HIGH-FLOW BUS OPERATION
ON URBAN ARTERIAL ROADS

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by

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To Cristina and Juliana, who listened, sympathized and encouraged.

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ABSTRACT

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HIGH-FLOW BUS OPERATION
ON URBAN ARTERIAL ROADS

by

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The research undertaken in this study is related to the investigation of bus priority measures in urban areas. The work has been concentrated on the evaluation of the effectiveness of high-flow median bus lanes prior to their suggested large-scale field implementation in the metropolitan areas of Brazil.

A comprehensive literature review identified the extent to which bus priority schemes have been investigated. It included critical comments on previous studies. Simulation was adopted as the method of approach. A microscopic model was formulated to reproduce the traffic behaviour of all classes of vehicles travelling on a section of a one directional multi-lane urban roadway. The specially constructed computer program, set in a modular format, enabled the representation of both bus priority and non-priority configurations. The 'do-nothing' situation was characterized by all vehicles sharing the use of the road space while in the 'priority' situation the median lane was reserved for the exclusive use of buses.

Particular emphasis has been given to the calibration and validation stages of the model. Traffic data was mainly obtained from time lapse films taken in Brazil. Comparisons between predicted and observed measures of effectiveness showed that the simulation model could adequately describe traffic behaviour over a wide range of conditions.

The effects of geometric and bus operational aspects have been examined by applying the model to alternative configurations. The cases studied included such measures as the adoption of bus platoons, different signal progression techniques, bus stop locations and cycle times.

1. INTRODUCTION

1.1 General background

Transportation plays an essential role in the process of economic development. It is a complex activity, expressing the spatial interactions between different elements of the socioeconomic system. The growth of economic activities and population in most Latin American countries in the last few decades, together with industrialization, rapid urbanization and increasing levels of per capita income have caused increased demands for faster, more reliable and more flexible passenger transportation. At the same time, energy importing countries have faced a growth in the real cost of energy relative to other factors of production. Consequently, the transport sectors of these nations have been increasingly concerned with the urgent need to improve urban transport efficiency.

Within this context, the research reported in this study is concerned with the operation of urban bus systems. Quite often buses are the only means of public transport available and therefore the traffic engineer must become involved with methods that encourage efficient and rational bus operation.

The most common technique used in urban areas to give bus priority over other traffic is to allocate special lanes for their exclusive use.

1.2 Objectives

Over the past years most of the reserved lanes implemented have been of the 'with-flow' type where buses travel in the same direction as the general traffic. In this thesis, the work has been confined to the investigation of the operation of buses on urban median 'with-flow' bus lanes. The importance of this area of study arises from Brazilian governmental policies which have recommended the implementation of such lanes to traffic situations usually encountered in metropolitan areas, i.e. high flow of buses travelling on multi-lane radial arteries.

Initially, the objectives of this study were defined as:

a. the identification of the adequacy of bus lanes as priority measures.
b. the investigation of the extent to which bus priority schemes have been examined by previous studies.

A comprehensive and critical literature review was therefore undertaken and gaps in the existing knowledge were identified with specific regard to the aforementioned Brazilian conditions. It was concluded from the review that the potential for median bus lanes in urban areas had not been adequately established.

1.3 The study

This step involved the selection of simulation as the method of approach to investigate the effectiveness of high-flow bus lanes. A computer based microscopic model, capable of simulating the behaviour and response of traffic under a wide range of operational conditions, was formulated. The main measures of effectiveness compiled by the model were travel time and energy consumption. The model was calibrated and validated with the help of field data collected in Brazil. This tool was then applied to the evaluation of alternative geometric and bus operational configurations.

2. REVIEW OF BUS PRIORITY TECHNIQUES

2.1 Introduction

Providing priority treatment for public transport is not a new or revolutionary concept. Young {1} reported that as early as 1914 a dual carriageway road was built by the city of Liverpool which incorporated median strip reservations for trams. At that time, companies providing public transport were frequently allowed special operating privileges to compensate for the public service they offered and the regulated fare constraint under which they were obliged to operate. Where bus service replaced tram service, and competition for roadway space emerged between buses, cars and lorries, various traffic engineering measures were applied to provide bus priority.

In the United States, the Clean Air Act of 1970 that required the reduction of vehicular emissions in large urbanized areas has been the major force used to expand public transport funding. Also, as a consequence of the 1973-74 energy crisis, policies and technologies to make the movement of goods and persons more energy efficient received considerable legislative attention because the transportation sector accounted for about 60 percent {2} of petroleum use in the US. In 1975 the Urban Mass Transportation and Federal Highway Administrations required regional Transportation Improvement Plans to include and thoroughly consider any possible low-cost, short-run methods of expanding the effective capacity of existing highways, transit and related networks. Priority techniques for high-occupancy vehicles was one of the major policy options under the recommended guidelines {3}. The combined effects of environmental concern, energy conservation and planning requirements has produced a tremendous expansion of the use of preferential bus lanes within American urbanized areas in the last decade.

In Britain, the Road Traffic Regulation Act 1967, as revised under the Transport Act 1968, provided legislation which simplified procedures and widened the powers of highways authorities to restrict the use of streets or lanes to specified classes of vehicles. In 1969, the Minister of Transport set up a working group to look into urban transport problems which recommended the introduction of a series of Bus Demonstration Projects {4}.

A number of studies have been undertaken to describe the 'state-of-the-art' of bus priority techniques as a result of the appreciable number of schemes that have been introduced throughout the world during the last two decades. In 1966 brief details of bus priority schemes then known to be in operation in Britain were published in a circular {5} by the Public Transport Association. Constantine and Young {6} contacted local authority engineering departments to ascertain the extent of priorities in Britain. The survey reported 35 instances where reserved bus lanes had been instituted or were in the development stage. Brower {7} mentioned a number of examples of traffic lane separation in 10 European countries and in the USA. A circular from the Public Road Transport Association {8} listed 45 British towns and cities where bus priorities were in operation in 1969. In 1972, Merin {9} presented reports on the status of projects involving exclusive or preferential treatment of buses on highways. Bus priority was acknowledged to be a measure of extreme importance by the NATO Committee on the Challenges of Modern Society and was included as one of the five projects in the Urban Transportation Pilot study which commenced in 1973. Among the objectives of the study {10} were: to produce a 'state-of-the-art' of the various types of schemes (including practical examples), to give guidance on the suitability of the different priorities, to identify gaps in the available knowledge and to make recommendations. Levinson et al {11} documented more than 200 existing and proposed preferential bus facilities world-wide. Apart from recommending needed research, economic and social benefits and costs were also identified. In 1974 in the United States, the Urban Mass Transportation Administration {12} described its research, development and demonstration projects in several areas including those on bus priority systems. The United States Department of Transportation {13} presented an overview of priority techniques designed to make more accessible the body of knowledge that constitued, in 1975, the 'state-of-the-art' in priority techniques for buses. The Organisation for Economic Cooperation and Development {14} produced an inventory of bus lanes and accompanying measures in member countries.

A bibliography {15} that comprised 350 references of studies on bus priority lanes was compiled by the International Union of Public Transport. Richardson and McKenzie {82} provided an assessment of techniques for priority lane projects with a view to defining methods of providing priority lanes under Australian conditions. Various bus system improvement projects are included in the reference source compendium {16} assembled by the LEA Transportation Research Corporation in 1977. A report {17} by the National Bus Company described briefly the 725 schemes operating in Britain at the Autumn of 1977. The features of the schemes are summarized in figure 2.1. Runnacles {115} reviewed selected approaches to bus priority in a number of West European countries noting how they differ from each other and from the British experience. Bennett and Elmberg {49} conducted a study whose objective was to review the extent to which different types of priority were used in various parts of the world. The purpose of a report by Fisher and Simkowitz {18} was to describe, summarize the results and draw implications of high occupancy vehicle preferential projects in the United States. Crowell {2} limited his review to high occupancy vehicle lanes within central city locations. His report represented an analysis of the questionnaires responded by traffic engineers employed in 54 cities in North America. May and Westland {22} provided an inventory of Transportation System Management projects, including bus priority treatments, which have been implemented, evaluated and documented in six selected European countries.

2.2 Objectives of the schemes

Objectives for the introduction of bus priority schemes include the fulfilment of social, political, economic and environmental aims:

a. they supply means of improving mobility by enabling a more efficient use of the existing roadway system.

b. they provide motorist with a reasonable alternative to their private vehicles. Although isolated schemes may not lure drivers from their cars, composite schemes incorporating bus priority as part of the package may cause appreciable transfer from car to bus.

c. they enable economic benefits to arise when, along the road, maximum person flow with minimum net person delay is achieved. This is likely to occur when the bus passenger flow is high and the method of giving priority to does not penalise other vehicles to a great extent.

d. reductions in bus operating costs can also be experienced by a possible reduction in the number of buses and staff required during peak periods. It is also reasonable to expect bus fuel consumption improvements.

e. they provide a better service for those citizens who depend on buses.

In some cases more limited objectives, such as the improvement of the image of public transport, have been quoted.

2.3 Different bus priorities

Most bus priority treatments consist of reserved bus lanes and are implemented on city centre roads. A typical example of a major metropolitan area system is shown in figure 2.2. Freeway-related treatments are relatively few in number and are, in most of the cases, found or proposed in large American cities.

Longitudinal priority separation of travel ways can be provided in a variety of forms with respect to {23}:

a. type of way - type, method and degree of separation of bus travel way
   - i. mixed traffic lanes - no special arrangement for buses
   - ii. exclusive bus lanes - physical separation from other traffic is used
     includes: median lanes, bus streets and busways.
   - iii. bus lanes - no physical separation is used
     includes: kerb lanes and contra-flow lanes

b. alignment - the characteristic that influences the type of service
   - i. city roads and arterials
   - ii. freeways

iii. independent alignment

c. travel direction - vary depending on the availability of space
   i. one way - only one direction is chronically congested
   ii. reversible - can be used for opposite directions during the two peaks
   iii. two way - provides priority treatment for both directions

d. duration - time of priority operation
   i. single peak period
   ii. both peak periods
   iii. permanent

e. vehicles - classes allowed on the priority facilities
   i. all classes of vehicles - refers to mixed traffic
   ii. buses and high occupancy vehicles
   iii. buses

For the purpose of this work it may be useful to describe the characteristics of the most common bus priority schemes adopted on arterial and city roads: bus lanes and priorities in mixed traffic flow. Although bus streets, busways and freeway related techniques are more briefly mentioned, references relating to them are also included.

2.3.1 Bus Lanes

Bus lanes, in general, serve major concentrations of buses in areas of frequent congestion. They are a common form of priority treatment and many cities have implemented them on central-area and radial roads. According to the definition of the Institute of Traffic Engineers {24}:

> "A transit lane is that portion of the roadway devoted entirely to the use of transit vehicles (1) in motion (2) in the act of receiving or discharging passengers, and (3) when stopped in response to street traffic controls. Other vehicles may enter, leave and cross this lane only when permitted but may not substantially interfere with the transit vehicle movement in the lane. Transit vehicles may use other street lanes on a street where a transit lane is established only when

permitted but under no circumstances may they make service stops outside the transit lane. The purpose of the transit lane is to segregate transit traffic from other vehicles and to prevent interference of one by the other."

Bus lanes operate in either normal-flow or contra-flow mode. The different types of bus lanes are illustrated in figure 2.3.

2.3.1.1 Normal-flow

Definition

Normal-flow lanes permit buses to operate in the same direction as the adjacent normal flow lanes and act as queue jumping devices by which buses are allowed to by-pass the non priority vehicles waiting at traffic signals. While the reserved lane is normally the kerb lane, median bus lane schemes are an alternative possibility. Also, normal-flow bus lanes are sometimes used to create bus-orientated one-way street pairs. Figure 2.4 includes typical American kerb and median bus lanes with the appropriate marking and signing. The layout of a typical UK kerb lane, including signing, is presented in figure 2.5.

2.3.1.1.1 Kerb lanes

Application, design and operating features

Kerb lanes are the most common measures used to provide priority for buses in urban areas. They have the following main design and operating features:

a. Parking and loading - have to be prohibited during the hours of bus lane operation.

b. Hours of operation - kerb lanes can be reserved during peak hours only or throughout the whole day.

c. Width - a minimum of 3 metres is normally required.

d. Setback - the length of the setback (illustrated in figure 2.5) is selected in order that {10}:

   i. the kerb lane carries, under nearly saturated conditions, the same pcu flow as each of the offside lanes

   ii. all buses pass through the junction during the first green period.

   Priority lanes with setbacks tend to be used with short sections of priority lane where the main objective of the lane is to allow priority vehicles to jump the queue caused by isolated intersection traffic signals and other bottlenecks. On the other hand, priority lanes which are continuous through signalized intersections are usually related to long priority lanes {82}. More details on the selection of the appropriate setback are given in section 3.4

e. Taper - to allow a safe manoeuvre to non-priority vehicles merging into a smaller number of lanes. A minimum taper value of 1 in 10 is recommended for use in the UK {10}.

f. Lane use - apart from emergency vehicles, taxis may be allowed to use the priority lanes where total bus volume is under 60 buses per hour {19}. In the normal UK practice bicycles may also use kerb bus lanes. Buses are only recommended to leave the bus lane if they are required to pass a stalled vehicle {19}. Careful consideration must be given to non-priority turning vehicles as they may disrupt the bus lane operation. Where pedestrian crossings are heavy, the prohibition of right turns (left in UK), for vehicles other than buses, improves bus efficiency. On two-way streets, left turn (right in UK) movements may have to be banned in order to increase lane efficiency. Left turn (right in UK) by buses require bus weaving from kerb to median lanes and some special sign controls {11} may be adopted (see figure 2.11).

g. Traffic separation - solid white lines and clear signing of bus lanes are necessary both for safety reasons and operational efficiency.

Advantages and disadvantages

Kerb bus lanes, operating in the same direction as the traffic flow are relatively easy to implement. They involve minimum changes in road routing and are, therefore, cheaper to implement than median and contra-flow lanes. Their use can be restricted to peak periods only, allowing the lane to be used by mixed traffic during non-priority hours. However, they are often difficult to enforce since non-priority vehicles are attracted to the kerb lane due to its free-running conditions.

Loading and unloading, as well as parking, may have to be limit to non-operational hours. In some occasions, the adoption of such a bus lane may cause an increase in traffic congestion for non-priority vehicles {10}. This congestion may induce diversion and further congest to neighbouring streets.

