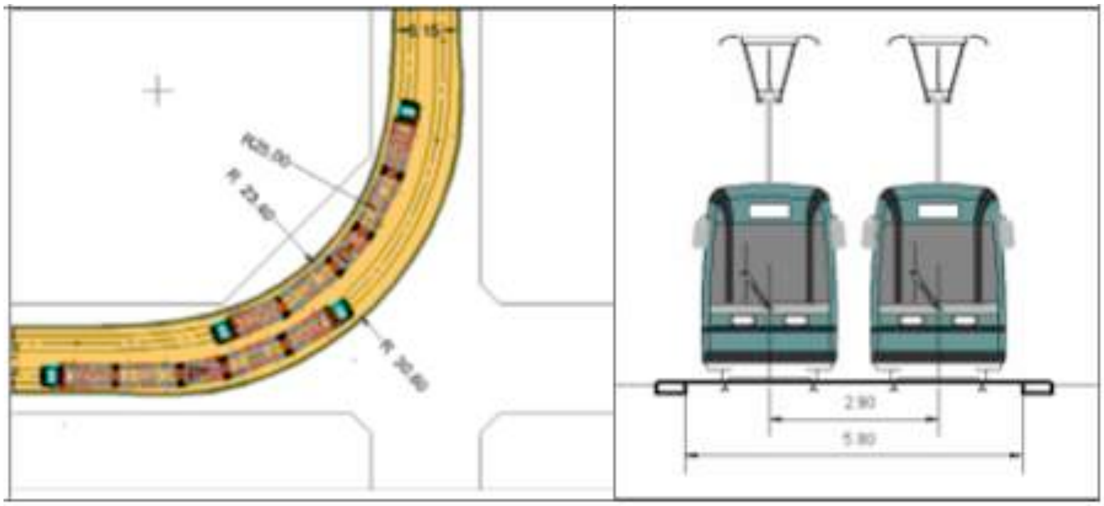

Figure 117: Insertion characteristics of tramway

(Source: SYSTRA, EREA, LACUB, Presentation des systèmes de transport Rapport annexe – Etape 2 Août 2004)

5.2.7 Reliability and technological risks

The development of tramway's range by manufacturers and their maturity's levels reduce considerably the risks linked to the choice of this type of rolling stocks.
Several technologies of track layings from now on are available and well under control. It is the same for the energy supply with overhead contact wires and with supply from the ground.

5.2.8 Investment and operating costs

5.2.8.1 Investment costs

The mean investment cost of several French projects is established and appears in the figure below. These investment costs are in a range of 20 to 30 M Euros per km.
This cost consist of rolling stocks, real state, pipes deviations, infrastructure (road modification, right of way, station and signaling equipments, involved equipments) stations and operating technical buildings, specific tramway equipments (tracks, overhead contact wires, energy, operating equipments) works of art, accompanying projects (car parks, transfer centers, urban development) workshops and expenses of master of work and consultancy.
Unit costs of the fixed part of the right of way (out of punctual posts like rolling stocks, land purchases, works of art, accompanying projects, workshops, expenses of consultancy and master of works) are around of 10 to 15 M Euros per km.
Concerning the rolling stocks, its cost depends on the length of vehicles and of supply manner (catenaries or from the ground). It is comprised between 1.7 and 2.5 M Euros (val. 2003). For Bordeaux, Citadis vehicle were bought for 1.9 M Euros for the 32 m long vehicle and 2.5 M Euros for the 44 meters long vehicle (value 2003) to which must be added the cost of 0.1 M Euros to each vehicle for the loaded equipments linked to the energy supply from the ground.

5.2.8.2 Operating costs

On French networks, operating costs are generally around 6 Euros par vehicle km. This cost includes expenses of preventive and curative maintenance (rolling stocks and infrastructures), staff expenses for operation, maintenance and energy's consuming.

5.2.9 Relevant field

Several French cities have adopted after year 1985 the new modern tramway to structure and stimulate their transit network.

Taking into account their cost and their capacity, tramways are generally retained:

- By important size's cities, generally bigger than 300,000 inhabitants and for a range of 3000 to 7000 passengers per hour and per direction at the peak hour.
- By cities of more one million inhabitants to complete their loud metro or automatic light metro VAL network: Ile de France T1, T2, T3, etc., Lille with Mongy's tramway, Lyon T1, T2, T3, etc.

5.3 Systems with a material guidance

These systems called generally intermediate systems in front of buses or trolleybuses and the classical tramway: Translohr of Lohr – Industry and TVR of Bombardier are in this case. The TVR is operated in Nancy and Caen. The Translohr is operated Italy (Padoue, L'Aquila and soon in Venise in Italy, in Clermont Ferrand in France and in some years in Ile de France (Châtillon–Velizy, St Denis - Sarcelles, etc.).

Translohr and TVR are two vehicles on tyres, they present more flexibility for urban insertion than the classic tramway from the point of view acceptable slopes and curves more higher. Compared with bus, they are guided by one central rail fixed on the track and possess a good image with a look near of the tramway.

5.3.1 Translohr

Like the French standard tramway (TFS of Grenoble, Rouen and Bobigny T1), the Translohr is a permanently guided vehicle with electric motorization. It belongs to the family of tramway on tyres. Initially, Translohr vehicle was conceived to run on a road or guided way, but the manufacturer decided to develop only a permanent guided tramway for public operation. Then the vehicle is no more obliged to stay under the rules of the road as it is on a separate right of way along the streets: its length is no more limited to 25 meters long and vehicles are bidirectional.

Figure 118: Translohr

5.3.2 TVR

The TVR is a bimodal vehicle, which can run on the road (with an autonomous mode without is guidance equipment) and can be operated as a guided tramway on tyres on a separate right of way. The TVR has a road conception; it is only 24.5 meters long, using classical techniques of road vehicles for braking and orientation of axles in manual mode. The TVR will be always mono-directional and its length will never overpass 24.5 meters long, maximum length authorized by the Code of the road.

Figure 119: TVR

5.3.3 Guidance system

5.3.3.1 Translohr

A single centrally embedded rail guides the vehicle on a guide way. Every axle is equipped with a guidance device composed of two rollers in V fixed on a swivelling arm. Each axle of the vehicle is indeed oriented with two arms, each bearing two rollers. The guiding system, mounted on all axles, is mechanically locked with the rail, and thus guarantees the precision of the trajectory, the perfect docking at the stations without any effort on the rail. A composite bandage to avoid direct contact iron upon iron covers the internal faces of the rollers. According to the manufacturer, there is no possibility of derailment including with much deteriorated grip conditions. The rail does not suffer wear, only the rollers bear it.

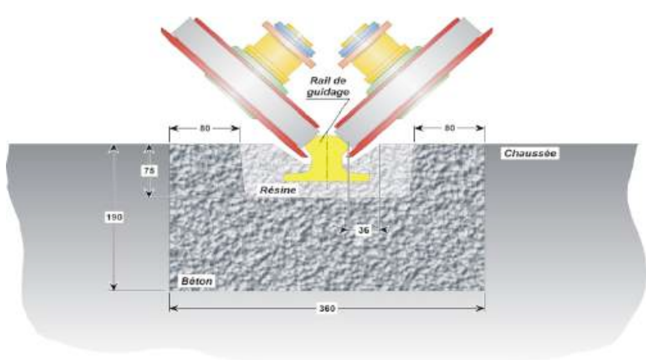

Figure 120: Guidance system of Translohr

5.3.3.2 TVR

The TVR guidance system consists in a pair of rollers, which, rolling on a central rail fixed on the track, gives orientation of the vehicle's wheels, all the axles being steered. Under every axle there is an arm, on which are fixed two vertical rollers, located before and behind the axle, which follows the rail and drive the wheels by means of rods. The arm can either be brought down or raised by means of an hydraulic jack: to introduce these vertical rollers on the rail, it is necessary to put the vehicle in an introducing zone on a insertion's triangle on the rail, that features a V shape switch or dropping place. We note that it exists moving triangle that can be used everywhere along the rail to change the manual mode in guided mode: it is necessary to get the help of the staff of a maintenance team.
With the guided mode, the steering movement is assumed independently for each axle. The roller located in front of the axle, fixed assembling, print a steering angle to the wheels from the steering device. The roller behind, transversally free assembling, assumes only an anti-derailment safety part. It is necessary to apply a vertical strength 750 daN, upon the central rail to avoid the derailment of each roller.
Going out of the guided mode is done imperatively when the vehicle is stopped. In manual mode, the angle steering wheel is transmitted, from an assisted steering, to the front axle which steers accordingly. Each intermediate guiding axle receives the steering impulse of the joint which follows it through mechanical links. The steering angle is transmitted to the last axle from the previous joint by means of a mechanical system.

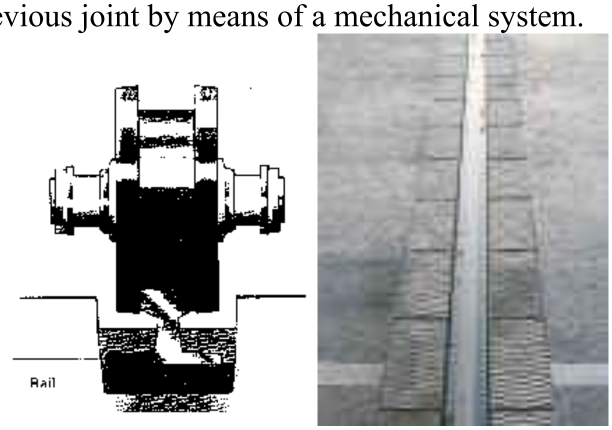

Figure 121: Guidance system of TVR

5.3.4 Rolling stocks

	TVR	Translohr		
		STE3	STE4	STE5
Traction	Bimodal diesel-electric	Electrical – 750 V		
Autonomy	Generator	Batteries for a two km empty ride (option)		
Guidance type	Rail central	Rail central		
Number of bodies	3	3	4	5
Length	24.5 m	25 m	32 m	39
Width	2.50 m	2.20 m		
Height	3.22 m	2.89 m		
Floor Level/rail rolling level	28/29 cm	23 cm		
Maximum speed	55* / 70 km/h	70 km/h		
Acceleration	1.2 m/s	1.3 m/s2		
Deceleration	1m/s	1.3 m/s2		
Emergency brake	5 m/ s^2	5 m/s2		
Bidirectional	No	Yes		
Life duration	30 years	30 years		
Multi unit possibility	No	No		
Total number of spaces (4sp/ m^2) within seats	131 with 37 seats	131 spaces With 30 seats	162 spaces 40 seats	200 spaces 50 seats
Flow per hour with an headway of 4 minutes (each direction) (4sp/ m^2)		1965 sp/h/dir	2430 sp/h/dir	3000sp/h/dir

Figure 122: TVR and Translohr

• Speed with guided mode

5.3.4.1 Translohr rolling stocks

The vehicle is produced with a modular building with 3 versions STE3, STE4, STE5. The Translohr has a narrow gauge, so restricting the axle's load and accordingly the rut. This narrow gauge allows the insertion in old centre cities, but increases the length of vehicle for a given capacity. The axle's load is included between 7.5 to 7.9 t by axle for the STE4 vehicle with 4 pas./s2 . For TVR the axle 's load is included between 6.4 to 9.4 t by axle.