Kerb bus lanes are usually slower than other types of lanes due to marginal friction caused by closeness to kerb, trees, poles and pedestrians. Furthermore, they have their effectiveness diminished whe used in cities with inadequate enforcement of traffic controls and chaotic street conditions {23}.

2.3.1.1.2 Exclusive median lanes

Application, design and operating features

Exclusive median bus lanes are located in the middle of two-way, multi-lane roads, often using the median right-of-way formerly reserved for tram operation. They are well suited for express bus services operating along wide multilane arterials. Buses in such lanes, operating nonstop or limited stop, could exceed peak-hour car speeds {19}. Median lane projects should include the following design and operating features:

a. Pedestrian islands - at bus stops, islands separating the median bus lane from the adjacent traffic lanes must be wide enough for passenger safety. It is recommended to maintain a minimum island width of 1.5 metres {19}. Access to these safety islands must be provided at the stopping place for passengers boarding and alighting.

b. Hours of operation - although median lanes are usually in effect throughout the day, part-time lanes can also be provided.

c. Width - a minimum lane width of 3 metres is recommended for one-way operation {19}.

d. Lane use - even if a median bus lane is adopted for part-time use only, it is recommended to keep the transit vehicles operating in the shared centre lanes during the off-hours with stops being still made at the designated loading islands {26}. There is no reason to restrict right turning (left in UK) by general traffic since these movements do not affect the operation of the bus lanes. Left turns (right in UK) by non-priority vehicles must be prohibited, if two-way centre lanes are established, and replaced by three right turns. Buses leaving the bus lane can merge directly with general traffic. Special traffic signals have to be adopted where left or right turns by major bus flows are required.

e. Traffic separation - solid white lines can be adopted in the separation of the bus lane from the general traffic lane {19}.

Advantages and disadvantages

The location of bus lanes in the middle of a roadway results in the removal of bus conflicts in the kerb lanes due to commercial deliveries, parking and right turns (left in UK). Such lanes are faster than kerb lanes {23}. In some situations they may be used in conjunction with a bus preemption system of signal control. The capacity of a median bus lane can be further increased by raising it over critical intersections {25}. Median bus lanes can be designed to allow future conversion to rail or other fixed guideway systems.

Only relatively wide streets can be used because of the necessity of accommodating the median pedestrian refuge. Bus stop placement requires passengers to cross lanes to reach the buses. The alleviation of the right turn (left in UK) traffic problem, that exists with the kerb lanes, is replaced by the prohibition of left turns (right in UK) in order to minimize the interference from users of the median lane priority facility, but, where left turns (right in UK) where previously prohibited this ceases to be a problem. Either buses must be adapted for left-side (right in UK) passenger loading and unloading or separate loading islands must be installed (see figure 2.4). The speed of non-priority vehicles may be increased both along the priority and on adjacent streets.

2.3.1.2 Contra-flow

Definition

Contra-flow bus lanes enable buses to operate in the opposite direction of the normal traffic flow. In the great majority of the cases, they are installed in one-way streets and make use of the kerb lane, being separated from the other traffic by a continuous pavement marking. In some cases, the reserved bus lanes are also made available to taxis. An example of a contra-flow bus lane with typical UK signing is shown in figure 2.6. Typical American contra-flow bus lane markings and signs are included in figure 2.4.

Application, design and operating features

Contra-flow bus lanes are usually found in town centres which contain a large element of one-way traffic. The bus lane should not cause an unreasonable reduction in the peak-direction capacity for other traffic, unless such reduction is an integral part of regional transportation policy objectives {19}.

Some design and operating features of the contra-flow bus lanes include:

a. Parking and loading - kerb parking and standing have to be prohibited during hours that bus lanes are in effect.

b. Hours of operation - normally they operate 24 hours a day.

c. Width - generally about 3 metres wide, with a maximum width of 4 m where only paint separation is used.

d. Lane use - buses and emergency vehicles only, although taxis may be permitted in the lanes where peak bus volumes are less than 60 buses per hour {19}. Buses should only leave bus lanes in emergencies caused by stalled vehicles.

e. Traffic separation - the most frequently adopted practice, in order of popularity {20} are:
   i. a continuous white line of width between 15 and 20cm;
   ii. a double white line
   iii. continuous concrete kerbing

   The physical separation should be mountable to permit buses to pass stalled vehicles.

Advantages and disadvantages

Unlike the normal flow lanes, the contra-flow technique is largely self enforcing. Contra flow bus lanes permit the retention or restoration of bus services along the routes used prior to implementation of a traffic management scheme. By permitting more direct bus routing, considerable savings in journey distance can be achieved, and therefore, much greater benefits than normal flow lanes may arise from their application. Also, it is generally desirable, from the point of view of the bus passenger, to keep together the inbound and outbound routes of a bus service.

A major disadvantage is that the pedestrian accident hazard is increased by buses running in the opposite direction to the normal one-way flow. This problem seems to be most acute during the initial months of operation. Also, the lanes may complicate loading and access to adjoining properties since the simple solution of allowing loading and unloading to take place in the lane at certain times of the day is rarely possible due to physical separators, accident risks and statutory requirements. Some turning conflicts with opposing traffic are re-introduced, and, on one-way streets with frequent signals, buses may have to operate against the signal progression. The delays of buses travelling against a "green wave" can be minimised by selecting a convenient sequence of near-side and far-side stops {23}.

The installation of a contra-flow bus lane requires special junction design, signs, signals, pedestrian barriers. Therefore, its implementation is considerably more expensive per unit length than that of a normal kerb lane {10}. In practice, modification of the junctions at the two ends of a contra-flow lane may cause extra delay to non-priority traffic and even, in some cases, to the priority traffic itself {21}.

2.3.1.3 Practical applications and results

A large number of bus priority schemes and traffic management schemes which include an element of bus priority have been put into practice throughout the world. The National Bus Company {17} have listed more than 700 schemes operating in Britain alone. However, not all schemes have been quantitatively assessed and in some cases the complexity of the schemes has been so great that true assessment has been virtually impossible.

Space does not permit an extensive documentation of the many priority projects implemented, but tables 2.1 and 2.2 provide a summary of the main results found by the adoption of bus priority lanes in several cities of the world.

2.3.2 Bus priorities in mixed urban traffic flow

Bus priority treatments in mixed traffic flow include priority at traffic signals, priority manoeuvres at junctions and the improved location of bus stops. They are usually applied in situations where bus flows do not justify the allocation of a whole lane to buses, or where, for other reasons, such treatment is not appropriate. Nevertheless, these preferential measures can be used in combination with the bus priority schemes described in previous sections.

Comprehensive traffic schemes combine town and traffic planning measures with public transport improvements. Some of the measures adopted in the creation of such schemes are also mentioned in this section.

2.3.2.1 Priority at traffic signals

Traffic signals represent one of the major causes of bus delays. It has been found that delays caused by traffic signals account for more than half of the overall bus delay time in urban areas {11,38}. In some instances these delays can be substantially reduced by controlling traffic signals to favour buses.

In order to improve the operational performance of the buses, the priority at traffic signals can be provided in area traffic control schemes or be limited to isolated intersections. Results obtained in some European cities have been briefly presented by May and Westland {22}. Bus signal adjustments include passive and active systems.

2.3.2.1.1 Passive system

Passive bus priority techniques at traffic signals only acknowledge the presence of a bus in terms of the timing pattern. The predetermined timing pattern is not affected by the presence or absence of buses. Such techniques require the retiming and re-phasing of signals, giving priority to buses in area wide timing plans and metering of vehicles.

Adjustment of cycle length. The provision of short cycle times at intersections carrying an appreciable flow of buses will generally benefit the buses {10}. If reduced cycle lengths increase congestion to the point of affecting bus operation, this measure will be counter-productive. The introduction of a bus lane on the approach to the junction will benefit buses from the queue-jumping aspect of the bus lane and from the shorter delay the buses will face due to the shorter cycle time.

Splitting of phases. Phase splitting is a way of reducing the effective cycle length for buses without necessarily changing the overall cycle length. This technique requires a minimum of two nonbus traffic signal phases for each bus phase or, as a minimum, a three-phase operation with buses on only one of the phases.

In figure 2.7 a three phase operation with three phases A, B and C is represented. Buses travel on the main street and make use of phase A only. The normal phasing would be ABC. A bus arriving at the end of phase A would be delayed during phases B and C. However if phase A is split in two, a new phasing system ABAC could be achieved. Buses would, now, not have to wait longer than phase B or C. The net result is a reduction in cycle length for vehicles on phase A.

This technique was successfully used in Bern, Switzerland {40}. Field experiments were conducted in New South Wales to test the applicability of this form of bus priority to Australian conditions. A statiscally significant reduction in delay to buses caused by traffic signals was reported {41}.

Areawide timing plans. In areawide traffic control timing plans, priority to buses can be achieved by:

a. converting buses in passenger car equivalents in order to give more green time to phases being used by buses;

b. traffic signal coordination where progression of buses is taken in consideration.

It is common practice to coordinate on a fixed-time basis the timings of signals at adjacent junctions. The benefits arising from coordination are considerable. The reduction in delay to vehicles using the network gives savings in passenger, driver and vehicle time, and fuel and maintenance costs. Benefits in terms of fuel efficiency result from a decrease in the number of vehicle stops and some evidence points to a decrease in accidents {42}.

Manual and graphical methods are the least sophisticated techniques of determining the progression for the signals. Although these methods may be difficult when applied to large networks, they can effectively be used in a grid of one-way streets. On the other hand, several off-line computer optimization techniques, such as SIGOP, TRANSYT and COMBINATION, are increasingly being used to generate areawide timing plans which minimize vehicle delay.

TRANSYT is regarded as the most successful of the off-line programs. While TRANSYT {42} treats all classes of vehicles identically, buses behave in a different manner from other vehicles. Figure 2.8 exemplifies a typical progression of bus and other vehicles between two signals operating on a common fixed-time cycle. The dotted band represents the movement of the platoon. After crossing signal 1 in the centre of the platoon, the bus stops. The relatively slower average bus speed further delays the bus and, as consequence, the bus arrives at signal 2 after the main platoon. In the figure, the green indication at signal 2 is retarded to reduce the delay to the bus. However, this procedure causes some delay to the platoon of non-priority vehicles.

BUS TRANSYT {43} was developed to take particular account of buses and when used in Glasgow {44}, produced substantial community benefits by reducing the average delay per person travelling in the central area of the city; the disbenefits to vehicles other than buses were too small to be measured reliably. The program uses a special 'bus dispersion' formula that takes account of the variation in the journey time of buses along a link. Once delays have been calculated separately for buses and for other traffic, the total passenger delay is estimated based on the average number of passengers of each class. The optimizing routine then attempts to find signal settings which minimise total passenger delay. The BUS TRANSYT method is likely to be most effective when the average time spent at bus stops is considerable less than the cycle time of the signals and bus flow rates are relatively high (more than 10 to 20 buses per hour) {42}.

Metering of vehicles. Metering, also known as gating or throttling, is a form of traffic control technique that regulates the flow of traffic through an intersection from one or more directions. The basic principle is analogous to freeway ramp metering. During peak traffic times it is not always possible to avoid the formation of queues on the approaches of critical intersections. Widespread congestion may result from queued vehicles blocking adjacent intersections. The metering technique consists of removing the queuing from closely spaced intersections and transforming them to other signal-controlled intersections where queues can be allowed to form without affecting other traffic. Its application is limited to areas where sufficient space is available to store the queueing vehicles. Therefore its introduction is usually restricted to perimeters of central areas of towns. Careful consideration should be given to possible deterioration of the environment by queues of traffic transferred to new areas.

It is dangerous to apply the metering technique at an isolated intersection since alternative routes would allow traffic to divert around the intersection avoiding the restraint measure. This technique would therefore be most applicable to areawide control where central computer control exists. Detectors could monitor the volume of traffic in the system and control green times at the perimeter to limit volumes to below congestion levels.

In order to give priority to buses, it is necessary to provide them with means of avoiding the metered signal phases. This can be achieved by providing exclusive bus lanes on the traffic signal approaches, providing a special phase for the buses, diverting the bus route which bypasses the gating intersection and re-routing non-bus traffic to lead to a gating signal.

A metering technique was successfully applied along Bitterne Road a major arterial leading to the central area of Southampton. No special bus lanes were provided on the major thoroughfare. Free-flowing conditions were achieved on the main road by a series of linked traffic signals which were also used to limit the flow of traffic from side roads at periods of peak demand. Other traffic management techniques were used to separate different traffic movements and to give buses priority. The results of the evaluation of the Bitterne Bus Demonstration project {53} demonstrated that substantial improvements in person movement can be obtained by metering of vehicles.

The NATO/CCMS report {10} points out that despite traffic metering techniques are used in several cities in Europe, comprehensive 'before and after' studies of such schemes are limited to the one carried out in Southampton.

2.3.2.1.2 Active system

Active system, or preemption, is an alternative method of giving priority to buses at traffic signals. Preemption is provided by using selective vehicle detection equipment which can extend or recall the green phase on a particular approach once a bus arrival is detected. Therefore, buses approaching a green signal can extend the green beyond the normal maximum in order to allow the bus through. If the detection occurs during the amber or red time for the bus phase, a special demand can be given to recall the bus phase green as soon as possible, subject to minimum and intergreen limitations. Such procedure is graphically displayed in figure 2.9. These methods assume that the bus is not obstructed between the detection point and the stop-line. If this is substantially incorrect a bus lane must also be used. At those intersections with three or more signal phases, further facilities (inhibit period and compensation) may be included to reduce disbenefits to non-priority traffic. An inhibit period is provided when for a pre-set period following a priority change, all phases may run to their normal maxima if there is sufficient demand, i.e., priority changes cannot occur. Compensation is given if during an inhibit period, a phase which was previously curtailed or omitted can be given additional green in excess of its normal maximum green, subject to there being sufficient demand.

Actuation of bus signals can be done either by a radio signal from the bus, or by an inductive loop in the pavement. Whenever trolley buses are used a sensing device may be adapted on the trolley wire. Whereas standard loops react to the presence of any vehicle, some cities use a system where detection is restricted to specially equipped vehicles. An example of bus-preemption of traffic signal is given in figure 2.10.

2.3.2.1.3 Progression vs. preemption

The provision of signal progression involves no significant capital expenditure and requires only engineering and support services. A preemptive system is a more expensive technique. It requires considerable modification of the signal controller and the mounting of transmitters on all buses which are to receive priority. Therefore, signal maintenance costs are likely to increase. In Australia, Moore {41} concluded that priority lanes and passive bus priority at signalized intersections return considerable community benefits for the relatively small investment required for these schemes while active bus priority schemes at signalized intersections are a poor investment of public funds if the aim is to minimise person delay.

While improvements in bus journey speed {47} and regularity can be achieved by using preemption techniques at isolated intersections, a preemptive system adapted in a network of interacting signals with heavy bus flows (e.g., less than one-minute headways) might not provide any benefit over signal progression {45}. El-Reedy and Ashworth {46} (further details in section 3.3) found that the bus-actuated system of control best suited a low flow of buses while fixed-time control gave a better performance index with a higher bus flow. Cottinet et al {80} observed that, in a group of intersections, preemptive methods seem better than fixed strategies in light traffic and worse in heavy traffic (also refer to section 3.3 for further details).

Fisher and Simkowitz {18} pointed out that signal progression appears to be nearly as effective as preemption for express bus operation on reserved arterial lanes at a significantly lower cost since many cities already have interconnected traffic signals. They also observed that signal priority techniques, whether preemption or progression, are not as effective for local buses or buses in non-reserved lanes that have to stop frequently for passenger service or because of traffic congestion; the most effective application is in the case of express buses or buses in a reserved lane. Vincent {48} mentioned that the important limitation when dealing with co-ordinated signals is that the cycle time is not freely variable as in the case of isolated junctions. He also observed that it is difficult to decide where and when to use active systems in such conditions and that partly due to this difficulty it was decided, in Bern, to make the best possible use of passive systems of network control before continuing with active systems.

2.3.2.2 Other priority schemes

This section describes some of the other priority schemes that can be adopted to improve bus movements on urban roads.

2.3.2.2.1 Junction priority manoeuvres

Allowing only buses to turn right, left or proceed straight on, at junctions where these manoeuvres are not otherwise allowed, can enable buses to retain their traditional routes and/or save them from making lengthy detours.

A different solution is provided by a special designed signal installation called 'bus gate' {23}, shown in figure 2.11. In the example, a set of presignals are located at the end of the kerb bus lane prior to the main signals forming the so called 'bus gate'. In order to empty the gate area prior to the red phase (I in the figure), the phases of signals 1 are advanced by several seconds in relation to signals 2. During the red phase the kerb bus lane signal 1B is kept green. Buses are thus allowed to proceed to signal 2. Phase II starts by changing 1B to red, 1 to green, and a few seconds later, 2 to green. Buses are then the first vehicles to enter the intersection and weaving maneouvres are reduced. Progression is provided through signals 1 and 2 and the only disadvantage occurs to buses arriving at the pre-signals during phase II which then must wait until the beginning of next phase II to cross the intersection.

This design, introduced in Wiebaden, has been also in operation in a few other German cities for several years {23}.

2.3.2.2.2 Priority at bus stops

Much attention is given in this section to the location of the bus stops and ways of easing the passage of buses at bus stops are briefly described:

Bus bays. Buses are removed from the traffic stream while loading and unloading their passengers. Bus bays reduce delays for other traffic but may be a disadvantage to buses if it is difficult for them to regain the moving traffic stream. Leong (107) described warrants for the provision of a bus bay, with particular application to Hong Kong.

Kerb and pavement marking and signing. Occasionally, buses are faced with a situation where bus stops are partially or totally occupied by other vehicles. In this instances, buses have to either let passengers on and off on the street or find some other undesignated place to load and unload passengers. Bus delays and potential safety hazards may result. The solution to this problem usually involves improved kerb and pavement markings and signing.

Bus stop location. The major factors affecting the choice of stop locations are:

a. bus routing patterns
   i. through
   ii. right
   iii. left

b. convenience to passengers
   i. proximity to destinations
   ii. transfer access from other routes

c. type of traffic control
   i. signal
   ii. stop
   iii. yield
   iv. traffic signal coordination

d. safety
   i. effect of stopped bus on sight distance for pedestrians
   ii. conflicts in the traffic stream caused by bus entering or leaving a stop
   iii. loading and unloading of passengers

e. turning movements
   i. geometry of bus turning
   ii. turning volumes of other traffic

f. direction of intersecting streets

i. one-way

ii. two-way

g. width

i. sidewalks

ii. roads

In determining the proper location of bus stops, the choice lies between near-side, far-side and mid-block stops. Due to the several factors mentioned above, a fixed policy on the selection of a particular bus stop location is difficult to establish {19}. Typical examples of urban bus stops are shown in figure 2.12. In 1967 the Board of Direction of the Institute of Traffic Engineers approved 'A Recommended Practice for Proper Location of Bus Stops' {50}. This document contains good descriptive guide lines for the selection of one of the types of bus stop locations.

The description and a summary of the general characteristics of the three bus stop locations are mainly based on references {50,51,19 and 78} and are included here:

a. Near-side bus stops - located at an intersection before passing the cross street. They are preferable where bus flows are heavy but traffic and parking conditions are not critical. Bus drivers prefer them because they make it easier to rejoin the traffic stream. Near-side bus stops are generally applicable where buses operate in median lanes, where signalized intersections are frequent and where kerb parking is permitted throughout the day. Crowell {2} pointed out that,when planning a median bus lane,near-side stops should be used exclusively. If right turning (left in UK) non-priority traffic exceeds 250 vehicles per peak hour, kerb bus stop should be located prior to the intersection, possibly at mid-block.

Near-side bus stops may offer the advantage to buses of combining delays due to red signals with loading and unloading delays. This potential advantage depends on buses consistently arriving at the intersection at the beginning of the red signal interval. Kraft and Boardman {52} observed, in a real-life experiment in the US, no advantage in the relocation of a bus stop from the near-side to the far-side of a signalized intersection (see figure 2.13). Bus stop operation minus passenger service time increased by 25% during the peak period. They concluded that this increase is logical because signal delay time at the near-side location could be used for passenger service time and that this was not possible at the far-side location. Near-side bus stop characteristics include:

i. a minimum of interference is caused at locations where traffic is heavier on the far side than on the approach side of the intersection.

ii. there is less interference with traffic turning into the bus route street from a side street.

iii. heavy vehicular right (left in UK) turns can cause conflicts, especially where a vehicle makes a right turn from the left of a stopped bus.

iv. buses often obscure stop signs, traffic signals, or other control devices, as well as pedestrians crossing in front of the bus.

v. a bus standing at a near-side stop obscures sight distance of a driver entering the bus street from the right (left in UK).

vi. where the bus stop is too short for the heavy demand the overflow will obstruct the traffic lane.

b. Far-side bus stops - located at the intersection immediately passed the cross street. They are preferable where either sight distance or signal capacity problems occur, where buses have the use of kerb lanes during peak travel periods, and where right or left turns by general traffic are heavy. Where buses turn left (right in UK), they allow sufficient manoeuvreing distance from kerb to left lanes. Among its characteristics are:

i. a minimum of interference is caused at locations where traffic is heavier on the approach side than on the far side of the intersection.

ii. they reduce conflicts between right-turning (left in UK) vehicles and buses.

iii. where kerb parking is not prohibited, they require shorter manoeuvring distances for buses to enter and leave moving traffic and make it easier to buses to regain the moving traffic stream at signalized intersections.

iv. buses in the bus stop will not obscure traffic control devices or pedestrian movements at the intersection and will encourage pedestrian crossings at the rear of the bus.

v. stops on a narrow street or within a moving lane may block traffic on both the street with the bus route and one the cross street.

vi. a bus standing at a far-side stop obscures sight distance, to the right (left in UK) of a driver entering the bus street from the right (left in UK).

vii. intersections may be blocked if other vehicles park illegally in the bus stop, thereby obstructing buses and causing traffic to back up across the intersection.

viii. where the bus stop is too short for the heavy demand, the overflow will obstruct not only the lane but also the cross street.

c. Mid-block bus stops - located away from intersections. They are usually applied in situations where long loading and unloading areas are required. They are also used when traffic, physical or environmental conditions prohibit near or far-side stops and where major bus passenger generators are located in the middle of the block. Their characteristics include:

i. a minimum of interference with sight distance of both vehicles and pedestrians is caused by buses.

ii. waiting passengers assemble at less-crowded sections of the side-walk.

iii. the removal of considerable kerb parking may be required.

Alternate stop patterns (i.e., near-side, far-side, near-side, far-side) may be preferable to all-near-side or all-far-side patterns specially where the traffic signals are coordinated.

2.3.2.2.3 Geometric and marking improvements on the road

Three different strategies that can be effective in improving bus flow are described:

a. Centreline and/or stop line relocation - involves reducing the width of a left turn lane and/or setting back the automobile stop line on the cross street to allow buses sufficient clearance to turn into the street. Figure 2.14 shows an example of such strategy.

b. Increasing kerb lane width - involves widening the kerb lane, at the expense of other traffic lanes, by repainting the lane delineators. More manoeuvring space is provided to buses required to pass stopped vehicles as shown in figure 2.15.

c. Provision of 'no stopping' areas in an intersection - involves determining junction 'boxes' or cross-hatching in intersections. Figure 2.16 shows the use of such priority to keep queueing traffic away from the area between two sections of a bus lane.

2.3.2.3 Comprehensive schemes

Priority to buses can be achieved through comprehensive traffic schemes. These schemes normally define an area or areas in the city where access by private traffic is discouraged, through-journeys are made more inconvenient than journeys circumscribing the 'prohibited' area, and the use of public transport is encouraged by establishing reserved lanes, bus streets, pedestrian streets, diverting through-traffic and providing park-and-ride facilities. The adoption of any particular scheme of this type will partly depend on the historic and geographic developments which have occurred in the city.

Two comprehensive systems are described here:

a. The traffic collar system. Its aim is to limit the amount of traffic entering a town centre by means of controls applied at all entry points along one or more cordons around the centre. Traffic signals are provided at each control point designated to meter traffic into the city at a rate which would not allow congestion to build up inside the controlled area. Bus priorities are provided to minimise delay to buses through the control points and car travellers are provided with park-and-ride facilities as an alternative to queueing.

b. Cell system. The downtown area of the city is divided into isolated sectors, with a system of pedestrian streets, one-way streets, bus streets, bus lanes and turning prohibitions that prevent cars travelling between sectors. These schemes rely on a ring road around the cells to carry the private traffic while buses are allowed to travel directly between the various zones. In some cases this concept is expanded to cover all the urbanized area of the city. In such cases the objective is to create a uniform area within which no particular sector is predominant and in which the various services, facilities and infrastructure are equally allocated between all the sectors.

2.3.3 Bus streets

A bus street normally has its use restricted to buses and pedestrians. In some cases bicycles, taxis, emergency vehicles and vehicles requiring access to adjacent buildings are also allowed. There are two types of bus only streets; one is where a properly-defined carriageway is reserved for bus use only and the second is where buses are introduced into a pedestrian precinct. In the first case pedestrians give way to vehicles whereas in the second vehicles are required to give way to pedestrians. The success of such priority is very much dependant on local conditions, and it is reported that the use of bus streets has been decreasing in popularity {10}.

Implementation is difficult because this type of preferential treatment must be limited to streets where access to local business by regular traffic is not required. Another problem is created when parking garages are present in an otherwise suitable location. Design and operating features including lane requirements, roadway width, sidewalk width, traffic controls and ancillary features have been described by Levinson et al {19}.

When a single bus street is expanded to include a series of streets or major portions of a downtown area, it is generally referred to as a traffic-restricted zone. Widespread implementation of these traffic restricted zones has not taken place in the United States, although they exist in several major European cities.

The two best-known American bus street examples are Nicollet Mall in downtown Minneapolis and the 63rd and Halsted bus streets in Chicago. Washington has one block section of a downtown street reserved for buses. One of the best known European schemes is Oxford Street in London {37}. The NATO/CCMS report {10} briefly described the experience in Granville Street in Vancouver and the traffic restricted zone of Trier, West Germany. May and Westland {22} identified eight bus only streets projects in selected European countries: one in Denmark (Copenhagen), one in Sweden (Örebro), two in West Germany (Trier and Mönchen-Gladbach) and four in the UK (London, Derby, Reading and Coventry).

2.3.4 Busways

Essentially, busways are exclusive bus roadways where buses operate on their own specially-constructed rights-of-way. Buses can circulate through residential communities providing a high quality of service. Busways may be constructed at, above or below grade. While little used or abandoned rail lines may provide relatively cheap busways, a new development, that involve the construction of a separate roadway, is both slow and costly. The greatest advantage of such system is the maximization of bus speeds since interference is minimized. The only delays on a true busway are bus stops. The convenience busways offers also rivals that of the automobile as the former is designed to serve the commuter with almost door-to-door service.

Levinson et al {19} discussed the applicability of such systems, listed design criteria and provided typical examples including cross sections, ramps, and station design. Ball and Brooks {27} suggested some geometric designs for exclusive busways. Construction standards were also recommended by Parsons et al {111}. Hoey and Levinson {88} identified parameters, principles, and procedures for estimating the capacity of a downtown busway. De Leuw Chadwich Oh Eocha {63} studied five different methods of central area distribution. The discussion was made using Manchester as a setting. NATO/CCMS {10} stated that very few busways, excluding freeway reserved lanes, have been constructed.

Busways schemes have been proposed for: Runcorn {28,74} Redditch {29}, Curitiba {25}, Eury {31}, Atlanta {32}, Boston {33}, Memphis {34}, Portland {35}, Halmstad {36} and Pittsburgh {113}.

2.3.5 Freeway related schemes

Freeway bus priorities exist almost exclusively in North America. They are the result of the general provision of urban freeways and consequent growth of express bus services feeding downtown working areas. May and Westland {22} did not identify such projects in European countries.

Freeway related schemes include: the construction of separated roadways where buses obtain exclusive rights-of-way, reserved bus lanes on freeway, and preferential treatment at freeway ramps. Following the introduction of freeway priorities in the early 1970s, there has been a trend towards allowing high occupancy vehicles also to use the facilities {13}.

Separated roadways are constructed within an existing freeway right-of-way, either in the freeway median or along one side of the freeway. The two major types of bus lanes on freeways are normal-flow and contra-flow lanes. Due to safety reasons high occupancy vehicles are not normally allowed to use contra-flow schemes. The preferential treatment at ramps may consist of providing buses with a ramp where access is denied to all other classes of vehicles. In cases where ramp metering techniques are used (see figure 2.17), a bypass lane facility will allow buses and/or car pools to avoid the delay caused to other vehicles. Table 2.3 contains a summary of the advantages and disadvantages of these various priority techniques.