The full guidance of Translohr with a central rail makes sure a very precise docking along the platform. The horizontal gap is 50 mm wide so the vehicle does not rub against the platform even if there is a tyre's puncture.
Like TVR vehicles, Translohr vehicles are designed for life duration beyond 30 years.

5.3.4.2 TVR rolling stocks

Concerning the TVR, the docking's precision under guided mode varies from 50 to 100 mm; the guidance system allows a side variation of 40 mm. To secure a full guidance of the 3 bodies, a tyre's guide equipment has been installed along the platforms in Caen and Nancy.
In the workshop, a central rail is necessary for a precise position on the visit's pit and under footbridges (many equipments are on the roof of the vehicle). No specific infrastructures are necessary between the separate right of way of the line and the workshop, that permit the reuse of existing bus or tramway workshops.

5.3.5 Separate right of way, track and surface processing

For Translohr system, the guidance rail is laid in a groove realized in the middle of the track. It is drowned in a resin which allows in the same time insulation against stray currents and ensure a good homogeneity in the laying.
For the rolling lanes although the axle's load and ground pressure are low, it is advised to use concrete or a very hard asphalt to avoid rut's problems. According to the manufacturer, the other parts of the right of way could be turfed and the rolling lanes enjoy aesthetic treatments. A surface layer renew has to be done around every 7 years.
For TVR system, the main types of carriageway indicated by the manufacturer for the guided sections are:

- a thick concrete slab ,
- continuous reinforced concrete
- a bounding layer bituminous concrete EME with a surface layer very thin bituminous concrete.

In Caen they chose, coverings according to sections are concrete or bituminous concrete.
The central guidance rail, 100 mm high and 65 mm width at the running level, is done by the manufacturer.

5.3.6 Energy's supply

5.3.6.1 Translohr

The energy supply of Translohr's vehicle is done through a catenary, the guidance groove rail assuming the traction current's return. An energy supply line breakdown can be treated by batteries, these one's being proposed as an option. However, the batteries 'autonomy is limited to 2 km being in charge.

5.3.6.2 TVR

The vehicle has two supply's modes:

- an autonomous mode thanks to an electric diesel group (autonomy limited to 4 hours),
- a supply mode by a 750 V continuous current, with a one wire catenaries and a pantograph, the traction current's return being obtained by the guidance rail or the catenaries with two wires and trolley poles.

There is not any development of batteries' supply or Natural Gaz for vehicles/ Liquefied petroleum gas.

5.3.7 Insertion's technical characteristics

5.3.7.1 Translohr

Compared with French Standard Tramway TFS, the Translohr insert more easily in common section on account of static reduced gauge. The width of RoW in a straight alignment without catenaries' pole is 5.40 meters.
Compared with TFS, the Translohr can take curves with small radii (< 20 meters) and take slopes until 13 %.
The minimum radius curve is indeed 10.5 meters at rail's axle. In these conditions, the maximum right of way is 6.7 meters wide without catenaries' poles.

RoW in a curve of 90° between two streets of 11 m wide	Right of way in current section

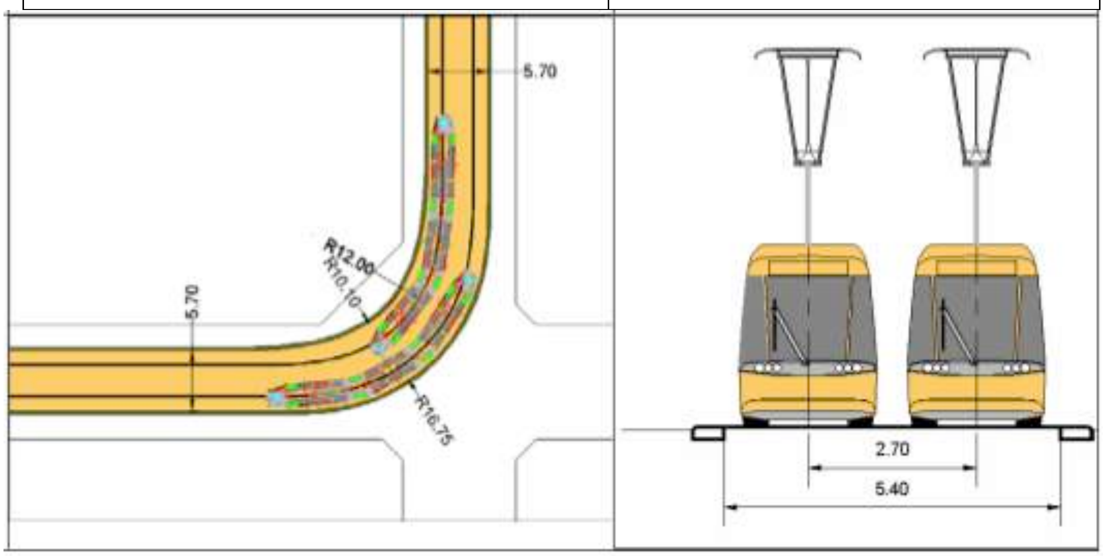

Figure 123: Insertion characteristic of Translohr

(Source: SYSTRA, EREA, LACUB, Presentation des systèmes de transport Rapport annexe – Etape 2 Août 2004)

5.3.7.2 TVR

The tyre grip allows the TVR like as the Translohr to climb slopes of 13%. Compared with TFS, the TVR can take curves with small radii (< 20 meters) and take slopes until 13 %. The minimum radius curve is indeed 12 meters at rail's axle instead of 25 meters for a TFS vehicle.
TVR characteristics are different according to it is used in manual or guided mode. In guided mode, the guidance system gives to TVR the advantages of a TFS, that is to say:

- monotrack's characteristics,
- in common section, right of way limitations to 6.20 meters wide around, instead of 7 to 7.50 m for no guided bus (but 5.80 m for the TFS for a vehicle 2.40 m wide),
- a limitation of the right of way in curves all the more important so the TVR is monotrack and accept radii of curves lower than the tramway; this right of way is 6.80 meters for a double track for a curve of radius of 25 meters long.

In these conditions, the maximum right of way is 6.7 meters wide without catenaries' poles.

RoW in a curve of 90° between two streets of 11 m wide	**Right of way in current section**

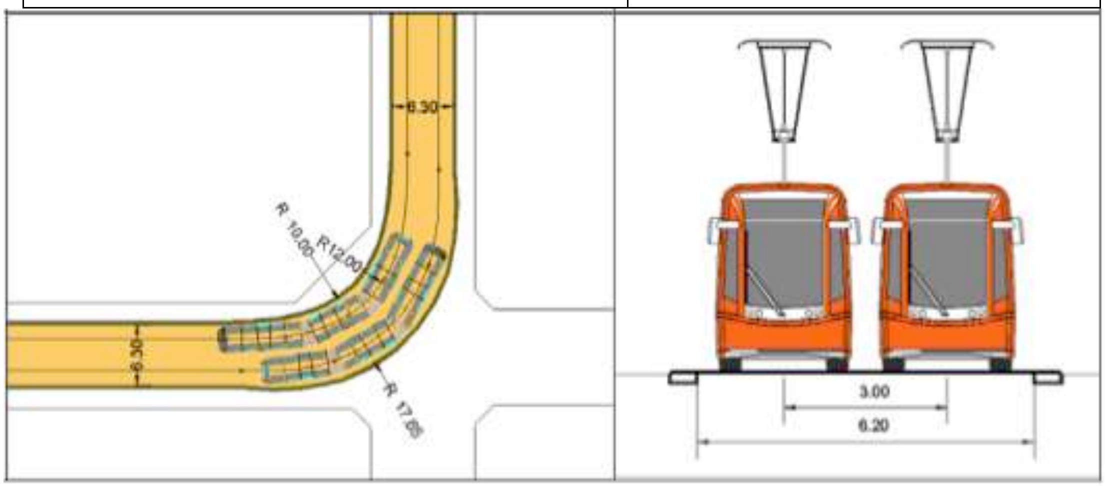

Figure 124: Insertion characteristic of TVR

(Source: SYSTRA, EREA, LACUB, Presentation des systèmes de transport Rapport annexe – Etape 2 Août 2004)

5.3.8 Reliability and technological risks

These is concerned with both Translohr and TVR, the fabrication of each system is based only on one constructor (Lohr, Bombardier). Indeed, it does not exist any provider for rolling stocks being able to circulate on the same infrastructure.

5.3.8.1 Translohr

Concerning the Translohr, it is under operation in Clermont Ferrand soon in Paris Velizy, Sarcelles, etc. and in Italy in L'Aquila, Padova and soon in Venise, Tian Jin in China.
The guidance equipment: it is under operation since around 3 years on 3 lines, any problems appeared, the real cost of maintenance (without warranty of constructor) begun to be known by operators.

5.3.8.2 TVR

Concerning the TVR, a feedback has been done since its inauguration in 2001, following the incidents of the system in Nancy where numerous examinations had to be done. We can give the elements following:
The TVR operation in road mode must be used on an exceptional manner: (e.g. in case of a breakdown of energy supply, to avoid the sections where the operation is perturbed) to avoid

numerous sequences of central rail detaching. It is this principle that is applied on the TVR line in Caen, where in case of perturbation, the TVR vehicle leaves its track and borrows another itinerary of deviation already plan with a prefect's decree. The difficulties met with the rotation road/guided retained in Nancy shows its system's limits. The multiplication of transitions (4 times by direction) increases undeniably the risks of failure and mistake from the drivers.
The too tightened curves must be avoided mainly if they are followed by counter-curves; in Caen, the kept minimal radius of curves is 20 meters, the 12 meters radii are limited to the terminal rings. On the other hand, in Nancy 2 curves in "S" of 12 m radius were changed in 15 m radius, the most important incident of derailment appearing in this location (70 % of guidance loosing). In the low radius curves, the speed must be strictly limited (5 km/h).
We must plan an increased and strict inspection and maintenance of tracks, to verify the respect of tolerances of wear between the rail and the rollers. Respecting these dispositions guarantees the system safety, the risks of guidance's loosing come principally of the wear of rollers and the rail. These dispositions involve increasing costs of maintenance.
In the case of innovating systems it is necessary to implicate the constructor in the maintenance and operation of system on an enough long period. In Caen, it is STRV Company (joint venture SPIE and BOMBARDIER), which insures maintenance and renewing of equipments as well as the second level maintenance of TVR for 30 years period.
In Caen, the maintenance's operation were carried on:

- Important ruts appeared on the TVR tracks during the first year of operation, due to the bad formulation of bituminous concrete for the TVR track carried out.
- The reloading of the rail (metal bringing) in the places were the most attacked by wear.

Concerning the rolling stocks, the operations consisted of improvements making guidance system sturdier, and on the tires type's change.