Examples and figures of such schemes are found in references {10,11,13 and 18}. Design criteria is presented in detail by Levinson {19} and more briefly by Vuchic {23}.

Table 2.1 Results achieved by urban normal-flow kerb bus priority lanes (source: ref. 10 and 11)

location	length (m)	peak hour bus volume (buses/h)	effect on buses	effect on other road users
BELGIUM				
Brussels				
Rue Beillard	1140	122	2-3min saved	
CANADA				
Ottawa				
Albert/Slater Sts.	2400	120	0-15% reduction in travel time (0-70 seconds)	0-10% decrease in speeds
Rideau St.	3050	170	5-25% reduction in travel time (15-80 seconds)	30% increase to 15% decrease in speeds
Toronto				
Eglinton Ave.	5150	80	7% reduction in travel time (30 seconds)	110sec. reduction in travel time
ENGLAND				
London				
Brixton Road	320	100	2 min saved, 0.5 min lost on cross streets	0.5min saved
Park Lane	165	140	0.5 min saved	1-2 min lost
Vauxhall Bridge	675	60	7 min saved	1-2 min saved
Westminster Bridge Rd	130	60	0.75 min saved	
FRANCE				
Paris				
Rue Beaubourg/ Rue de Renard	885	35	speed increases of: peak 3.4km/h off-peak 0.8km/h	
Rue du Faubourg	400	52	peak 2.7km/h off-peak 1.1km/h	
Ave de Wagram 1. Rue Beaujou to Place des Ternes	225	30	peak 4.6km/h off-peak 4.6km/h	
2. Rue Cardinet to Rue Courcelles	50	18	peak 1km/h off-peak 0.3km/h	
Blvd.St.Germain	145	47	peak 3.7km/h off-peak 1.6km/h	
Blvd.des Invalides	450	34	peak 7.4km/h off-peak 1.6km/h	
Blvd. St.Michel	660	62	peak 3.2km/h off-peak 3.4km/h	
Quai de Louvre	670	95	peak 7.2km/h off-peak 3.7km/h	

Table 2.1 (continued)

location	length (m)	peak hour bus volume (buses/h)	effect on buses	effect on other road users
Quai de la Magisserie	350	97	speed increases of: peak 7.2km/h off-peak 3.7km/h	
Quai des Orfevres	400	20	peak 8 km/h off-peak 3.5km/h	
Marseille				
Blvd. Longchamp	480	120	speed increased from 1.6-6.4km/h to 16km/h	
Blvd. Michelet/ Ave.de Prada	1660	70	speed increased from 1.6-6.4km/h to 16km/h	
IRELAND				
Dublin				
North Strand Rd	3360	170	2min. saved	2.5min. lost
SPAIN				
Madrid				
Onesimo Redondo	530	51	speed increases of: peak 2.6km/h off-peak 2.1km/h	speed changes: no change during peak; increased 6.4km/h off-peak
Serrano	540	93		decrease 5.3km/h during peak and decreased 12.8km/h during off-peak
Paseo del Prado	240	46		decreased 2.7km/h during peak and decreased 6.4km/h during off-peak
Paseo de Calvo Sotelo	540	103	peak 6.2km/h off-peak 5.6km/h	increased 4.8km/h during peak and increased 6.4km/h during off-peak
Paseo Castellana	2270	110	peak 1.6-8km/h off-peak 1.6km/h	increased 5.9km/h during peak and increased 6.4km/h during off-peak
Calle de Alcala	270	127		17sec increase in travel time on one direction and decrease of 23sec. on the other direction, both off-peak
THE NETHERLANDS				
The Hague				
Lijnbaan	190	-	1min. saved during peak hours	
UNITED STATES				
Baltimore,Md.				
Charles St.	2400	38	21% increase in speed during AM peak 87% increase in speed during PM peak	39% increase in speed during AM peak 22% increase in speed during PM peak

Table 2.1 (continued)

location	length (m)	peak hour bus volume (buses/h)	effect on buses	effect on other road users
Birmingham, Ala. Third Ave.	1290	44	27% decrease in bus travel time	29% decrease in travel time
Nashville, Tenn. Capitol Blvd.	400	-	5% reduction in bus travel time	
Newark, N.J. Market St.	550	100	7min. time saving	
New York			reduction in travel time	
Madison Ave.	1790	96	42%	
2nd Ave.	3040	110	22%	
1st Ave.	3060	110	27%	
Peoria, Ill. Adams St.	4 blocks	-	25% increase in speeds	10% increase in speeds
Vancouver, B.C. West Georgia	800	40	20% reduction in bus travel time	

Table 2.2 Results achieved by urban contra-flow bus priority lanes (source: ref. 10 and 11)

location	length (m)	peak hour bus volume (buses/h)	effect on buses	effect on other road users
CANADA				
Calgary				
7th Avenue	2300	46	speed changes: 23% reduction AM peak 12% increase PM peak	speed reduced by 15 to 80% and volume by 4 to 12%
FRANCE				
Paris				
Avenue Montaigne	660	33	56% increase during peak and 44% over whole day	
Bd. St. Michel	630	68	30% increase	
Marseille				
Rue de Rome	700	70	200% increase	
Cours Gouffé	700	20	180% increase	
Rue de Paradis	1000		230% increase	
Toulouse				
Rue d'Alsace-Lorraine	800	135	10% increase	
Lille				
Rue Faldherbe	240	-	25% increase	
ITALY				
Bologna				
Via Saragozza	2250	18	20% increase	
SPAIN				
Marid				
Delicias	230	100	20% increase	speed increased by 20%
UK				
London				
Tottenham High Road	780	73	33% increase	
Reading				
King's Road	920	50	48% increase	
USA				
San Juan	17600	49-67	45% increase	
Louisville, Ky.				
3rd Street	2400	12	25% reduction in travel time	

Table 2.3 Advantages and disadvantages of various freeway priority techniques

(source: ref. 13)

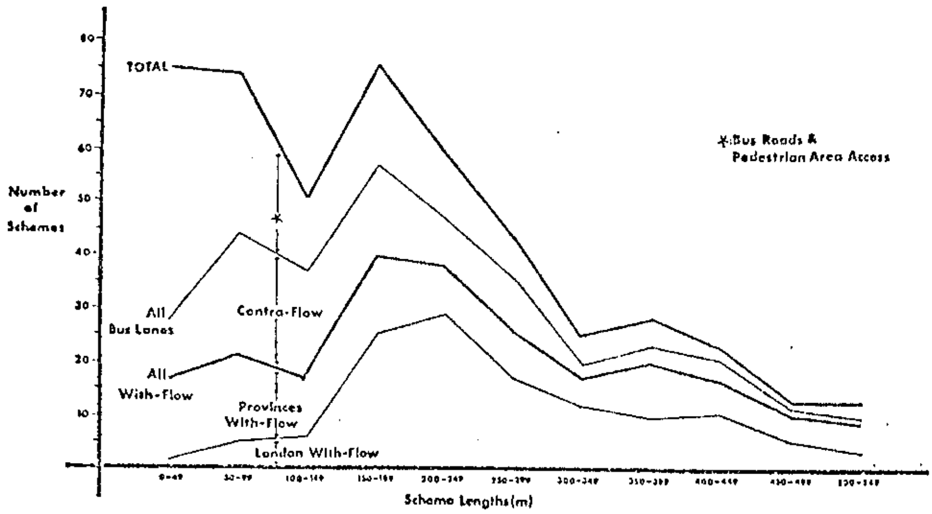
Technique	Examples	Advantages	Disadvantages
I – Construction of Exclusive Rights-of-Way	Shirley Busway, Washington, D.C. San Bernardino Busway, Los Angeles, CA Pittsburgh, PATways (under construction)	1) Priority vehicles can operate at high speeds 2) Efficiency of existing highway not reduced 3) Operating costs are low 4) Easily enforceable	1) Major construction takes relatively long time for implementation 2) Capital costs are relatively high 3) Community opposition may develop
II – Normal-Flow Reserved Lanes	San Francisco Oakland Bay Bridge, CA Marin County, San Francisco, CA Moanalua Freeway, Honolulu, HI	1) Involves minimum construction 2) Can be rapidly implemented	1) Weaving problems 2) Takes lanes away from peak direction 3) Enforcement may be more difficult
III – Contra-Flow Reserved Lanes	I 495, Lincoln Tunnel, NY/NJ Long Island Expressway, NY Southeast Expressway, Boston, MA Marin County, San Francisco, CA	1) Capacity in peak direction is increased 2) Capital outlay is low 3) Such lanes are rapidly implemented	1) Should not be implemented if congestion would occur in off-peak direction 2) Operating costs are relatively large 3) Bus speeds are relatively low
IV – Preferential Treatment at Freeway Ramps	I-5 Blue Streak, Seattle, WA Los Angeles Area Freeway Ramps I-35W, Minneapolis, MN	1) Low construction costs 2) Causes minimum delay to non-users 3) Problem of freeway under-utilization is avoided 4) Speed difference is diminished so safety is enhanced	1) Violations may be high 2) May not always be physically possible 3) Priority vehicles subject to delays once they are on freeways during days with accidents or incidents

Table 2.4 Summary of the state of the art of bus priority treatments, 1974

(source: ref. 19)

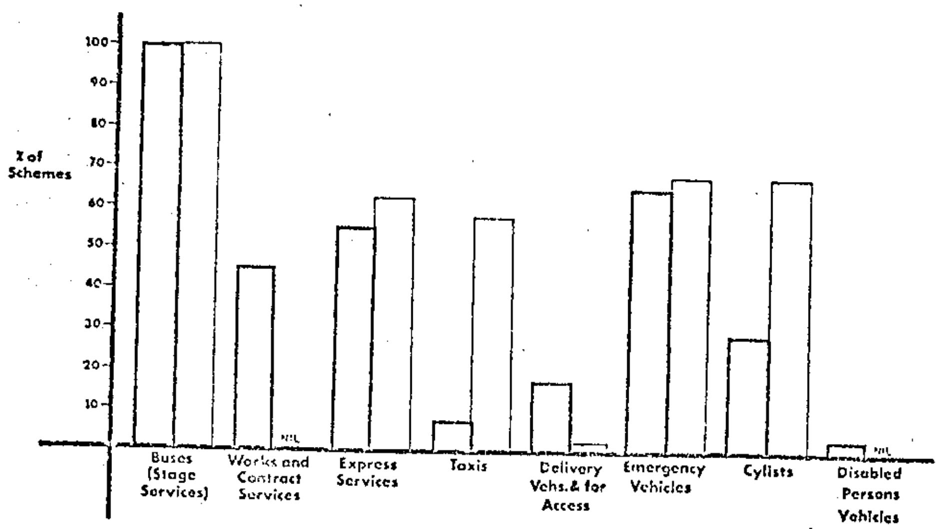
TYPE OF TREATMENT	SIGNIFICANT EXAMPLES OF EXISTING TREATMENTS
1. *Freeway-Related:*	
A. Busways:	
1. Busway on special right-of-way	Runcorn, England, Busway
2. Busway on freeway, median or right-of-way	Shirley Busway, Washington, D.C., area San Bernardino Busway, Los Angeles
3. Busway in railroad right-of-way	None
B. Reserved lanes and ramps:	
1. Bus lanes on freeways, normal flow	9th Street Expressway, Washington, D.C.
2. Bus lanes on freeways, contra-flow	Southeast Expressway, Boston; I-495, New Jersey; Long Island Expressway, New York; US 101, Marin County, Calif.
3. Bus lane bypass of toll plaza	San Francisco-Oakland Bay Bridge
4. Exclusive bus access to non-reserved freeway (or arterial) lanes	Seattle Blue Streak express bus service and bus ramp.
5. Metered freeway ramps with bus bypass lanes	Harbor Freeway, Los Angeles
6. Bus stops along freeways	Hollywood Freeway, Los Angeles
2. *Arterial-Related:*	
A. Reserved lanes and streets:	
1. Bus streets	Nicollet Mall, Minneapolis; 63rd and Halsted Sts., Chicago
2. CBD curb bus lanes, normal flow	Washington, D.C.; Baltimore, Maryland
3. Arterial curb bus lanes, normal flow	Hillside Avenue, Queens, New York City; Connecticut Ave., Washington, D.C.
4. CBD median bus lanes, normal flow	Canal Street Neutral Ground, New Orleans; Washington Street, Chicago; 14th Street, Washington, D.C.
5. Arterial median bus lanes, normal flow	None
6. CBD curb bus lanes, contra-flow	Alamo Plaza, San Antonio
7. Arterial curb bus lanes, contra-flow	Ponce de Leon, Fernandez Juncos, San Juan
B. Miscellaneous:	
1. Bus signal preemption	Kent, Ohio
2. Special signalization	Cermak Road, Chicago
3. Special turn permission	"No Left Turn, Buses Excepted," Los Angeles
3. *Terminals:*	
A. Central-area bus terminals	Midtown Terminal, New York City
B. Outlying transfer terminals	Dan Ryan—69th Street bus bridge, Chicago; Dan Ryan—95th Street bus bridge, Chicago; Eglinton Terminal, Toronto
C. Outlying park-and-ride terminals	Lincoln Tunnel approach at I-495 contra-flow bus lane

Comparison of Lengths



Permitted Users

All Schemes(Provinces/London: ▭▭)



Periods of Operation

All Schemes

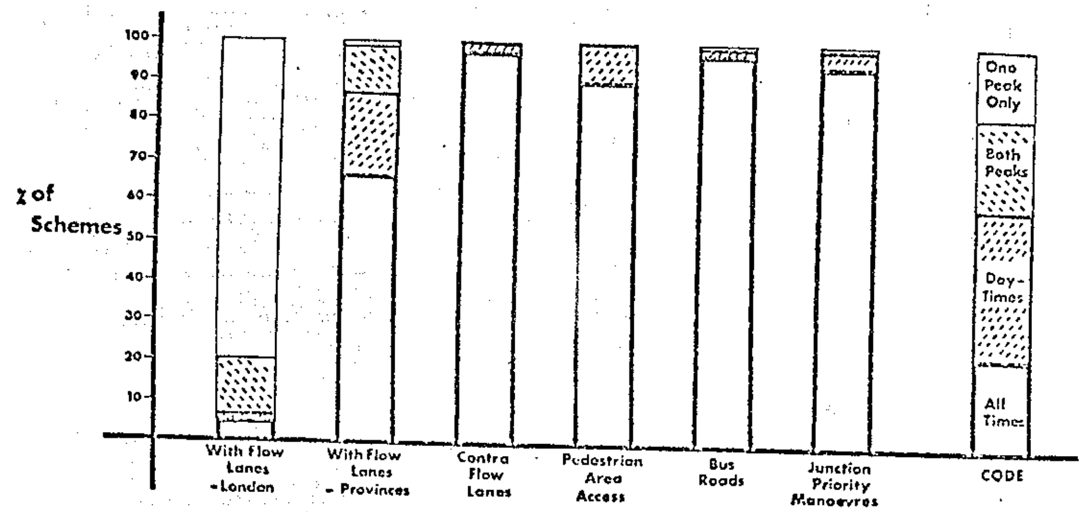


Figure 2.1 Features of priority schemes in Britain (source: ref. 17)

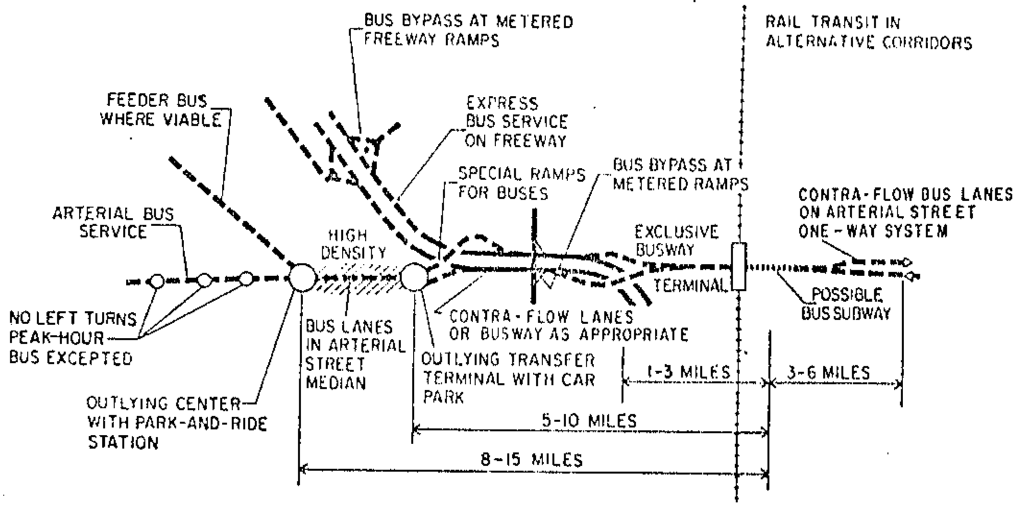


Figure 2.2 Bus priority system in metropolitan areas
(source: ref. 19)

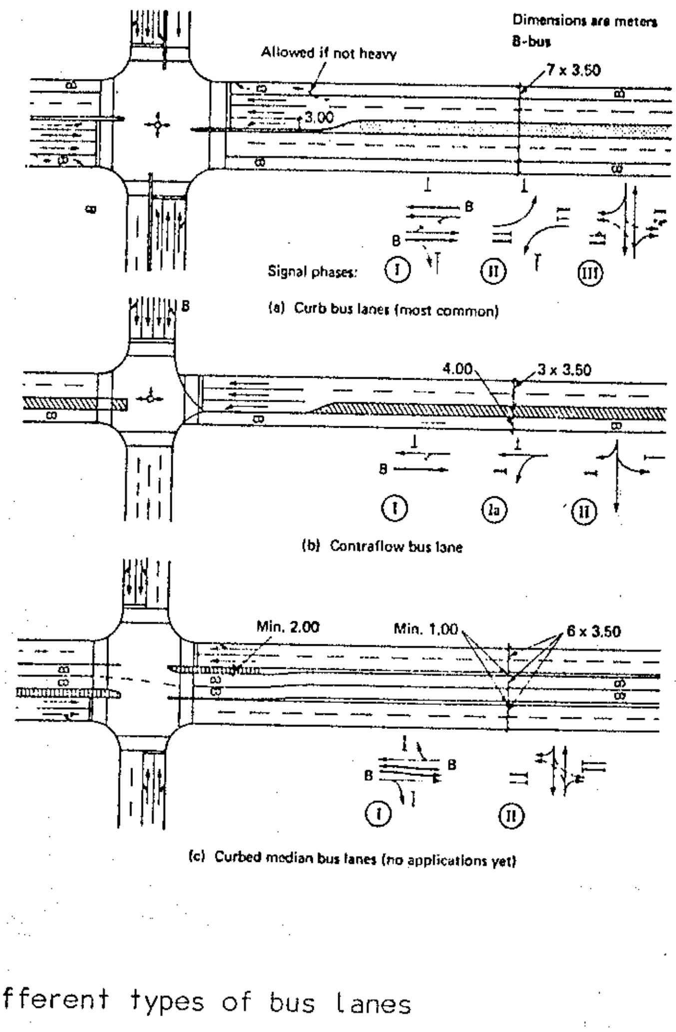


Figure 2.3 . Different types of bus lanes
(source: ref. 23)

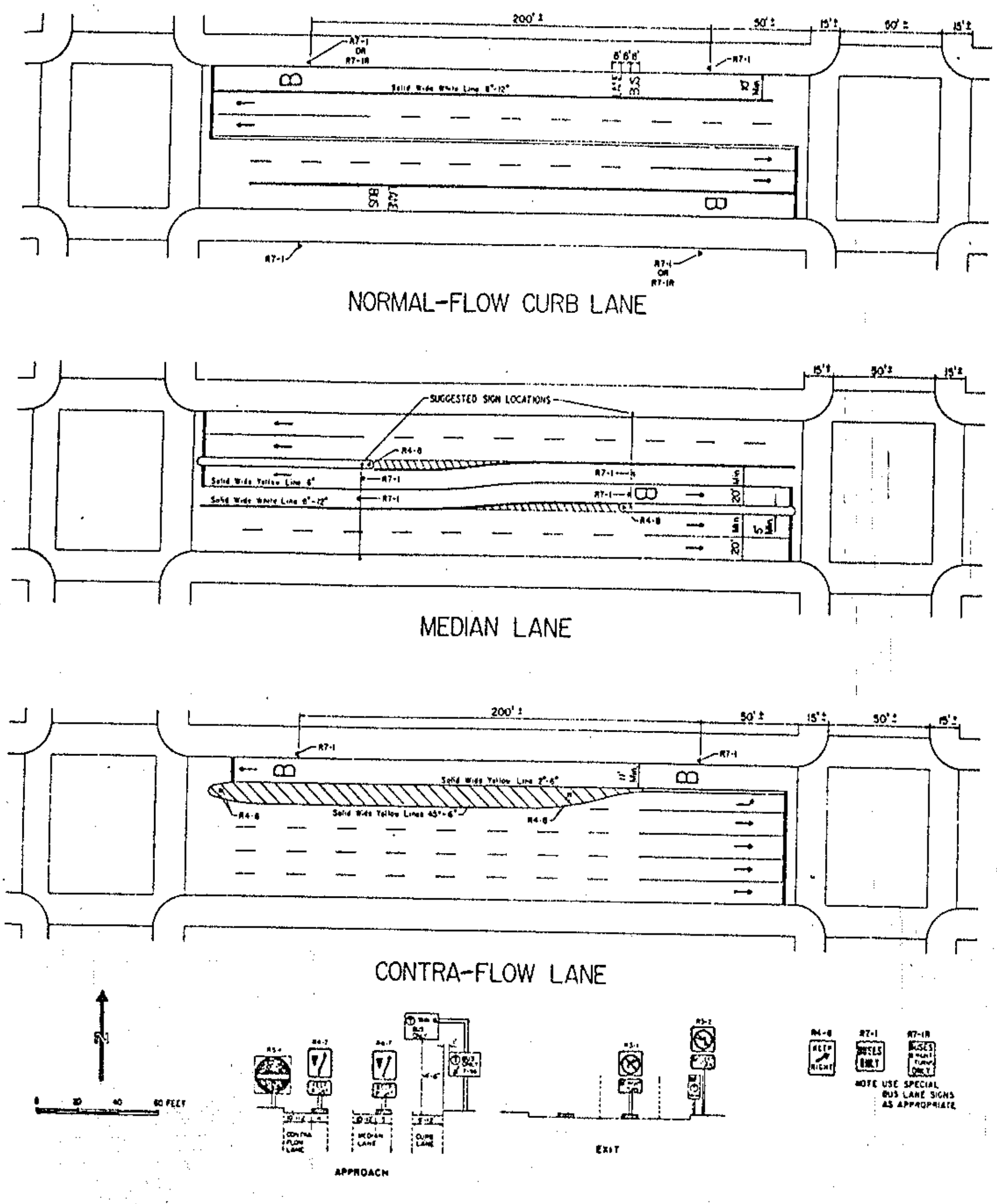


Figure 2.4 American signing and marking of typical bus lanes (source: ref. 19)

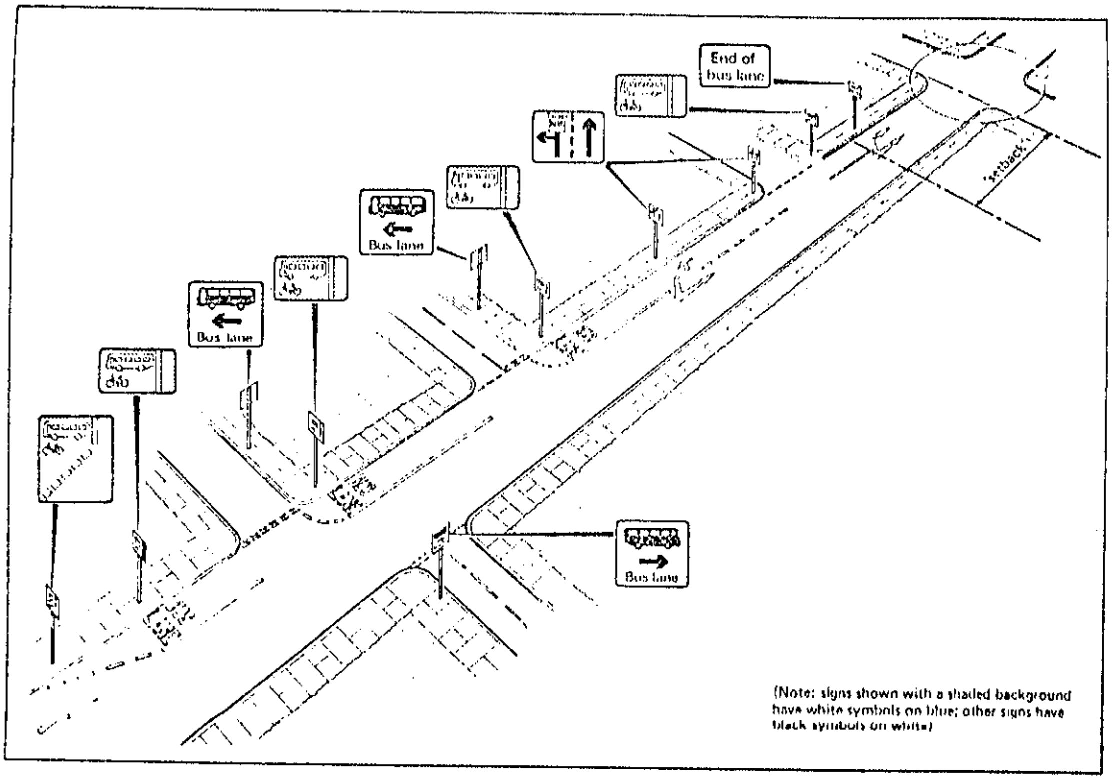


Figure 2.5 UK signing of a normal-flow bus lane
(source: ref. 10)

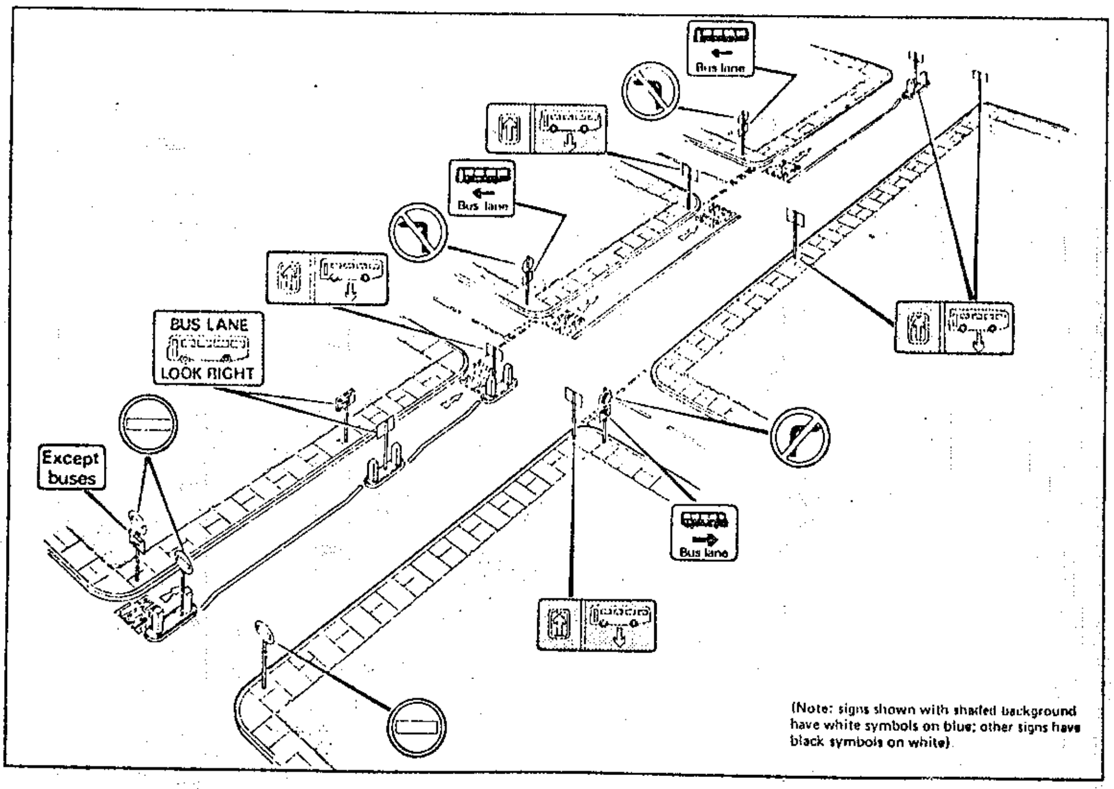


Figure 2.6 UK signing of a contra-flow bus lane
(source: ref. 10)