5.3.9 Investment and operating costs

5.3.9.1 Investment costs

a. Translohr

The total investment cost of Translohr is similar to the investment cost of the standard tramway. In Clermont – Ferrand, the line 1's investment was 290 M Euros (2003) for 14 km long that is to say a little more than 20 M Euros per km.
The unit cost of a bi-directional vehicle STE4 (32 m) is around 2.35 M Euros that is to say 14 500 Euros the offered space what is more 50% over to a standard tramway (9000 Euros the offered space).

b. TVR

Concerning the TVR, the mean investment cost is around 15 M Euros (free taxes) per kilometer of line: for Nancy this cost is nearer 18 M Euros if we exclude the section operated under the road mode (2.3 km) and without the other expenses made for the improvement of the track changing the radius of 12 meters in a radius of 15 meters and the ruts along the track. The unit cost of the TVR vehicle was 1.9 M Euros that is to say 12 500 Euros the offered space that is superior to the standard tramway.

5.3.9.2 Operating costs

a. Translohr

Operating costs of Translohr could be the same than those of the standard tramway: some doubts remain on the maintenance costs that could be estimated after a long period of operation (after the guarantee's period).
The preventive maintenance plan of the constructor includes integrated checking of the main functions of the vehicle, the usual servicing, revisions and relook operations (changing components and arrangements).

b. TVR

In Caen, taking into account the adopted concession assembly, these costs are well known. There are 5.04 per km for staff, energy, daily servicing, commercial operation, insurance and taxes expenses. We add 1.50 Euros per km for the "big maintenance" of rolling stocks and infrastructures. It is a total amount of 6. 54 Euros per km what is around or more than the mean operating cost of a standard tramway.
The consumable parts, compared with the standard tramway, are mainly the tyres and the rollers. A big part of spare parts come from road providers (brakes, tyres, lights, etc.) in a manner to optimize the spare parts' stock and so reduce the costs.
The TVR vehicles have been conceived for a life's duration of 30 years. This value has to be checked for road equipments.

5.3.10 Metropolitan areas that have chosen these systems

The Translohr has been retained by:

- Clermont Ferrand for its first TCSP line (14 km in separate right of way) under operation since 2006.
- Paris with 3 lines under design.
- In Italy, Padoue (10.5 km, 14 rolling stocks STE3) put into service in 2005.
- L'Aquila (5.7 km, 10 rolling stocks STE3) put into service in 2005.
- Venise (20 km, 20 rolling stocks STE4) put partially into service in 2009.

TVR is operated in Nancy since February 2001 and in Caen since October 2002. With a difference of Nancy, the TVR of Caen is entirely guided all along the line (15.7 km) only the return to the workshop is done under a road mode (1.5 km).

5.3.11 Relevant field

TVR and Translohr are in the intermediate transit range.
Conceived for metropolitan areas of a mean range between 100 000 to 300 000 inhabitants (Caen, Nancy, Clermont - Ferrand) and in traffic range normally lower than those of standard tramways: 2000 to 4000 passengers per direction at the peak hour.

5.4 Intangible guided systems

These systems are involved in the range of "intermediate systems" compared to the bus and the classic tramway: the Civis and the Phileas.

The Civis has been operated in Clermont Ferrand and it is under operation in Rouen; the Phileas is under operation in Eindhoven, it was chosen for the network of Douai where they are waiting for the opening of the system called here Eveole.

Civis and Phileas are guided road vehicle, for the image they are nearer to the bus than the tramway.

Figure 125: CIVIS and PHILEAS

5.4.1 CIVIS

Civis came from cooperation between Irisbus and Siemens companies. Irisbus provides the vehicle and Siemens takes into account the optical guidance system. The result is a vehicle with electric motor wheels, being able to circulate as well in road mode as in guided mode, mono-directional and no monotracks.
The guidance is based on painting' s marks on the ground read by a camera located on the vehicle. This system is limited until now as a help to accost along the platforms of stations.

5.4.2 PHILEAS

Phileas is a new road guided transit system developed by APTS (Advanced Public Transport System B.V.). The vehicle can circulate as well in classic road mode as in guided mode, monotracks and monodirectional.
The guidance system is of an intangible type; both computerized and automated, based on the comparison of the position of magnets installed in the lane and the way to follow, recorded in the computerized system. The trajectory of the vehicle is established in acting on the torque motor, linked to the steering mechanism. We can note that the vehicle and guidance system have not still the approval in France.
The Phileas vehicle can be operated under three modes:

- In manual mode, the vehicle functions like a bus.
- In semi-automatic mode, the stability of trajectory is carried out by the automatic electronic direction system and the driver is only responsible to acceleration and braking. Moreover in semi-automatic mode, speed in the curves is limited and slowed down automatically at the level of stops, to ensure exact positioning in the direction of wheel.
- In automatic mode, the speed regulation is also taken again by an automatic system. In the two automatic modes, the driver has always the possibility of taking again the control of the vehicle.

5.4.3 Guidance system

5.4.3.1 CIVIS

The guidance system of CIVIS is based on the principle of image processing and path's recognition. A video camera, located behind or on the top of the windscreen, detects the position of the vehicle compared with a double painted stripe beaconing on the pavement. Data are processed by an electronic central unit which acts automatically on the steering column, by the intermediate of an electric motor, so that the vehicle follows the reference's path. The system being intangible and declutching, the driver can take back the driving in a manual mode, at every moment if circumstances require, without vehicle's slowing down.

It is important to note that the optical guidance system concerns only the front axle; the rear axle being not guided, the vehicle is not mono-track.

Interface with infrastructures is limited to marking on the ground. It is made up of two parallel stripes of dotted line, 10 cm wide each and spaced of 25 cm. On both sides of this double stripe of 45 cm wide, a space of 30 cm wide must be free of other marking. The dotted line is realized with road standard paint, by a pounces' method. The marking accuracy must be the largest possible for a guidance of quality; a gap lower than 0.5 cm is advised. Its service life depends strongly of the applying and traffic conditions.

The optical guidance allows a docking in the station reducing the gap between the platform and the vehicle to less than 50 mm wide. This system was tried and tested In Rouen and Clermont-Ferrand.

We must note that the guidance system is used for docking at the stations; the system is not validated between the stations. Indeed, on guided mode and beyond a certain speed (30 km/h), the path of the vehicle is not perfectly controlled, it is required to take into account the margin induced by the taking back in hands the vehicle in case of "derailment" of this one.

Two solutions are indeed advocated for taking into account this parameter:

- either the right of way is widened (addition of 40 to 50 cm to the cinematic gauge of the guided vehicle)
- either the guidance is completed by a system of concrete curbs of 18 cm high fixed on the track and on which the vehicle guidance wheels will come to lean on. This solution initially designed for Rouen was abandoned by Siemens afterwards.

5.4.3.2 PHILEAS

The guidance system of Phileas, developed by FROG Company, is an evolution of a guidance system by transponder. In the context Phileas, transponders are replaced by little standard passive magnets which are embed every 4 around meters in an hole drilled in the road, then fixed with adhesive resin.

This solution is insensitive to the external request like atmospheric conditions (rain, snow, lightning). If magnets are correctly fixed with the resin, any maintenance intervention is necessary.

On the vehicle, metallic detectors located at each axle level detect the position of magnets. Information is transmitted to the computer on board which determines the vehicle's position and corrects its path accordingly, if necessary, compared with that one recorded in the system.

5.4.4 Rolling stocks

	CIVIS	PHILEAS		
		18.5 meters	**24.5 m**	**26 meters**
Traction	Bimodal diesel-electric	Thermal		
Guidance type	Optical	Magnetic		
Number of bodies	2	2	3	5
Length	18.5 m	18.50 m	24.50 m	26 m
Width	2.55 m	2. 54m		
Height	3.22 m	3.12 m		
Floor Level/ground level	32 cm	34 cm		
Lox floor percentage	100%	100%		
Maximum speed	80 km/h	80 km/h		
Acceleration	1.3 m/s^2	1.3 m/s^2		
Deceleration	> 5.5 m/s^2	> 6.9 m/ s^2		
Bidirectional	No	No		
Life duration	20 years	20 years		
Multi unit possibility	No	No		
Total number of spaces ($4sp/m^2$) within seats	110 spaces	103 spaces	129 spaces	141 spaces
Flow per hour with an headway of 4 minutes (each direction) ($4sp/ m^2$)	1650 sp/h/dir	1545 sp/h/dir	1935	2115 sp/h/dir
Weight				
Empty		16.65 t	21.6 t	21.6 t
$4\ p / m^2$	32 t	23.35 t	30.00 t	30.00 t

Figure 126: CIVIS and PHILEAS

5.4.4.1 CIVIS

The Civis's axle load varies from 7.2 to 13 t for a normal load of the vehicle ($4p/m^2$) of 32t. The life's duration of the system is planned for 20 years: a maintenance's range is planned at 10 000, 30 000 and 90 000 km operated and every year or 2 or 3 years. At the level of guidance equipment half of the equipments will be changed after 10 years.

5.4.4.2 PHILEAS

Contrary to Civis, Phileas is a modular designed vehicle. Two versions of the vehicle are currently proposed; a third version of 26 meters long exists. Vehicles are designed for life's duration of 20 years.
Maintenance's specific equipments for the guidance system will consist in:

- a test area with a platform to grade the system's elements,
- a diagnosis and adjustment bench which is under development
- a footbridge to maintain equipments on the vehicle's roof.

5.4.5 Right of way, tracks and surface processing

The choices of surface processing are very limited as much for Civis as Phileas: concrete made tracks are necessary for Phileas and also for Civis to prevent the vehicles from the ruts that appear generally on bituminous concrete with guided vehicles.

5.4.6 Energy supply

5.4.6.1 CIVIS

Civis has the choice between 3 types of supply:

- thermal with a diesel motor of 30HP Euro 3,
- bimodal, electric (trolley) and thermal, with the same motor which guarantees nominal performances equivalents with the two modes,
- electrical (trolley type), with or without autonomy's motor.

Vehicles Civis under operation in Rouen were Diesel version: this version does not look economically acceptable. Fuel consumption (100 liters per 100 km) is higher than classic bus consumption around 30 %. Agora buses, which took place in Rouen consume 70 liters per 100 km. This over consumption is due to the overload of the vehicle, to a low efficient generator and a no optimal thermal electrical traction chain.
The objective of the Civis maker is to decrease the consumption of the vehicle from 100 to 80 liters per 100 km so the consumption overcost could be of only 10 % more than these of bus.
Irisbus and Siemens direct themselves to the promotion of the electric version, which should be more efficient than the diesel version.

5.4.6.2 PHILEAS

Phileas is a hybrid vehicle with an electric traction. The electric generator is driven choosing a diesel motor or LPG or NGV. Energy can be stocked either by flywheel or by batteries. Each wheel has an electric motor with independent transmission. The energy released by braking is sent to the batteries.
For the LPG, a 800 liters store is planed below the vehicle allowing a 550 km ride. For NGV the pressure vessels are on the roof because the gas goes down.