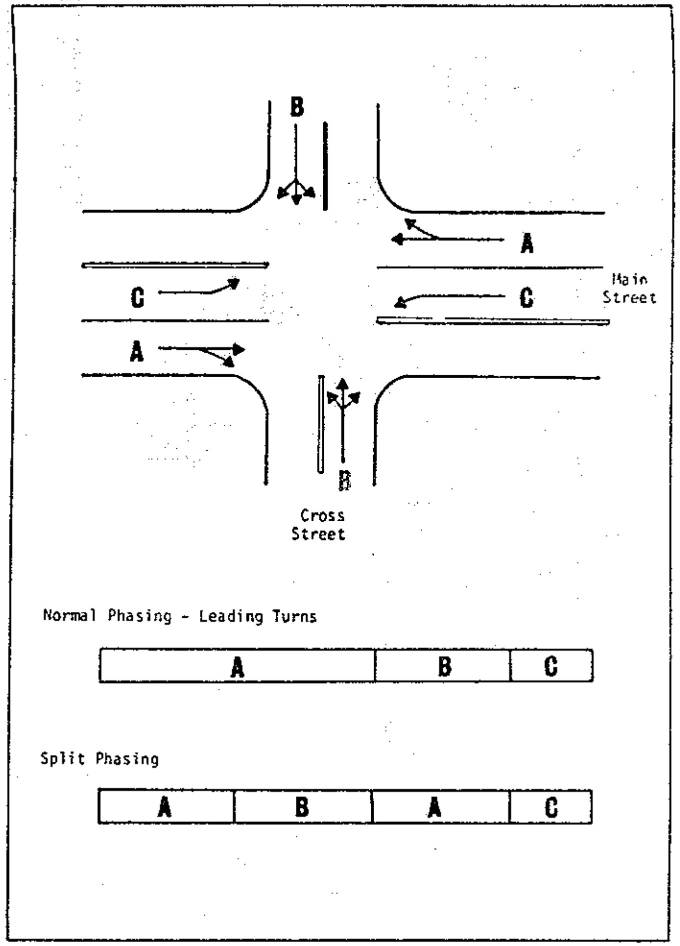


Figure 2.7 Example of split phasing to reduce bus delay

(source: ref. 45)

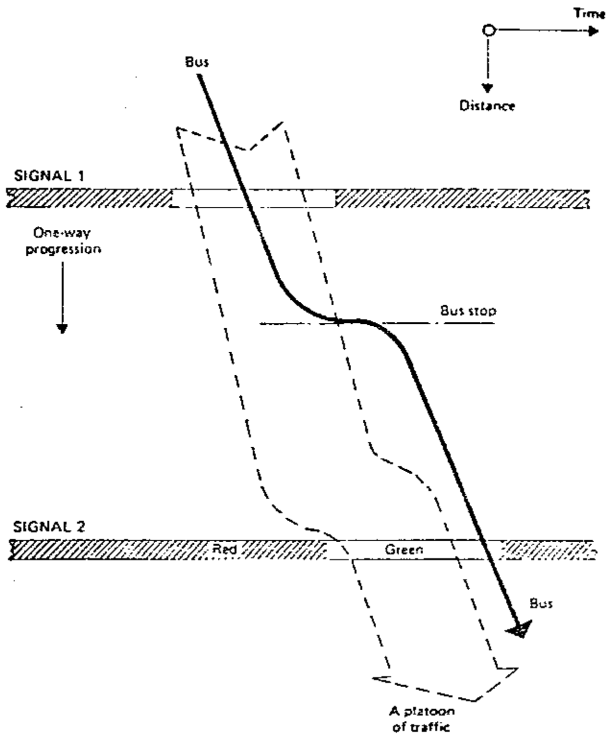


Figure 2.8 Different typical movements of a platoon of traffic and a bus

(source: ref. 42)

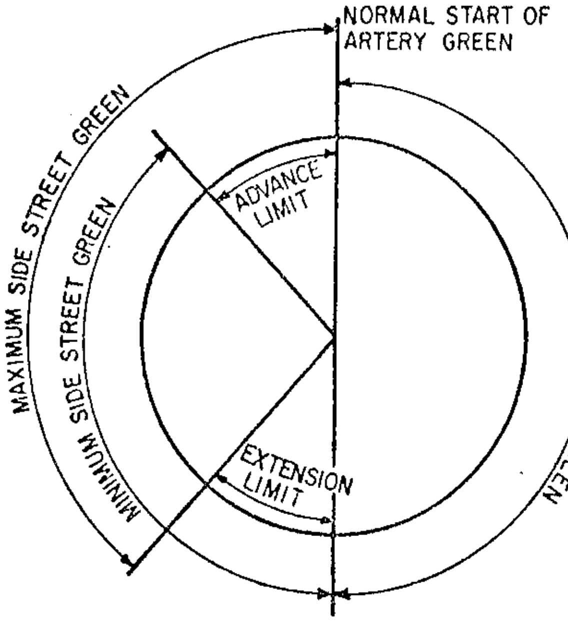


Figure 2.9 Bus preemption signal cycle
(source: ref. 19)

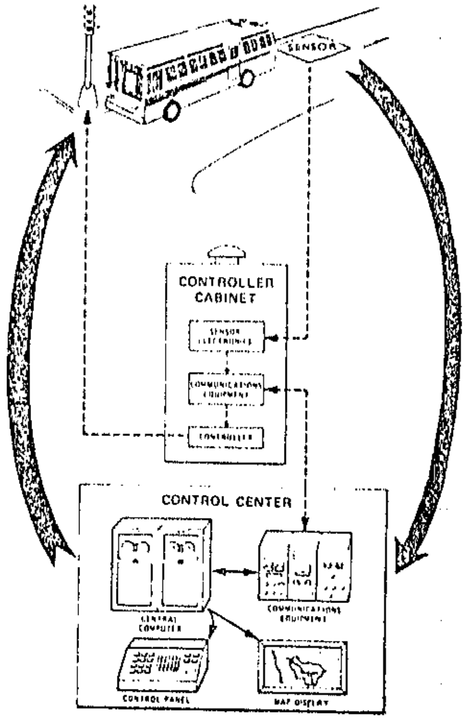
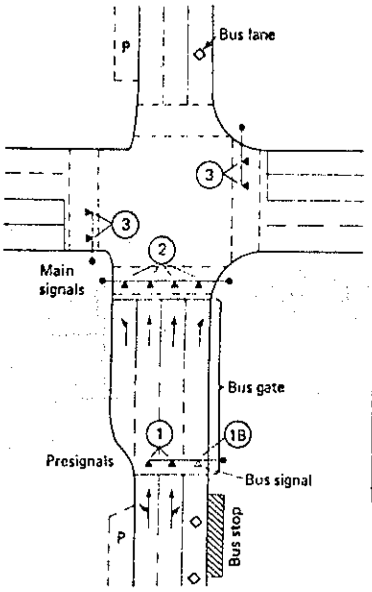
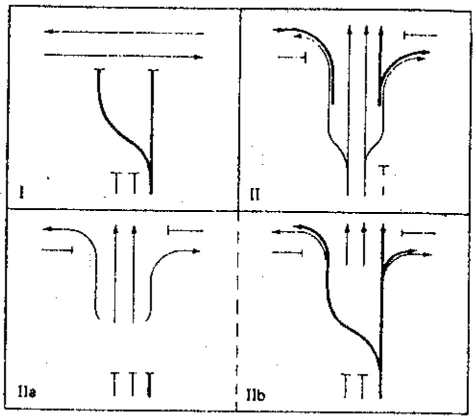


Figure 2.10 Example of bus preemption of traffic signal
(source: ref. 13)



(a) Intersection layout



(b) Signal phases (IIa and IIb are alternates).

Phase / Signals	I	II	IIa	IIb
1	R R	G Y	R R	R R
1B	G Y	R R	R R	G G
2	R R	G G	G Y	G Y
3	G Y	R R	R R	R R

(c) Signal face indications plan

Figure 2.11 'Bus gate' intersection approach
(source: ref. 23)

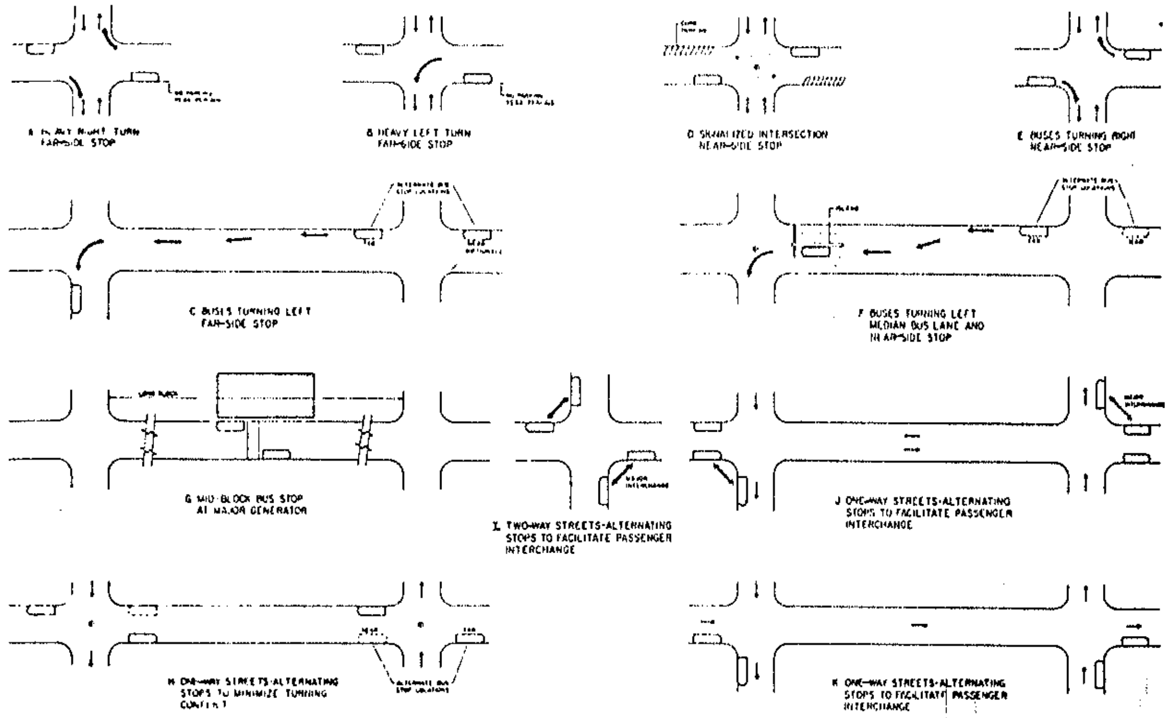


Figure 2.12 Typical bus stop locations

(source: ref. 19)

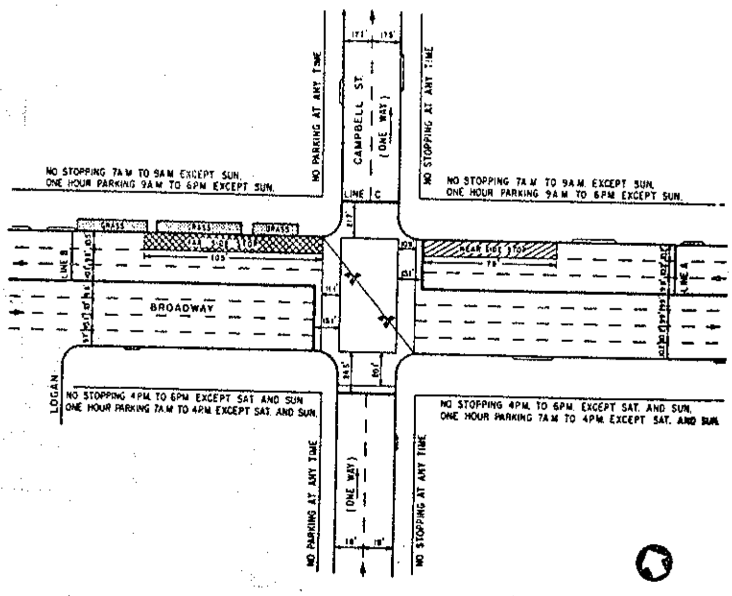


Figure 2.13 Bus stop relocation experiment

(source: ref. 52)

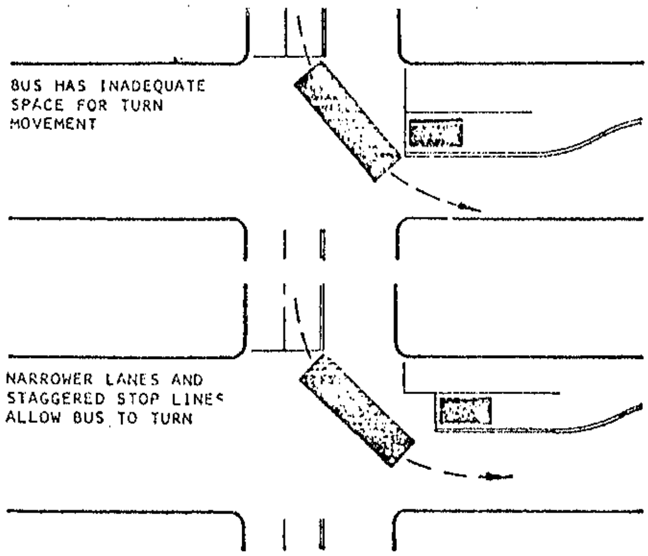


Figure 2.14 Centreline and/or stop line relocation
(source: ref. 30)

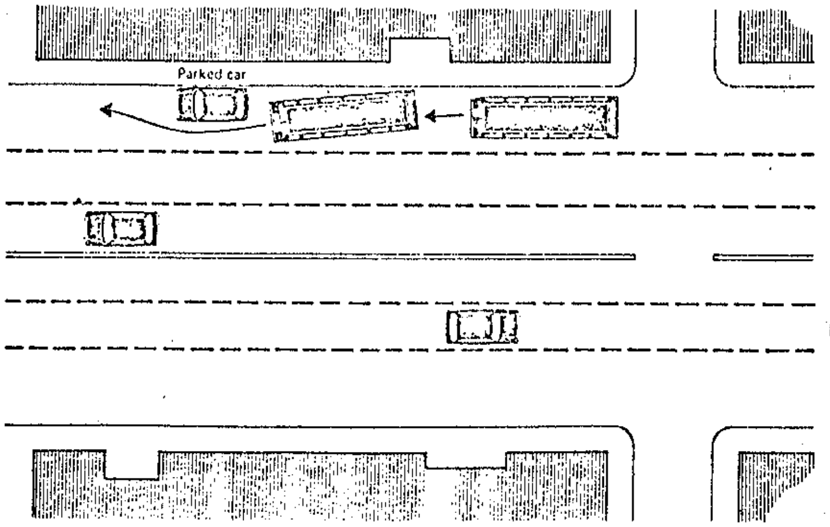


Figure 2.15 Increasing kerb lane width
(source: ref. 10)

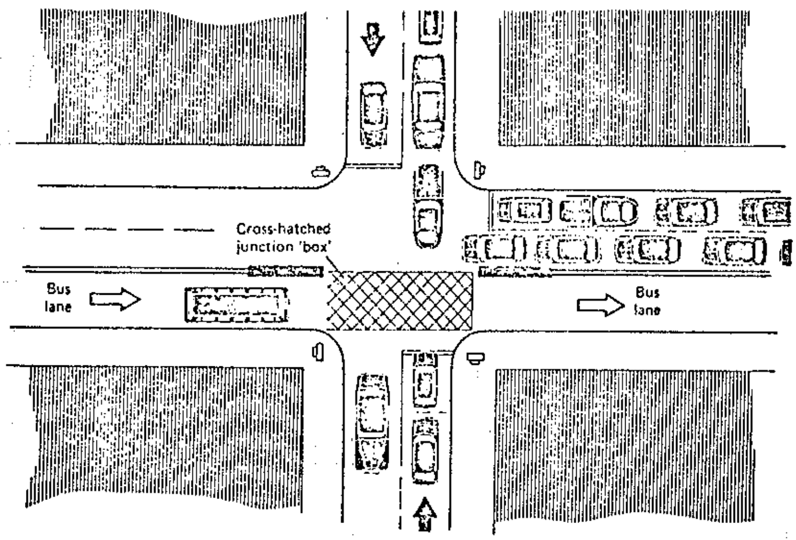


Figure 2.16 Use of junction 'box' at an intersection
(source: ref. 10)

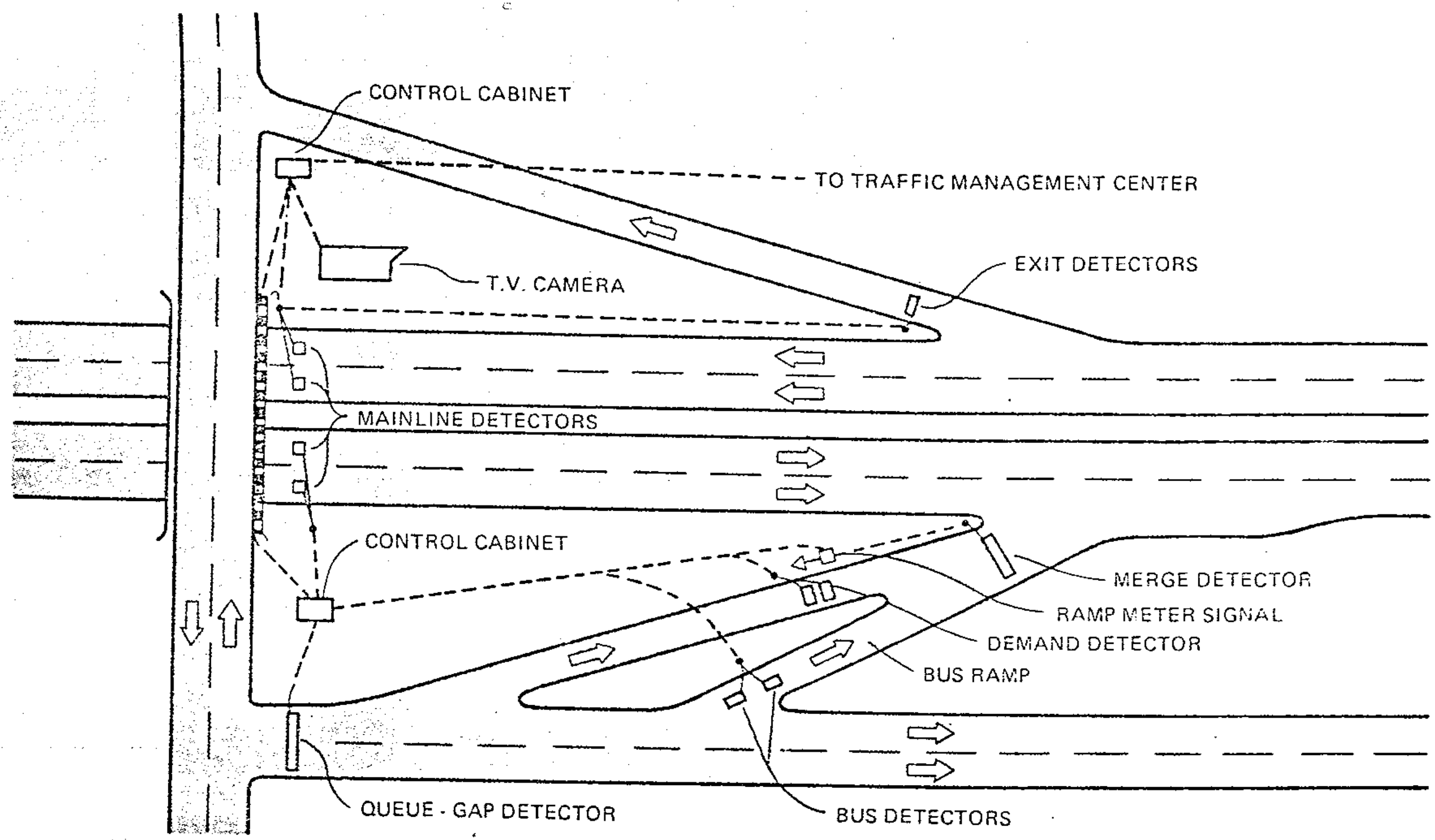


Figure 2.17 Example of a ramp metering technique
(source: ref. 13)

3. PREVIOUS ASSESSMENT OF URBAN BUS PRIORITIES

3.1 Introduction

There are five main methods of assessing the suitability of bus priority schemes:

a. Broad warrants - provide a rough indication of the minimum flow of buses required to produce benefits.

b. pre-evaluation models - those designed to give a set of warrants for priority measures in terms of bus and other traffic. The warrants obtained are general and do not apply to any specific priority measure location.

c. survey and simulation models - these models are similar to those in the previous category except that they are developed to represent a specific location in question. Recalibration is required if the model is applied to another location.

d. track experiments - controlled experiments carried out on a test track, enabling traffic and road layout factors to be altered in a controlled manner. The results of track experiments cannot directly predict the effect of providing bus lanes in a real-life situation but they are valuable in providing the basic data to enable real situations to be studied by mathematical modelling and by simulation {65}.

e. studies of actual schemes - not all the schemes implemented have been quantitatively assessed and in some cases the complexity of the schemes has been so great that true assessment has been virtually impossible.

Previous sections have dealt with actual schemes; tables 2.1 and 2.2 give a brief summary of data relating to bus lane schemes. The evaluation of implemented schemes is the subject of Chapter 4 and table 4.1 provides a summary of the area of interest of before and after studies. This chapter reviews the most significant and representative studies related to the first four methods described above.

3.2 Broad warrants

In the NATO/CCMS report {10} the validity of the warrants is discussed:

> "So far, few countries have specified official warrants for with-flow lanes; most leave the matter to be decided by the local authorities concerned. In any case, it would be undesirable to specifiy rigid warrants: they should be sufficiently flexible to permit adaptation to the local conditions."

The Institute of Traffic Engineers {24} developed warrants and operating criteria for the establishment and operation of bus priority lanes. Nevertheless its Technical Committee stated:

> "It should not be concluded that the committee does not recommend the establishment of a transit lane under circumstances that do not meet the suggested warrants ... if such establishment may be otherwise justified with official and public support."

Several "rules of thumb" were used in the past to justify the implementation of priority techniques. One such rule was that reserving one lane for buses is a justified procedure when buses carry as many people as private vehicles carry per lane in the remaining lanes. The volume of buses required for this warrant is {23},

$$q_b \geq \frac{q_a}{N - 1} \quad X$$

where q_a and q_b are hourly volumes of private vehicles (including lorries as passenger car equivalents) and buses respectively, N is the total number of lanes per direction and X is the ratio of average car to bus occupancy. Figure 3.1 shows the bus volumes that justify bus lanes for several values of N and X.

However this rule does not differentiate among the various priority techniques available. A set of generalized applicability criteria, or warrants, for the implementation of various priority techniques has been developed on the basis of a review of priority techniques for high occupancy vehicles {19}. These warrants attempted to achieve simplicity, uniformity, applicability, measurability, replicability and flexibility. The warrants, presented in table 3.1, are expressed in peak hour buses and passengers but other relevant factors are also identified. Levinson and Hoey {57} suggested that a 'bivariate approach' be taken in the application of these warrants. Transportation demands for a future design year as well as the base-year conditions should be used as the bases for implementation decisions, in the following manner:

a. warrants should apply to design year conditions
b. seventy-five percent of the warrants should apply to base year or current conditions.

Generally accepted minimum installation criteria for bus lanes are 30 to 90 buses per hour {61}. Such criteria assume at least one bus present in each city block during the peak hour {19}.

The Greater London Council established several criteria for assessment of the feasibility of a bus lane scheme. According to Allen {58} a bus lane:

a. should give a significant advantage to buses;
b. should not seriously reduce traffic capacity or cause secondary congestion by developing excessive queues;
c. should give a net benefit to the community and should have a reasonable cost/benefit ratio;
d. should be reasonably easy to enforce;
e. frequency and occupancy of buses should be high enough to encourage compliance by other drivers;
f. must be practicable to prohibit waiting and loading during the hours of operation of the bus lane;
g. should not increase accident potential;
h. should minimize any detriment to the environment;
i. should have a sufficient life prior to being superseded by redevelopment or other changes in the situation.

The Institute of Traffic Engineers warrants {24} require:

a. a minimum of 60 buses per peak hour or 400 buses per 12 hour period to justify a kerb bus lane;
b. a minimum of 75 buses per peak hour and 500 buses per 12 hour period to justify a full time median bus lane;

c. a minimum of 60 buses per peak hour to justify a part time median bus lane;

d. when considering a full time median lane, the number of bus passengers in a 12 hour period should be equal or greater than the number of occupants of other vehicles in the street;

e. in all the situations above the number of bus passengers during the peak hour should equal or exceed 1.5 times the number of drivers plus passengers of other vehicles using the street.

Bakker {81} considered the suggested warrants of the Institute of Traffic Engineers too restrictive. He mentioned that other criteria should be considered:

> "... what is the total people delay now, and what will it be if traffic is segregated into bus and car lanes?... can this delay be reduced with a revised signal timing plan?"

3.3 System simulation models

Pre-evaluation models produce sets of warrants that are more detailed than the broad warrants described above. The results produced are intended to be applicable to a variety of situations.

3.3.1 Pre-evaluation models

Oldfield et al {55} observed that:

> "The willingness to give buses priority appears to vary considerably from place to place and though this may reflect real differences in policy towards bus priority it is equally possible that it results from the lack of a standard method for judging whether or not priority is justified in any particular situation. Some attempts have been made to establish warrants for the installation of bus lanes, but these have tended to be rather arbitrary and not based on any rigorous economic footing."

While discussing the role of warrants, Ritchie {56} wrote:

> "...it is suggested that the use of relatively simple person-time or economic warrants permits a rapid and more rational determination of potential priority lane sites and strategies, particularly amongst a large number of competing alternatives. Resources can then be directed more efficiently into detailed studies of schemes which might be most beneficial, in the broadest sense, to the community."

In France, a theoretical simulation study was conducted to quantify the balance of time savings experienced by users of private and public transport on the establishment of a reserved bus lane. In that study the minimum number of buses per hour justifying a reserved lane was related to the number of traffic lanes available, their level of saturation and average bus occupancy. The results of the study by Delgoffe {60} are shown in table 3.2.

A study by Frebault attempted to assess the operation of a bus lane running in the same direction as general traffic and replacing a general traffic lane. A summary of his work was reported by Richardson and McKenzie {82}. Simulation was used as the method of approach. He employed the assumptions that motorists did not change route or mode, a bus was equivalent to 3 pcu and car occupancy was 1.2 persons/vehicle. With these assumptions the model was run and a collective time advantage was then estimated as,

$$y = W\left(n_b(t_b - t'_b) + n_a(t_a - t'_a)\right)$$

where y is the collective time advantage, W the weighting coefficient for time saved by travel on each mode, n_b the number of affected bus passengers, t_b the bus passenger travel time before, t'_b the bus passenger travel time after, n_a the number of affected car passengers, t_a the car travel time before and t'_a is the car travel time after. The value of W was reported to be dependent on the saturation level. The resulting warrants, shown in table 3.3, are those bus flows which result in a positive collective time advantage if buses are given priority under certain specified conditions.

Theoretical work was carried out by Oldfield et al {55} while examining the economic justification of normal-flow lanes in a variety of situations. Their model represented a section of a road with a signal-controlled intersection at each end (see figure 3.2). Diversion to the parallel system of minor roads was allowed. The appendix of their report contains a manual which permits the results of the study to be generalized to particular situations.

Warrants have been deduced for a bus-only kerb lane and for a bus/taxis kerb lane installed on either a two-lane or a three-lane approach to the traffic signals. Two types of situations were considered:

an 'easy' situation in which diversion was short and the diversion routes had plenty of spare capacity, so that the diverted vehicles did not cause the speed of traffic on the diversion route to fall appreciably; and a 'hard' situation, in which the diversion was long with routes which had little spare capacity, so that congestion increased greatly and the effect on the other traffic was severe. The warrants provided in table 3.4 are also function of a constant bus occupancy of 60 passengers and of providing a setback of optimum length or not providing a setback.

The table shows that when no setback is provided, benefits are possible only at high degrees of saturation with a high bus flow and with conditions that allow 'easy' diversion to take place. However, the NATO/CCMS {10} report pointed out:

> "It must be emphasized that these calculations relate to hypotetical situations and are based on a number of assumptions not backed up by very concrete evidence. Consequently, the detailed predictions must be considered to be unreliable and treated as a guide rather than as a warrant..."