5.4.7 Technical insertion characteristics

5.4.7.1 CIVIS

Civis like the other vehicle on tires can climb slope of 13 %. Its insertion's characteristics are lower than these of other modes called "intermediate". The minimum radius is indeed quite high: 25 meters in guided mode. The radii lower than 25 meters imply taking back the manual driving. In no guided mode, the minimal radius is 12 meters. This difference is explained on the fact that the camera has an aiming angle not enough wide to go on the marking in the low radii.

RoW in a curve of 90° between two streets of 11 m wide: CIVIS 2.55 m and Bus 2.50 m wide	Right of way in current section

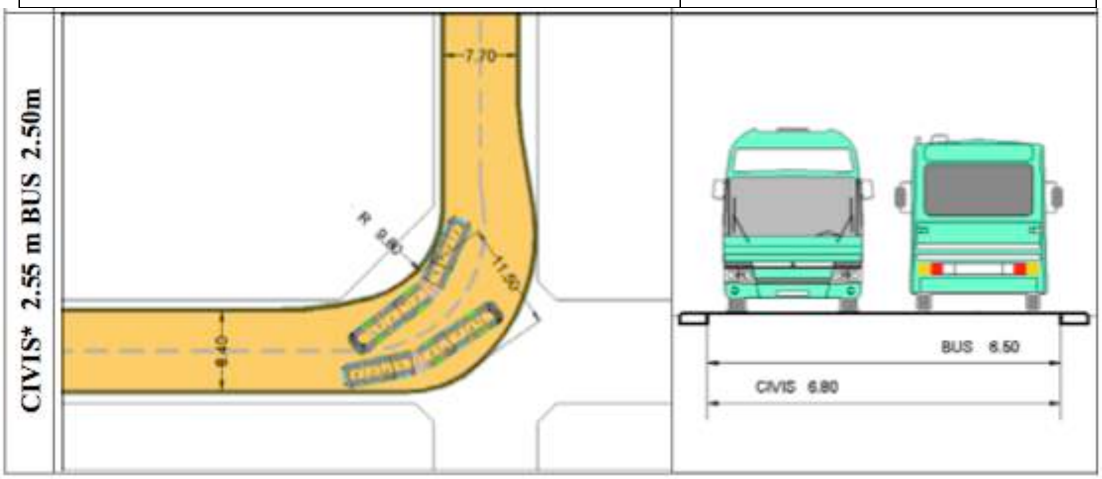

Figure 127: Insertion characteristic of CIVIS

(Source: SYSTRA, EREA, LACUB, Presentation des systèmes de transport Rapport annexe – Etape 2 Août 2004)

At the level of developed kinematic envelope DKE, as we are in front of an intangible guidance system, it is important to take the margin led by taking back the driving in a manual mode in case of "derailment". It is suitable to add 40 to 50 cm to the dynamic gauge of the guided vehicle.

The right of way of CIVIS is so, of the same order that those of articulated buses:

- on straight alignment and on a double track, we obtain a right of way varying of 6.7 m for 20 km/h to 7.3 for 50 km/h
- in a curve, a computing simulation is necessary to take into account the effects of sweeping. The right of way in a 25 meters radius curve with double track is higher than 9 meters wide.

So, it seems preferable to limit Civis 'operation in guided mode to the station's docking.

5.4.7.2 PHILEAS

The maximum slope being got over by Phileas is 12 %. On general manner the minimum radius of a curve is lower than 12 meters. The right of way in straight alignment is for a double track 6.6 to 7 meters.

The monotrack character limits the right of way in the curves. So e.g., the right of way in a curve for a 24 meters long vehicle is 4.1 meters on single track, the minimum external radius being 11.2 meters long. In the version 18 meters long, the right of way in a curve is 3.80 meters (single track), the minimum external radius being of 11.8 meters long.

5.4.8 Reliability and technological risks

5.4.8.1 CIVIS

Guidance system under operation is technically perfect. It is kept in Rouen to equip Agora buses.

5.4.8.2 Phileas

Technological risks of Phileas are inherent as always exist for developing a new system: these risks concern mainly homologation, software debugging, fabrication time and durability.
However, the guidance system with magnets is a development of the system with transponders, which is already tested.
This magnets system is already under operation on several industrial sites.

5.4.9 Investment and operating costs

5.4.9.1 Investment costs

a. *CIVIS*

The unit cost vehicle is for the Diesel version is 0.8 M € val. 2003 that is to say near 7500 € by offered space or 3 more times than an articulated bus.
The investment cost based on TEOR project is 7.17 M€ value 07 without the vehicles. In this cost there is no catenaries, the vehicle being tracked by thermal motor and infrastructures take into account 1/3 of existing right of way. The other costs include the whole accompanying development as well as stations or operating equipments similar to tramway.

b. *PHILEAS*

Concerning Phileas the investment cost in Douai is 10.92 M € per km value 07, the unit cost of an 18 meters long vehicle being 1.1 M€ value 03 and 1.4 M€ for a 24 m long bi-articulated vehicle. The investment cost of the tracks and infrastructures rises to 4 M€ value 03 per km for new tracks without vehicles. Operating costs are not known, Douai's network is not still under operation.

5.4.9.2 Operating costs

a. *CIVIS*

Operating costs are not known but they are more expensive than one's bus, the reason why is an overconsumption of the vehicles CIVIS too heavy for the Diesel version. The operating overcost for the maintenance of guidance device and the renewing of marking, spare parts more costly and electronic equipments, is estimated to 0.7 € per km opposite to articulated bus.

b. *PHILEAS*

Like CIVIS maintenance costs should be higher than those of articulated bus, and we must add the maintenance of guidance system and the steering gear.

5.4.10 Relevant field

Civis and Phileas systems are in the range of intermediate systems. They have been conceived for mean size cities not being able to pretend to tramway (financially and with passengers' demand). They are in a traffic range lower than those of existing tramways: 1000 to 2500 passengers per direction at the peak hour.

5.5 The non-guided road-based systems

The bus is the most common road vehicle, which is operating on the urban transit network. There is a standard version (12 m long) and an articulated version (18 m long). Numerous improvements have been carried out on this mode, notably in accessibility terms with the appearance of low floors or integrally low, and for traction.
Concerning the image of vehicles, important progresses have been realized these last years, giving a new attractiveness and a new boost to this urban transit mode. At the same time as the comfort improvement of vehicles, noise emissions were reduced and numerous elements were redone, e.g. exterior, new headlights, lateral faces, windows, high-beam unit, etc.
The articulated bus range is not so wide than those of standard bus, however generally being conceived from these last one, they took advantage of the same development in term of accessibility, of comfort and passenger supply modes. The big bus makers propose several bus versions presenting innovating and attractive characteristics.
Trolleybus characteristics and performances are near those of bus and the only one difference with this one is the energy's supply.
It has the advantage to be silent and no polluting. However, the power collection system pick up from the aerial contact line makes it less flexible and exposes it to the hazards of road traffic.
However, trolleybus of new generation are bi-traction: electrical and diesel/electrical that give them a better operating flexibility. The new generation trolleybus benefit of an integral flat low floor, and an increased habitability (wide corridors) thanks to motor wheels adopted system.
The trolleybus Cristalis of Iribus is a new generation trolleybus.
The empty bodies of standard and articulated buses vary between 25 to 30 tons. Some bus makers developed stainless steel body structure and composites body to reduce the empty weight.
The axle's loads are often high, notably for the rear axle, which can reach 13 tons loaded.
Bus and trolleybus are conceived to operate during 20 years. Any specific equipment of maintenance can be made by bus makers except in the case of Cristalis vehicle, who needs a handling equipment and a tester of motor wheels. Maintenance plan vary according to makers and equipments.
The new generation of bus and trolleybus are equipped of low floor or integral low floor. The height of the floor is generally at 320 mm above the level of the road.
Some bus makers propose a kneeling system on the side allowing buses to reduce the vertical gap between the vehicle and the platform as well as an access slope with an electrical control to ease the access of persons with reduced mobility.

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Figure 128: Bi-articulated bus and trolleybus

5.5.1 Rolling stocks

The empty bodies of standard and articulated buses vary between 25 to 30 tons. Some bus makers developed stainless steel body structure and composites body to reduce the empty weight.

The axle's loads are often high, notably for the rear axle, which can reach 13 tons loaded.

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Characteristics and performances of bus and trolleybus standard and articulated are in the figure below:

	BUS		**New Generation TROLLEYBUS**	
	Standard	**Articulated**	**Standard**	**Articulated**
Body number	1	2	1	2
Length	12 m	18.50 m	12 m	18.50 m
Width	2.50 to 2.55 m		2. 55m	
Height	2.90 m		2.90 m	
Empty weight	11.5 t	17.3 t	13.2 t	19.1 t
Acceleration	1 m/s^2		1.2 m/s^2	
Maximal speed	70- 90 km/h	65 – 90 km/h	80 km/h	
Height compared with ground level	34 cm		32 cm	
Life duration		20 years	20 years	
Multi unit possibility		No	No	

Total number of spaces ($4sp/m^2$) within seats	80	110	70	100
Flow per hour with an headway of 4 minutes (each direction) ($4sp/m^2$)	1200	1650	1050	1500

Figure 129: Bus and Trolleybus

(Source: SYSTRA, EREA, LACUB, Presentation des systèmes de transport Rapport annexe – Etape 2 Août 2004)

5.5.2 Right of way, tracks and surface processing

Bus and trolleybus can ride in mixed traffic, but separate right of way development and a priority system at traffic lights allow us to reach commercial speeds more attractive.
The right of way is not ex ante specific. Bus and trolleybus can go on existing road (asphalt, bituminous concrete…). In case of a road's repair, the possibilities of surface processing, being due of road type, are limited.

5.5.3 Energy supply

A wide choice of motors and alternative traction modes are available for the no guided road systems.
Some vehicles are proposed in NGV version like the AG 300, the CityClass, the Access'Bus GX 417 or the NG 313. Some are available in trolley mode with a possibility of an auxiliary autonomous group or of bi-modal group. It is notably the case of the articulated Cristalis, proposed in trolley mode in version ETB with poles and a little motor of 88 HP, or in a bimodal version with poles and a 300 HP motor Euro 3. Van Hool and Iveco have equally diversified their range by proposing vehicles with hybrid rear wheel drive or trolley.
More the Cristalis presents a rear wheel drive technique with motor wheels.
In case of trolleybuses, the electric supply is insured with double poles on catenaries and a diesel electric generating set allows to guarantee to the vehicle an autonomy light in case of electricity (loosing the poles), as well as to reach the workshop.

5.5.4 Technical insertion characteristics

Concerning urban insertion, bus and trolleybus present the advantage to adapt oneself to urban configuration. They can move around with low radius curves of 12 meters and take slopes of more 13 % thanks to the tire grips.
Their length allows them to go on separate right of way or on mixed traffic, what confer to them a wide operating flexibility. The width of the right of way is determined in straight alignment by the circulating speed, by the traffic level and the nature of separator (crossing possibilities or not).
So in urban area, for a circulation speed of 50 to 60 km/h, bus or trolleybus needs a separate right of way of:

- 6.80 m double track for a traffic less than 60 vehicles per hour (2 directions),
- 7.10 m double track for a traffic higher than 60 vehicles per hour (2 directions),
- 3.50 m on a single track.

For a lower circulation speed, these widths can be reduced:

Bus speed	Normal width per track
10 km/h	2.80 m to 3.00 m
30 km/h	3.00 m to 3.25 m
50 km/h	3.25 m to 3.50 m
70 km/h	3.40 m to 3.60 m

Figure 130: Bus speed and track width

At stations, 6.00 meters width is necessary between the platforms. In curve the width can be reduced with steering drawings. But it depends specially of the drivers'dexterity. The right of way in a curve of 25 meters radius is at least of 9 meters wide, the bus being not monotracks and highly sweeping.

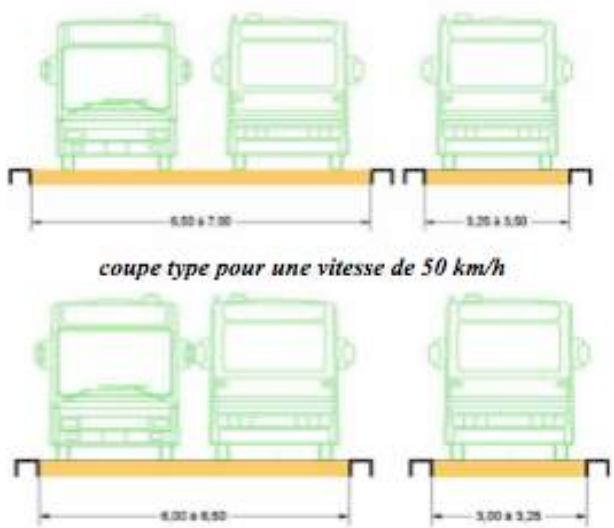

Figure 131: Sections of tracks

Bus and trolleybus are not reversible, so we must create a moderate size space at the terminal to return.

5.5.5 Reliability and technological risks

New generation's bus and trolleybus do not present particular technological risks.
Cristalis is operated nowadays already for several years on Lyon's network without difficulties.

5.5.6 Investment and operating costs

5.5.6.1 Investment costs

Investment costs of bus and trolleybus separate right of way are very variable, but keep the benefit to present very interesting investment costs. They depend on the length of the separate right of way and the quality of the development of other linked projects.
So they can go from 3 M€ / km to more than 8 M€ / km without the rolling stocks. Concerning the vehicle costs, we must count 0.2 M€ for the standard bus and 0.3 M€ for an

articulated bus, that is to say 2500 € the offered space on average. We must count an overcost of around 38 000€ per vehicle for a NGV bus compared to the diesel bus, and an overcost of around 32 000€ per vehicle for an LPG bus.
The cost of a standard Cristalis is 0.5 M€ free taxes and 0.75 M€ free taxes for an articulated Cristalis, that is to say 7 500 € per offered space on average (like Civis).

5.5.6.2 Operating costs

Bus operating costs are on the average of 3 € / km. For the modern trolleybus like Cristalis, it is convenient to take the hypothesis of 3.6 €/km for the articulated version and 3.10 €/km for the standard version.

5.5.7 Relevant field

Bus and trolleybus are conceived:

- for all the metropolitan areas,
- for a range of traffic limited to 2500 passengers per peak hour and per direction.

They can answer to the needs of little, mean and wide metropolitan areas.

5.6 Choosing the more relevant mode

For each identified alignment and inside each corridor, the choice of transit system must form the outcome of a thought taking into account different parameters. Among the different parameters there are the potential of the expected frequentation, insertion's constraints and the costs.

The demand will be however a decisive element of system choice.
At the same time as this thought, an essential question will be to know what are the transit systems could really be considered, taking into account the state of the market and technological risks of "innovative" systems located between bus system and standard tramway, but also and above all considering the existence of the standard tramway on the network of the metropolitan area of Bordeaux.
So, it will be about giving answers to the following questions:

- Should we keep one technological uniqueness and limit the choice of systems between the bus on separate RoW and the standard tramway?
- A priori what will be the consequences if other modes will be introduced inside the metropolitan area's network?

Technological reliability and continuity are also important factors
Technological reliability of a system guarantees its adoption under operation without risk of sliding of design times and costs. The continuity of a system allows us to order similar equipments in low quantity being able to benefit of a mass production done for another town, to obtain spare parts without excessive overcosts, to renew the rolling stocks benefitting of evolutions. With these criteria, it appears today that only the standard tramway and the classic road systems (bus, trolleybus) look without any risks.
The TVR, under operation in Caen and Nancy, was the purpose of wide valuation that concludes to its industrial reliability, however with requirements of improvements of the

system, operating safety's rules and significant reinforcement of maintenance measures. The Civis is not still approved with a guided mode operation between stations.
At last, Phileas and Translohr in the period of the 2004 study were not already under operation: nowadays Translohr has the experience of Clermont Ferrand and 2 networks in Italy L'Aquila and Padova. Phileas has some experiences in Eindhoven and Istambul with still some problems.
The main risks of these innovative systems are in keeping costs under control, particularly those of maintenance. Moreover, most of these systems are offered by only one carmaker restricting so the fact of competing with another constructor to order the equipments of another line or an extension of a line.

Figure 132: Surface transport systems

(Source: SYSTRA, EREA, Ingérop, LACUB, Etude de faisabilité des extensions du réseau communautaire de TCSP (3ième phase), Rapport – Etape 2 Janvier 2005)

Here is a presentation to compare different systems being able to be operated along the extensions of the metropolitan area network in Bordeaux (3rd stage) and bringing out the benefits and no-benefits of new systems compared to the already existing modes on the metropolitan area 's network, that is to say the bus and the standard tramway.
Besides these 2 modes, we take into account:

- the systems with a tangible guidance system (TVR, Translohr)
- the systems with intangible guidance system (Civis, Phileas)
- the modern trolleybus.

5.6.1 Capacity and relevant field according to the level of traffic

The figure below shows the relevant domain of different systems according to their capacity of transport during one hour (passenger per direction during the peak hour). It takes into account of the total capacity of vehicles on a basis of 4 standees per m² and of a frequent service around 3 to 5 minutes.
If the tramway is relevant for traffic ranges relatively high, the other systems are based on lowest ranges with however an "area of recovering" between 2500 and 3500 passengers per direction for Translohr and TVR. The other systems correspond to traffic's range lower than 2500 passengers per direction and per hour.

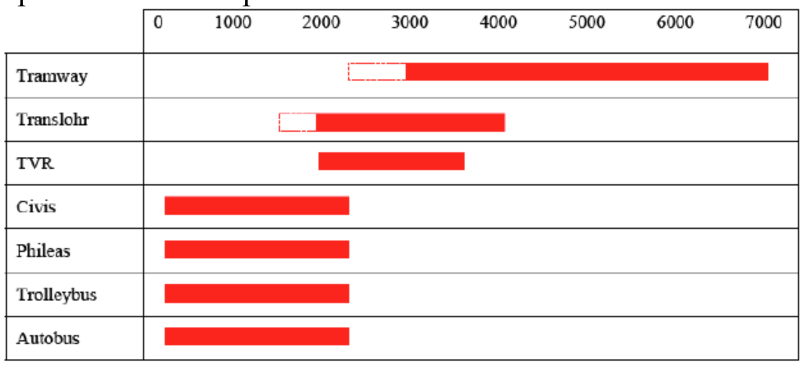

Figure 133: System Capacities (spaces/direction/hour)

(Source: SYSTRA, EREA, Ingérop, LACUB, Etude de faisabilité des extensions du réseau communautaire de TCSP (3ième phase), Rapport – Etape 2 Janvier 2005)

5.6.2 Geometric insertion

The rolling stock's gauge is the main element that conditions the insertion of the separate right of way TCSP in the urban sites.

5.6.2.1 Gauge

It is the static gauge, or the width of vehicle, that allows us to determine the dynamic gauge of rolling stock then the developed kinematic envelope DKE that fixes the width of the right of way.
The static gauges of the 5 systems vary in width from 2.20 m for the Translohr to 2.55 m for the Civis and in height from 2.95 m for the Translohr to 3.27 m for the Citadis. The figure below allows us to compare the bulkiness of these different systems.

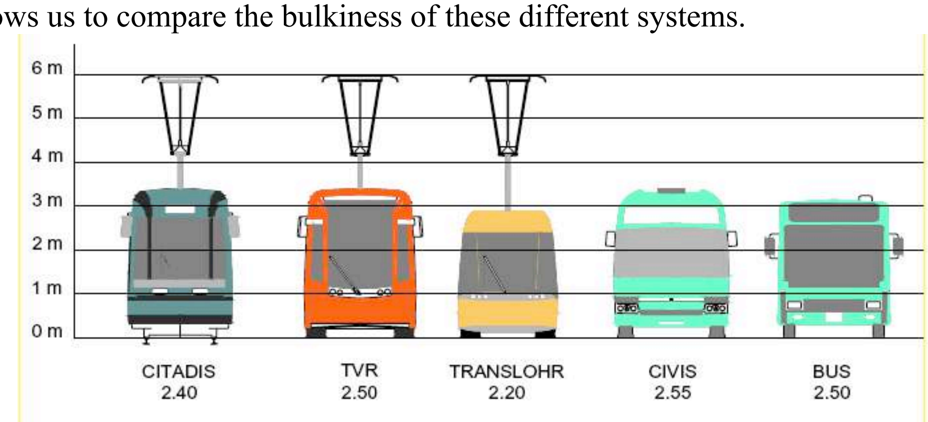

Figure 134: System's Widths

(SYSTRA, EREA, Ingérop, LACUB, Etude de faisabilité des extensions du réseau communautaire de TCSP (3ième phase), Rapport – Etape 2 Janvier 2005)

a. For the tangible guided systems (Tramway, Translohr, TVR)

To obtain the dynamic gauge it is suitable to add to static gauge the sum of different plays whose these assigned to guidance for alignments and added over-widths in the curves.

- The value of plays is the sum of the movements of different mechanic parts (shock absorbers, joints, etc. In principle, the more a vehicle is articulated the more the plays in alignment increase.
- The value of over-widths in the curves depends on directly, of the rolling stocks 'length, of the chassis frame overhang length, of the distance between center pins. The more the distance between center pins is important, the more the interior widening (belly) is important, the more the chassis frame overhang is big and the more the exterior widening (horn) is high.

So, the more a vehicle is articulated with short stocks, the more the widths in curve are reduced.

b. For the intangible guided systems (Civis, Phileas)

The only one intangible guidance system under operation in France is an optical guidance system of Civis in Rouen: it is used only for docking at stations of the BRT line. Indeed in the common section of the line this guidance system does not allow a path perfectly controlled. On high-speed routes (40-50 km/h) the optical guidance system must be either completed by curbs joined to guidance wheels fixed on the vehicle either the separate right of way must be widened to answer to a possible failure of the guidance system.

Concerning the Phileas, the magnetic guidance system is doubled by a computer 's memory allowing it to record the path. Its main innovation consists in steering of all the wheels making the vehicle perfectly monotrack whose benefit is to limit the right of way in the curves.

c. For no guided systems (bus, trolleybus)

There are in the range of standard buses and trolleybuses, of Civis and TVR when these one's are not guided. TVR is a vehicle monotrack when it is not guided, all axles are steered what allows it to stay in the curves very near of the guided vehicle's right of way. Civis in no guided mode like bus and trolleybus sweep strongly, the front axle only tracking.

5.6.3 Width of the right of way

For the tangible guided systems, the width of the right of way is defined from the developed kinematic envelope DKE. The DKE is determined by applying the air spaces to the dynamic gauge. These air spaces allow to compensate the deflection of the track and to respect safety allowances.

For the non-guided systems, the width of right of way on alignment is determined by the operating speed, by the traffic level and by separator's nature.

In curve, the width can be deducted from gyration's sketch given by specific software. But above all it depends on the drivers' skill.

The widths of right of way for a double track are presented below in common section for each system. The widths of right of way are given without catenaries' poles for tramway, Translohr, TVR and trolleybus systems.

It appears that Translohr and tramway systems are the less space's consumers with a width of a double track right of way lower than 6 meters on the fact of their low gauge and their guidance equipment.

The Civis under guided mode is the more penalizing mode in term of space consumption with a right of way of 6.80 m wide.
The bus right of way 6.50 m wide is valid for a commercial speed inferior to 30 km/h.

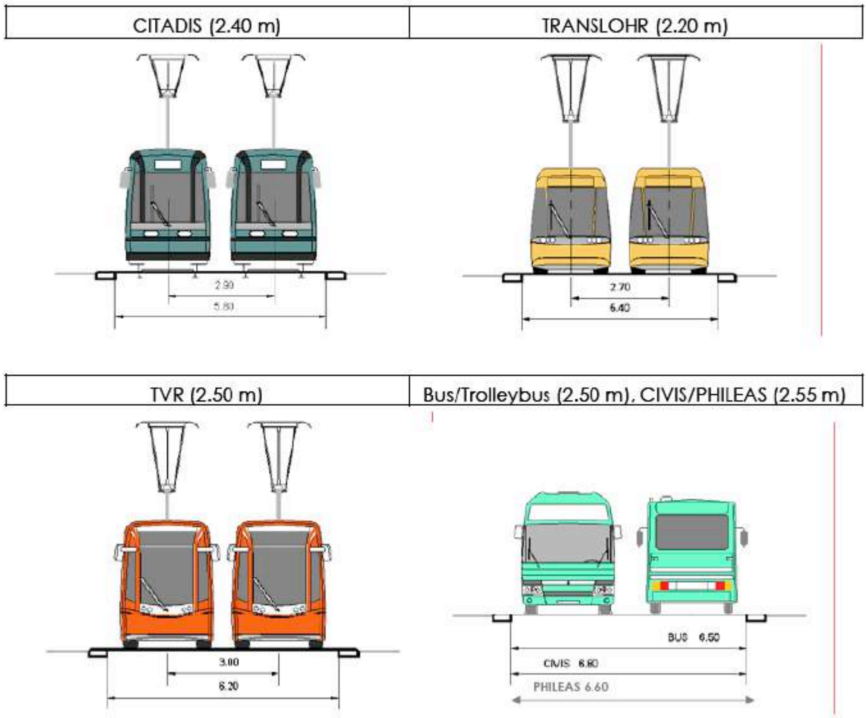

Figure 135: System widths with 2 lanes

(SYSTRA, EREA, Ingérop, LACUB, Etude de faisabilité des extensions du réseau communautaire de TCSP (3ième phase), Rapport – Etape 2 Janvier 2005)

5.6.4 Insertion in a restricting situation

To compare different systems, an example of crossing a crossroad was examined (curve at 90° between two narrow streets). For crossing this obstacle the extreme performances of different systems were used.

Translohr inserts better in the curve, followed by TVR operated under guided mode. The bus and the Civis in spite of a low radius sweep all the area of the crossroad and come close to façades. On account of its 25 m radius, the tramway needs to encroach on the corners of building.

On the other side to negotiate low value radii, it is necessary to spread more the tracks or the paths and to widen the right of way before and after the curve. This is particularly sensitive for the bus and the Civis.

Insertion' ease	Bus & trolleybus	Phileas	Civis	TVR	Translohr	Tramway
Straight alignment	-	-	-	+	+++	++(+)
In a curve	+	+	+	++	+++	+
In a slope	+++	+++	+++	+++	+++	+

Figure 136: Synthesis of insertion characteristics

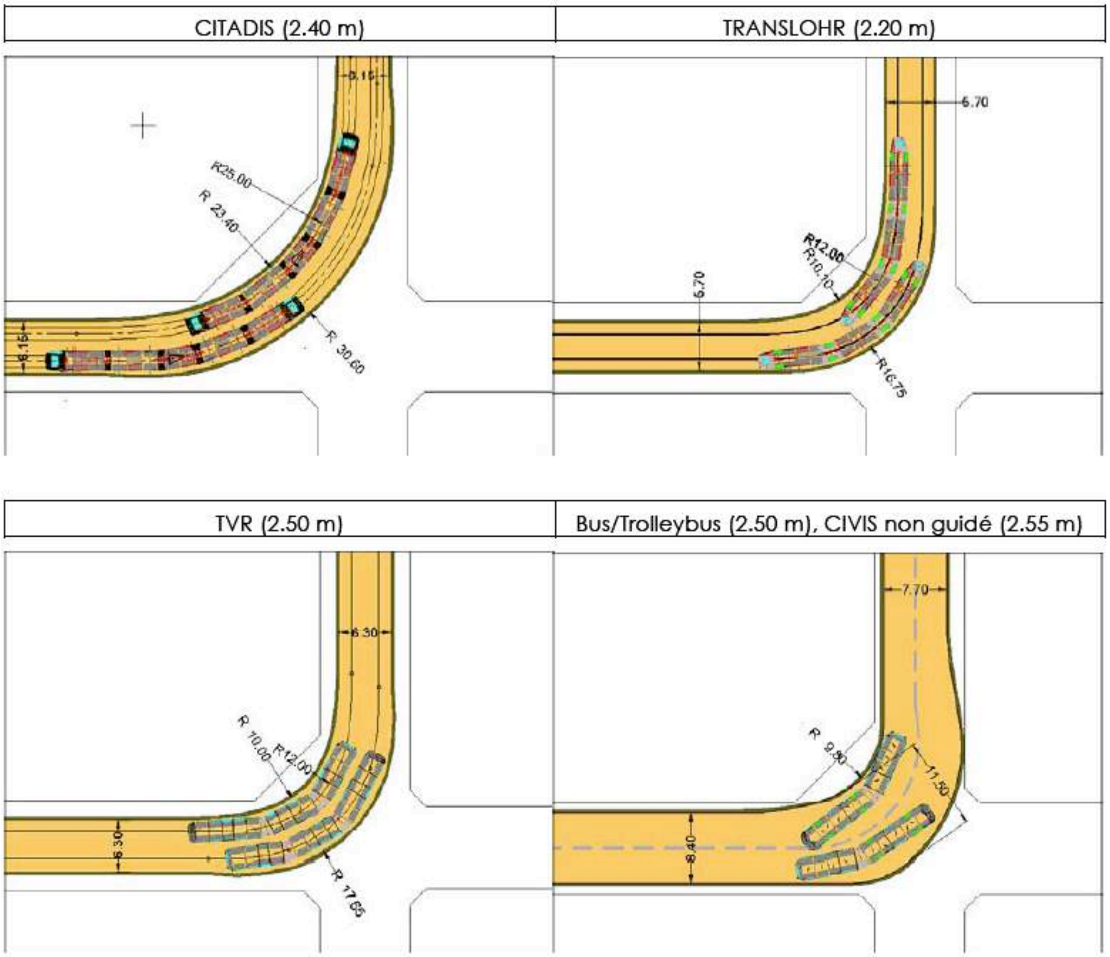

Figure 137: Insertion Characteristics

5.6.5 Costs

5.6.5.1 Mean global investment cost

These costs are in table below and also in table of "Characteristics of 39 tramway lines under operation in France".

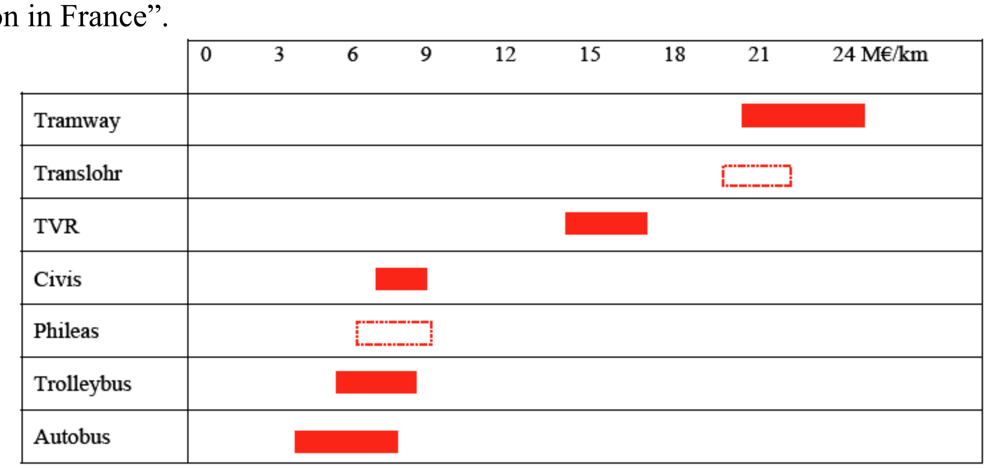

Figure 138: Investment Costs

These costs correspond to a mean total cost of the project brought back to one kilometer value 2003, based on french projects or hypothesis in red dotted line. They consist of rolling stocks, real estate, pipe and wire network deviations, infrastructures, operating and energy supply specific equipments, bridges, accompanying projects, the workshops, and expenses for project manager and master of work.
The line kilometric cost varies from 1 to 5 according to the considered mode in separate right of way. Tramways (on steel wheels or on tires) have a line kilometric cost definitely higher: the cost of tramway on tires could decrease with the effect of mass production.

5.6.5.2 Operating cost

Operating costs are shown in the figure below. These costs correspond to mean costs observed on different projects under operation (red line) or supposed (red dotted line). They consist of driving costs, supply of energy, of maintenance (rolling stock and infrastructure) and the other expenses (managing staff, taxes,..).
Operating costs vary from 1 to 3 for one vehicle kilometer. However, if we take the place kilometer operating cost are in the same rough estimate, even more favorable to the high capacity systems (rail).

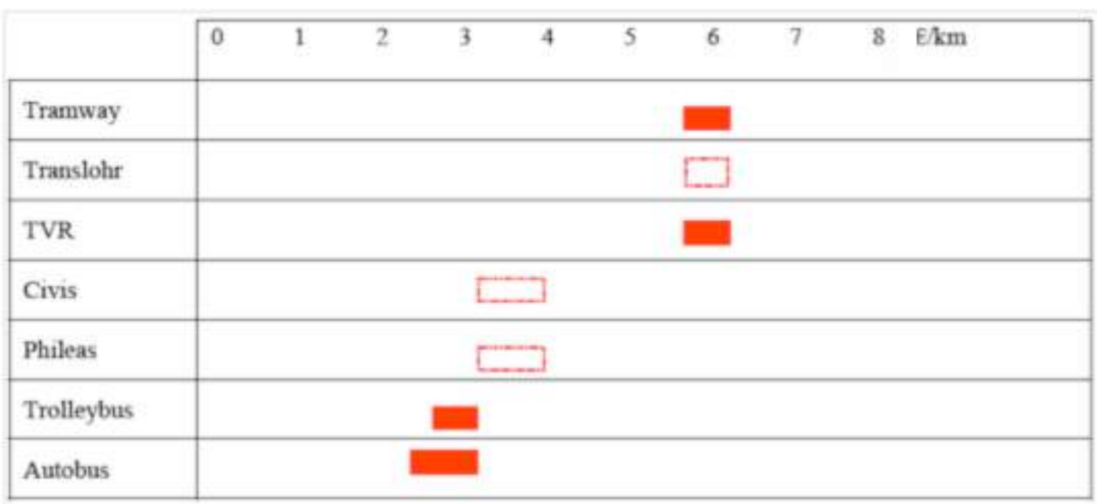

Figure 139: Operating Costs

5.6.6 Image, comfort and impact on environment

The electrical traction modes are less polluting. Thermal motors are more noise than electrical motors. Mechanical guided vehicles (rail) emit more vibrations (screech in the curves) than the intangible guided systems.
The innovative appearance is more difficult to judge so many new proposed techniques are varied, the intangible guided vehicles being more innovative but with monotrack performances less good. The supply from the ground SFG in energy to the tramway makes the tramway more innovative.
The choice of tracks and surface processing is more varied in the case of a tramway (pavement, grass, ballast, bituminous concrete). Systems on tires need rolling stripes "hard" concrete or bituminous concrete made, to prevent or rut's risks, especially the vehicles are guided and monotracks.

A list of criteria reflecting the aspects linked to image, comfort and to the respect of environment is presented in table below:

Characteristics	Stand/ articul.bus	Stand/ articul. trolley Cristalis	Phileas	Civis	TVR	Translohr	Tramway
Polluting gas emissions	+	+++	+	+	++	+++	+++
Noise and vibrations	+	++	+	+	+++	+++	++
Innovative appearance	+	++	+++	+++	+++	+++	+++
Low floor accessibility to platform	+	+	++	+++	+++	+++	+++
Design's possibility, renovation	+	++	++	++	+++	++++	++++
Choice of facilities and covering	+	+	+	+	+	++	++++

Figure 140: Other aspects

5.6.7 Modal choice's problems in the metropolitan area of Bordeaux

The network of urban transit in Bordeaux is operated with tramways and buses. The modal choice problematic for each corridor must take into account these existing network data. It will be moreover difficult to choose systems according to different corridors whether they are at the end of a line or not.

5.6.7.1 For the corridors being at the end of a tramway's line

For the corridors linked to the terminus of tramway's line (2^{nd} stage), the identified layouts have a short or very short length, generally included between 2 to 5 kilometers. For these corridors it is few reasonable to think about other modes which will need specific infrastructures and equipments and which will not be compatible with the present tramway system, for investment and operational cost levels located in the same rough estimates.

So, the choice of system for the corridors located at the end of a tramway's line of the 2^{nd} stage network would be limited to the tramway extension or a bus in a separate right of way.

The frequentation of corridors will be a determinant element for the final choice of the system. We will look if the number of new passengers on the extended line operated with the tramway mode is sufficient to justify this extension.

On the contrary, the adopted system will be the bus; the TCSP line will be linked to the tramway line.

5.6.7.2 For the other corridors

For the other corridors the layouts are between 10 to 15 kilometers long. This level of length and a "relative independence of these lines in comparison with the tramway's network allows a wider choice of systems opening the door to new technologies. We can add to tramway and bus intermediate systems like Translohr, TVR, Civis, Phileas.
However it is important to think about the consequences of introducing new technologies in the metropolitan area of Bordeaux in term of scale economy (orders of rolling stocks, specific equipments for maintenance of rolling stocks and infrastructures, drivers' training, etc.) and "compatibility" with present modes (in case of a possible connection with the tramway network.
The tramway on tires Translohr presents similar costs than the tramway for a lower capacity: it is few reasonable to keep this system that is in the cost range of tramway going against the logical economy's scale of the city, even if its high interest is in an easy insertion in a urban site with very high constraints.
Concerning the TVR, if the investment costs are 25 to 40 % lower than the investment cost of tramway, the technological reliability of the system do not reach those of tramway. However the horizon in which enrolls the 3rd stage of TCSP network of the metropolitan area of Bordeaux allows us to think that this reliability will be confirmed.
At last the stake of Civis and Phileas is to improve the buses and classic trolleybuses adopting new guidance type equipment called "intangible" which has not led to a line under commercial operation.
To sum up, the choice of a system for the corridors not linked to the tramway 2nd stage network would be done between the tramway, the bus and an intermediate guided system on tires (out of Translohr).
Here also the waited frequentation will be a decisive element to direct the modal choice.

5.6.7.3 First facts for the modal choice by line layout

We give here the whole facts that will allow explaining the choice of a system.
Generally speaking, several facts must be taken into account into the definition of a new line of TCSP[36] besides the layout: the service's headway, the minimal unit capacity of vehicles – that follows the estimated frequentation on the most loaded section at the peak hour – and the degree of priority given to public transport which will determinate its attractiveness.
For mere reasons of comparison, the level of service that has been held on first approach for the estimation of potential frequentation of each layout is identical to the whole corridors, that constitute or not tramway's lines extensions.
For notice, this level was fixed on the basis of a level of service "objective" equivalent of those of the lines of 2nd stage tramway network, that is to say 4 minutes headway at the peak hour. This first hypothesis does not prevent to hold, afterwards, a headway more adapted in relation to the held project.
This leaves a supplementary room for maneuver to choose the most adapted system, while remaining in the relevant limits (particularly for the "heavy" TCSP systems like tramway, that is to say a minimum load taking into account the investments in play).
By way of example, to carry 2400 passengers per hour in comparable conditions of regularity and speed, we can turn to either the articulated buses of 105 spaces at the rate of one bus every 3 minutes, either TVR of 131 spaces every 3 to 4 minutes, either tramways of 220 spaces every 5 minutes and 30 seconds.

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[36] TCSP Transport en commun en site propre, Public transit on separate right of way

5.6.8 Synthesis

The "project the more relevant" is the one, which presents the best compromise between the concern to optimize the frequentation, maximizes the effect of urban structuration and the legibility of layout, and minimizes the insertion's difficulties, in the eyes of an adapted mode of transit with expected charges.
This more relevant project follows then from the combination of three factors, which define it:

- the itinerary or layout,
- the transit mode,
- the operated length, the TCSP being able to reveal itself to be relevant on only one section of the studied link.

These three factors interact strongly between them: the choice of the mode acts on the insertion's constraints (and then on the layout) and on the waited frequentation, that itself interacts on the modal choice and on the operated length.

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Annexe

1. Current Trends of Light Rail

The tramway revival in France and other countries is not up to date or a fashion; three reasons explain this continuous expansion:

A. For carrying potential flows of 2000 to 5000 passengers per hour per direction, the tramway is the public transit mode the most adapted.

Trying to carry the same flows by buses is not impossible but this costs more. Operating cost of the space per kilometer offered PKO is on an average twice more expensive for bus than for tramway. The question of vehicles capacity is an essential question but little mentioned. An articulated bus line on a separate right of way of tramway type costs a little less in investment, but to carry 3000 passengers in one hour on a given section we need:

- 27 articulated buses (110 spaces with 4 passengers / m2)
- 10 trains of tramway type Montpellier Citadis 401 (300 spaces with 4 pas. / m2).

B. Tramway is an exceptional tool of renewal

On the contrary of the busways and metros, the projects of tramways oblige to handle the public space from one front to another front including crossed places. For example, at the beginning of the first three projects of Nantes, Grenoble and T1 of St Denis, this aspect was considered as a constraint but rapidly adapted by elected representatives as a strong point and a lucky.

To understand that the tramway is an exceptional tool of urban renewal we have to ask ourselves to whom benefits the expenses realized:

- for the system, the benefit is limited to the customers,
- for the urban landscape, the benefit is stretch to all those who frequent the site.

C. Tramway is a tool well known to fight again the car expansion

The main political strong point of tramway is the main reason of his eviction: the tramway was removed because it embarrassed the car and we put it again because it embarrasses the car.

The tramway is today the best tool to solve this contradiction:

- removing the cars of a street, if the street does not fill with pedestrians, nobody will understand why and the cars will return quickly.
- replacing them by rails (with bonus grass) and this decision is understood.

The main advantages of LRT are its commercial speed, its capacity, its attractiveness to car users and a number of qualitative factors, which are called "image". LRT is not only seen as a means of transport, but also a tool of urban design and improvement of public space. LRT also has the important advantage of running on electricity. LRT is non-polluting mode at the point of use. There is now considerable evidence that LRT attracts car users.

Surveys of passengers on new LRT systems in France, Canada and UK have shown that although the majority of passengers were drawn from other public transport, around 15 to 20 per cent formerly made their journeys by car, with about the same number making new journeys. In the right location, LRT can be very successful and can justify its costs.

2. The life cycle cost of tramway and urban bus

Across an example, the figures of Montpellier for the year 2003 presented by the general manager of the operator of Montpellier's network TaM, we try to show how the LCC and in final, the ratio receives/expenses is positive for the tramway and only 39% for buses.

PHYSICAL DATA	TRAMWAY (1 line – 15 km)	URBAN BUS (15 lines)
Rolling stocks	30 trains	149 buses
Vehicle km 2003	1 613 000 km	5 882 000 km
Spaces km offered 2003	450 100 000 spko	470 700 000 km
Carried passengers 2003	24 600 000 pass.	19 200 000 pass.
	INVESTMENT	(In Million Euros)
Compared investment cost (out of city beautifying)	317 ME	103 ME
Annual deadening	On 23 years 14.0 ME	On 16 years 6.3 ME
Yearly financial expenses	At 5 % 8.0 ME	2.4 ME
	ANNUAL COST 2003	
Investment cost	22.1 ME	8.7 ME
O&M costs	14.2 ME	28.4 ME
Total (investment + O&M)	**36.3 ME**	**37.1 ME**
	2003 RATIOS	
Cost / SpKO (Inv + O&M)	8.0 Cents E	7.9 Cents E
Cost / passenger	1.47 E	1.93 E
O&M cost / passenger	0.58 E	0.58 E
R / E (without invest. cost)	101 %	39 %
R / E (invest+ O&M)	39 %	31 %

Source: M. Le Tourneur, "Le développement du Tramway en France" Journée ATEC du 3 Juin 2004, Ppt.

Fig 1: Comparison between investment and operating costs of tramway

1st line and 15 bus lines with data of 2003 in Montpellier

3. The success of Light Rail transit

After the recommendations of Prof. Vukan Vuchic in "Livable Cities", and the guidelines of UITP about the "Light rail for liveable cities", we list the main parameters, which characterize the light rail transit.

3.1. Capacity

Investment costs are high (we saw in above chapters, costs are between 15 to 40 M € per km according to the localization and the level of spaces offered), and thus the challenge is to develop the right mode in response to the right transit need.

Light rail is the ideal mode for carrying between 3,000 and 11,000 passengers per hour and per direction.

3.2. Speed and regularity

LRT, thanks to their high performance, light rail vehicles accelerate quickly and can attain good service speeds. With a segregated right of way and priority at traffic lights' crossings, which make light rail congestion free, LRT has a good average commercial speed (which depends also of the length of inter-stations and the real priority at traffic lights).

Measures to reduce dwell times at stops (e.g. stepless and gapless boarding, wide doors, tickets sold off the vehicle) increase speed and regularity and also improve the accessibility of the system.

3.3. Reliability

Congestion-free transit is regular and hence reliable. Thanks to this reliability, high frequency time tables at peak hours can be designed, obtaining better passenger flows. Light rail can also operate when adverse meteorological road conditions such as snow or ice affect road traffic.

3.4. Environment-friendly

LRT produces no emission at street level with electric traction. Modern traction equipment allows regeneration of breaking energy and consequently considerable energy saving if the operation of vehicles is organized on the line (vehicles braking and vehicles accelerating in the same time and the same electric section).

LRT is a relatively silent transit mode and rolling noise and vibration can be attenuated further by good maintenance of vehicles and tracks. Floating slabs under the rails can attenuate vibrations, "green" track reduces noise even more (grass-covered).

3.5. A positive image for the city

LRT can be fine on the aesthetic point of view and gives a strong positive image to the city. Extensive experience shows that customers' response is more enthusiastic than with improved bus system.

Using LRT contributes positively to the social dimension of a city, improves the quality of life and makes it more liveable.

3.6. Impact on urban life

Light rail schemes are not only transit projects, but also city projects. In contrast to bus routes, light rail tracks are permanent and highly visible. Light rail is thus a strong long-term political commitment of the authorities in favour of public transit.

LRT contributes to the regeneration and modernisation of urban centre and to the development of new areas. It attracts real estate development and the creation of new housing, new offices and shopping centres along its path. It increases the value of existing real estate as well.

Light rail systems encourage the compact and dense development of towns and cities and avoid unnecessary urban sprawl, increasing their efficiency.

3.7. Impact on the overall transit situation

Success of LRT depends on a well-thought redesign of the existing public transit lines, as feeders to light rail lines, to make the structure more visible, integrated, understandable and consequently user-friendly. It will lead to an increased use of public transit, and consequently has a positive impact on the modal split.

3.8. Development by stages

The development of a LRT could be planned and executed in several stages, providing benefits to its clients and operator from the early beginning of the project. Initial street running operation or "basic" rolling stocks could reduce high initial capital costs and attract private partnership with a reduced risk of overspending or prolonged start of operation. Hence, below the critical capacity threshold, buses or other intermediate transit modes could be more appropriate, securing capabilities for introduction of light rail at some later stage.

Other parameters of course, should be added to the list above as comfort, accessibility and ease of use, safety and adaptability.

4. Future developments

4.1. Technology

Over the last 20 years, low floor technology, AC chopper control and modular vehicle design concept have been widely introduced. Trends for the near future will include the introduction of composite materials, and measures leading to lower energy consumption and simpler maintenance.

Current collection at ground level or batteries may improve light rail's visual aspect in historic city centres (e.g. Bordeaux, Nice, Angers, etc.). Complementary to "classic" or French Standard light rail, new and innovative "intermediate" forms of guided transit are becoming available. Several types of "tramways on tyres" are under operation in France (in Nancy, Caen, Rouen, Clermont–Ferrand) and under construction in Douai.

Dual-mode or hybrid drive systems, combined with onboard energy storage devices like batteries or flywheels, will allow circulation beyond the bounds of track and overhead catenaries.

4.2. An affordable Light rail

High investment costs dissuade to begin the planning and construction of a new LRT line. Harmonisation of LRV design, wide constructors bid should result in lower unit prices and a LCC approach should lead to lower operation & maintenance costs.

New financing techniques such as Public Private partnership could help to fund new projects.

LRT can be very appropriate as a complementary mode in wide metropolitan area: for transit within suburbs and for links between different suburbs by avoiding the urban centre where the separate surface right of way is very difficult to obtain.

Tram-trains running on former railways tracks in rural areas and in the suburbs, continuing in the city on urban tramway tracks allow a journey without break in riding between town and suburbs.

5. Conclusion

We saw in this paper that French transit industry has successfully developed since the 1980's, the light rail system even an automatic light rail, the VAL, which is adopted in three cities like Lille, Toulouse and Rennes. Among the 39 LRT lines on 19 networks under operation we find several kind of light rail levels.

Systems in Nantes (1985), Grenoble (1987), and Lyon (2000) were built mainly in-street, with urban renewal and improved beautifying aesthetics of the street as main objectives. Similar to Germany and Switzerland, urban transit in French cities is managed by a single authority UTOA, that has significantcontrol over operations and fare policy. By this measure, France's light rail systems have been more successful delivering frequent, high-quality service that is well integrated with feeder services and the built environment.

All French systems are primarily for local travel within a city or built-up area providing many stops with convenient walk-on access.

LRT is typified by its variety of Right of Ways (RoW), which include:

- 1. a single line (Montpellier L2),
- 2. in-street with traffic (Saint Etienne L4),
- 3. on-street segregated (T1,T2,T3) most of the linear of French LRT,
- 4. various kinds of at-grade but segregated track alongside a road (Lille's tram along the Grand Boulevards of Roubaix Tourcoing) or in median (T3 on the Marshal's Boulevard South)
- 5. Completely separate private RoW, which may or may not be grade separated
- 6. Tunnels or subways (Strasbourg Line A, Rouen L1 and Lille Line 1 & 2).

This flexibility is the essence of LRT.

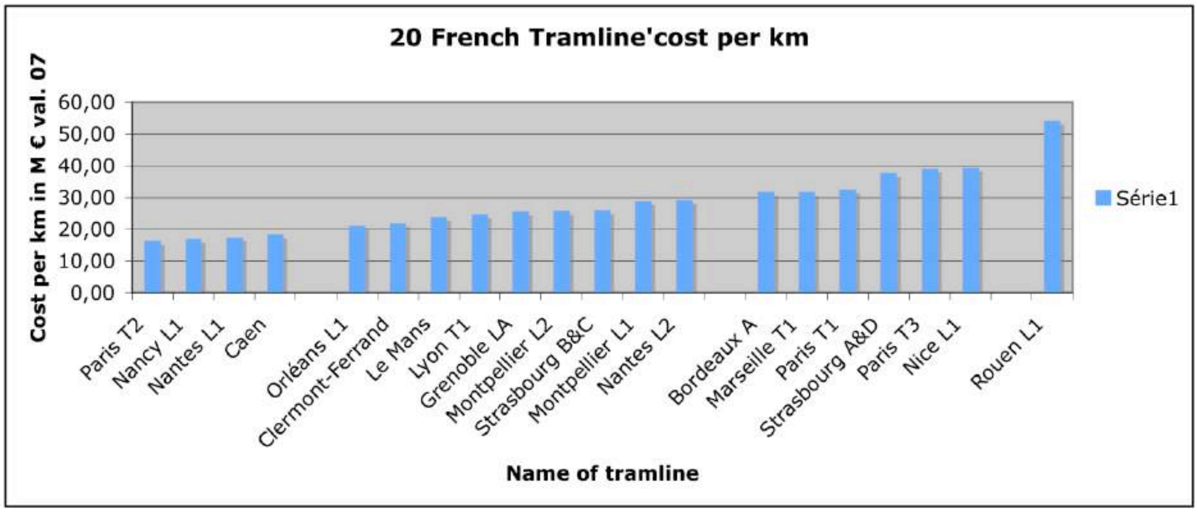

Fig 2: The four range of Tramline's cost per km in M € val 07

In the chapter 3 above, we have made the description of different lines of tramways under operation today in France. Among these lines we distinguished the high flow lines around 100,000 passengers per day and new lines being as yet around 50,000 passengers a day.

We found three categories of lines:

- the lines whose cost is in a range of 15 to 20 M € per km, generally built on former railway tracks in Paris Trans Val de Seine T2 or Nantes 1rst line. We find also in this range the lines of tram on tyres TVR of Nancy and Caen (cf. Figure 14 above).
- the lines whose cost is in a range of 20 to 30 M € per km, we find in this range most of the new lines built on surface these last years, Orléans, Le Mans, Clermont Ferrand (Tram on tyres), Montpellier L1 & L2,
- the lines whose cost is in the range of 30 to 40 M € per km, we find in this range the first lines with a specific equipment i.e for Bordeaux the ground electric alimentation, for Marseille it is 2.36 vehicle / km vs 1.49 for Le Mans L1, for Paris T1 it is also 2.94 vehicles / km and an architectural insertion (cf.Chemetov), Strasbourg A & D it is a tunnel built in the sands of Rhein river, Paris T3 it is also an architectural insertion in Paris Marshal's Boulevard and Nice choosed a specific vehicle with batteries to go through 2 magnificent places.

At last we find a network out of range, the first line of tramway in Rouen (cf. bibliography: 2 km and 5 stations underground costed the same price than 9 km of surface line and 15 stations, the 11.6 km costed 2500 MF or 381 M€ with the economic conditions of 1990).

If we examine the lines in the first range below 20 M€ per km, even if the cost is low the space kilometre offered per day on line T2 and Nantes L1 are respectively 1. 863 M and 1.064 M per day. This offer is of the same level than the tramway of Strasbourg line A & D, Nantes L2, Montpellier 1st line (140,000 passengers per day).

For the tram on tyres of Caen and Nancy the offer is respectively 0.763 M and 0.534 M per day what is correct to carry 50,000 passengers a day.

As it is said in "La Gazette des Communes" (cf. Bibliography), Systra, project manager, indicates that a tramway line costs nowadays around 20 M€ per km without big public works like bridges, tunnel, etc. and specific beautifyings outside the RoW of 6 to 12 meters wide. Extension of a line is generally 25 % less expensive than the former line for which the master of works should pay a workshop and a fleet of vehicle.

For the flows around 20,000 passengers and below the UTAO could choose a project by stage, building a busway and operating a BRT with articulated or sometimes bi-articulated buses for some years. When frequentation will increase enough a project of tramway could be realized.

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