While reviewing these bus lane warrants with respect to Australian conditions, Ritchie {56} observed that the priority lane bus operating speed of 35km/h used in the model by Oldfield et al suggested that only express bus operations were considered. He also stated that the delay equations for random arrivals, used in the model, underestimated average delays for arrivals downstream from a signal (250-600m) which are bunched or in platoons. This underestimate was particularly acute during high average flow rates. Nevertheless, he presented a generalization of Oldfield's warrants for lower bus occupancies and the results of his study are presented in table 3.5.

While trying to establish a set of warrants to be used, in practice, in order to assess the suitability or otherwise of a particular site for the implementation of a contra-flow lane, Bly and Wesbster {54} found that:

> "... the resulting warrants were so sensitive to the characteristics of the networks, and in particular to the properties of the main junctions, as to render such a selection procedure almost unworkable in practice, unless the situation being reviewed happened to coincide, in the network design and the values of the relevant parameters, with one of the cases tested."

They concluded that there was no substitute for a detailed economic assessment related specifically to the particular contra-flow site being studied and therefore, provided a manual with an assessment methodology.

In the studies conducted by the Transport and Road Research Laboratory {21 and 55}, warrants for the adoption of a bus lane were defined as the minimum flows of priority vehicles which were necessary to produce a positive overall benefit. While no consideration was given to environmental or social effects of priority lanes, it was acknowledged that it might not be desirable to use a set of warrants based only on economic considerations because other non-quantifiable aspects could make bus priority worthwhile.

3.3.2 Survey and simulation models

Having established, by means of a general warrant, that a location appears to require a priority measure, it is then advisable to conduct a more specific study. Since the development of the high speed automatic computer there has been a growing tendency to use digital computer simulation as a method of modelling a variety of situations.

The studies described within this section are intersection and link specific models, employing macroscopic (speed-flow relationship) or microscopic methods, updated either by event or time scanning techniques. Models that have attempted to incorporate aspects of travel demand in their analyses of what is, basically, a change in the supply of traffic facilities, are only briefly described at the end of the section.

Muzyka {70} reported that a computer model, SCOT (Simulation of COrridor Traffic) to simulate traffic flow within a specified traffic system, was used to predict the effect on bus service and general traffic performance of implementing candidate bus priority strategies. This program is the amalgam of two computer programs: UTCS-1 (urban traffic control system) and DAFT (dynamic analysis of freeway traffic).

The urban and microscopic part of the model was used in order to simulate the traffic flow within part of central Minneapolis, a rectangle of 10 by 11 streets. This study area was modelled by a grid consisting of a set of links representing the street roadway and a set of nodes representing the intersections. The information required to describe the study area traffic system was divided into four sets: geometric, traffic demand, control system, and bus service data. The output included bus routes and network performances (table 3.6) and plots of bus trajectories (figure 3.3).

The extremely detailed output given by SCOT helps to identify bottlenecks and underutilized streets for each candidate control strategy. The strategies can then be changed, another simulation run made, and the performance observed until it merits field implementation. However an enormous amount of data has to be collected and a lot of storage and computer time is required to simulate the microscopic behaviour of all vehicles within a network. Richardson and McKenzie {82} discussed the weakness in the simulation assignment process of this model and stated that because of it, SCOT was incapable of truly assessing area wide impacts of the provision of a priority scheme.

Salter and Memon {67} simulated the operation of a two-way, four-lane road 1.1km long with three signal-controlled junctions in Bradford, England. In order to investigate the overall travel effects of a kerb with-flow bus lane both the nonpriority and the priority conditions were simulated during the morning peak.

Right turning vehicles (left in UK) were not considered in the model because the number of these vehicles in the traffic flow was small. Also a vehicle assigned to a lane at the entry of the section was not allowed to change lanes or to overtake vehicles in its own lane. However, at the traffic-signal approach, the bus-priority lane terminated 60m from the stop line to allow vehicles travelling straight ahead to bypass vehicles turning left (right in UK). The shifted negative exponential distribution was used for the headway distribution and the normal distribution was noted as an adequate description of the velocity distribution.

A vehicle-following procedure and a uniform time scanning increment was adopted. Buses and nonbus vehicles were assumed to have similar charactersitcs during the simulated congested flow conditions. No provision was made for the time lost for passengers alighting or boarding because this time was considered to be similar for both non-bus-priority and bus-priority conditions. The traffic signals along the route operated on a fixed-time basis without coordination. The validation of the model was made by comparing the delays at the signal controlled intersection along the route given by the model with those delays obtained by using the expression derived by Webster {39}.

A comparison was made between the travel times of buses and other vehicles by running the priority and nonpriority models under identical traffic flows and signal settings. Under bus priority conditions an increase in journey time was found as well as a decrease in overall speed for nonbus vehicles compared to nonpriority conditions. This was explained as being a consequence of the fact that nonbus traffic was confined to a single lane under bus priority conditions. Speed-flow relationships were derived for bus and nonbus traffic under priority and nonpriority conditions as shown in figure 3.4. It can be seen in figure 3.4 that for a wide range of bus flows the travel time during the priority situation may be regarded as almost constant. Nevertheless the model does not include the time spent by buses at the bus stops. With passengers boarding and alighting, the total journey time under high bus flow conditions will be influenced by factors which include the number of buses that could be simultaneously serviced at the bus stop.

Salter and Shahi {68,69} described a computer simulation model which has been developed to test the effectiveness of a variety of measures which give priority to buses over a considerable length of their route. The model was a development of earlier work on the simulation of bus priority schemes on a radial highway in the city of Bradford {67}. The primary purpose of the model was to measure the effects of kerb with flow bus lanes on buses and their passengers. The investigation of effects of the priority scheme on non-bus vehicles was restricted to the intersections.

The model followed the progress of each bus in service along a particular route as it moved from stop to stop on the service route. The running speed for buses between intersections was determined from a speed-flow relationship appropriate to the section of the service route on which the bus was travelling. A uniform time scanning microscopic simulation was employed only in the immediate vicinity of the intersections.

Input to the model included an activity index to describe the traffic characteristics of the route and influence the speed-flow relationship. The output information of the program included bus travel time between successive bus stops, the number of passengers boarding and alighting at each stop, the maximum passenger queue length at the bus stop, bus occupancy along each part of the service route, a measure of the variation of actual bus time schedule from the input schedule, delays as shown in figure 3.5, and queue lengths for buses and other vehicles at intersections.

Eriksen {72} developed a computed simulation model capable of testing alternative transit distribution systems in central areas. The model simulated a number of buses running through a central area during the afternoon peak hour. He felt that the afternoon peak hour would be more critical than the morning peak hour, since boarding consumed more time than alighting. His model is event-advanced, the time between events being calculated and added to the total accumulated time for each bus as they move through the area. The test route was 12 blocks long, having 12 signalized intersections and from four to eight bus stops. The flowchart of the operation of buses, as they proceeded along the route, is shown in figure 3.6.

A total of 20 different systems were tested (table 3.7). Figure 3.7 shows the journey time along the route for each system. The increase in efficiency that can be expected from various transit improvements is presented in figure 3.8.

While the validations of the frequency distributions such as bus headways, passenger arrival rates and passenger boarding times were based on field observations, little effort was placed on modelling travel time between intersections. However, the link conditions depend on the amount of interference from other traffic and represent more than 50% of the total bus time in all the alternatives tested as demonstrated in figure 3.7. From a planning viewpoint, the Eriksen model is of little use, since as no car traffic is simulated, no indication of overall benefit can be obtained.

Bowes and Mark {71} described a simulation model that was developed during the course of a study to simulate bus behaviour of a downtown kerb normal-flow bus lane in Ottawa, Canada. The bus lane operating strategy simulation model, BLOSSIM, simulates bus movements only; the effects of other traffic components are introduced by means of coefficients. At each time interval of one second, buses must either accelerate, if travelling at a speed less than the maximum cruising speed, or decelerate, depending on the bus in front, the state of the traffic lights, and the need to pick up passengers. A bus will stop for a red traffic signal, to load passengers, and for the bus in front.

The road system simulated consisted of six blocks, each 180m long. A block was measured as shown in figure 3.9. There were three stops per block and these were located midblock, near side, or far side. The model had 18 bus routes divided equally into the three groups of bus stops, A, B and C. The A route buses stopped at all A bus stops, and so on. The frequency of the routes varied. Passengers were generated for each route at each stop as a function of route frequency, which in practice was determined by demand. Each intersection was signal controlled and each cycle length was 80s with 40s green and 4s amber in the direction of travel. Variable offsets were set at 15, 25, 40 and 65s in the model.

The output data consisted of data relating to each bus, queues at selected time points and comprehensive traces of individual or groups of buses during a time period. Three different operating strategies were tested, the summary of results is shown in table 3.8. The most effective strategy tested consisted in alternating bus stops by increasing the average bus stop spacing from 180 to 360m. Bus platoons were also tested; the order of arrival at a bus stop was automatically given in advance to waiting passengers by means of a scanning system which allowed passengers to queue and board more efficiently. In this strategy buses were not permitted to overtake. In the third strategy buses were allowed to overtake but other vehicles were not allowed to make right turns (left in UK) from the common section, even though, some of these turns would be required in the downtown area.

The authors concluded by recommending refinement, validation and some modification in the model. Their bus platoon system required an advance bus arrival sign system that would be very expensive for practical use. No effects on the non-priority traffic were reported for the different strategies.

Radelat {73} developed a simulation model, SUB (Simulation of Urban Buses), that was used as a evaluation tool in the formulation of new schemes to improve bus operation on signalized arterial streets. He created a special bus simulation model to represent in detail urban bus operation ignoring the effect of variations on bus performance on other traffic. He pointed out that even if this effect was significant on traffic operation, the changes in traffic flow induced by variations in bus flow would not cause a significant feedback effect on the bus system. Only the kerb lane and its adjacent lane were simulated since he assumed that urban bus operation was confined to these two lanes.

The model consisted of links and nodes and a maximum of 20 blocks could be simulated. The arterial street representation used in the model is shown in figure 3.10. General traffic was simulated macroscopically by a time-scanning procedure. Non-bus vehicles were assumed to travel within a link at a constant speed specified by the user. Bus simulation was microscopic and proceeded according to an event-scanning scheme. These events were the arrivals of buses at stop lines and bus stops, the departures from them, and the completion of a passenger service operation. The buses were moved along a link according to a speed-flow relationship.

Radelat concluded that although the prediction of the effects of an exclusive bus lane on bus travel times appeared to be reasonable, a long series of applications of the model was required to thoroughly validate it.

with fixed-length phasing, where one of the approaching lanes could be designated as a priority lane. This model was used in order to study complementary situations to the ones investigated by the track experiment at TRRL, described in section 3.4.

The aim was to identify the optimum setback of the bus lane with respect to the stop-line of the junction, and to determine bus journey time savings, changes in delays to other traffic, apart from overall net benefits. The model was calibrated for fully saturated traffic flows using parameters obtained from the track experiment and validated against both the experimental data and an existing bus lane signal approach in London. The suggested setbacks are shown in table 3.9.

Bly observed that the saturated intersection condition was so complicated that no simple rules could be laid down to determine the optimum setback. He also mentioned that even more complex was the situation where the incoming traffic flow varied with time through some maximum flow. The disbenefits caused by queues building back from one intersection and blocking the previous intersection, a situation that might occur when the junction was working under saturated conditions, were not considered in the model.

The simulation considered only vehicle delays at one intersection and nothing was said of the benefits or disbenefits arising from the bus lane on the link between intersections. He considered that, for flows much less than capacity, the link travel times of priority and non-priority vehicles were more important than the effect of the bus lane on passenger delay at the intersection.

Gaham {76} used a computer simulation study developed in the United States {84} to make a theoretical evaluation of the effect of introducing a bus lane arterial route in Dublin. This model was originally formulated to enable the assessment of the total passenger time spent on a section of a motorway under normal and priority conditions. Speed-flow relationships were required as input. The advantages and disadvantages of adopting a priority lane operation were obtained by comparing the results of the 'do nothing' and the bus priority operation.

Several important assumptions had to be made to apply this motorway operation program to urban conditions. It was assumed that there was no turning for vehicles either onto or off the roadway section under consideration, no provision was made for the time lost either in stopping or in the picking up or setting down of passengers at bus stops, and the capacity of the road was assumed as constant over its entire length and also over time. The program indicated that a reserved bus lane solely for buses would be justified if one-third of existing car users would transfer to buses.

El-Reedy and Ashworth {46} carried out an investigation to determine the possible improvement to the overall performance of a traffic signal controlled intersection when a bus-actuated system was superimposed on fixed-time control. A section of a road was identified downstream from a signal-controlled intersection and data concerning flows, journey times and arrival patterns of vehicles were recorded.

The TRANSYT models, described in section 2.3.2, were run to obtain basic offsets and green splits for the hypothetical junction. These were input into a simulation program in order to calculate the respective performance indexes. The program was then altered to represent a bus-actuated system where the signals would change at the detection of buses according to a predetermined policy, but subject to overriding constraints imposed by the fixed-time settings.

With the flows observed in practice, 17 buses/hour, bus actuated policies showed an improvement in the calculated performance index over the fixed-time system with offsets and splits given by BUS TRANSYT. This result was reversed when the number of buses was doubled as the extra delay encountered by the side road traffic overcame any benefit gained by the major road vehicles.

Vincent et al {47} used BUSPAS (BUS Priority Assessment Simulation) reported by Wood {87} to estimate benefits to buses and disbenefits to other traffic when using various forms of priority control superimposed upon the normal UK vehicle-actuated signal operation. All cases considered were for two-stage signals controlling crossroads-type intersections with buses travelling on the major road only.

Buses were given priority by extending an existing green signal or regaining a green signal sooner than normal. The extension of the green curtailed the green time on the non-priority stage, and various methods were considered for alleviating disbenefits to this traffic. Bus flows were varied between 20 and 80 buses per hour for both directions on the main road.

Different traffic flows, saturation flows, cycle times, and priority control methods were studied. For the conditions examined, the researchers concluded that it was usually possible to achieve a reduction in total passenger delay at the intersection by giving priority to buses. However, benefits were difficult to attain if the high time-value of non-priority vehicle occupants was taken into account.

Yedlin and Lieberman {109} modified the NETSIM model, the Federal Highway Administration's network flow simulation, to compare the performance of bus systems operating with and without bus signal preemption. Their simulation study showed that this priority strategy applied at an isolated intersection reduced bus delay for bus headways of 3 min. in one direction and 5 min. in the opposing direction. In a second experiment the priority was extended to several junctions of the simulated arterial road. Although the two cases were not directly comparable, the reduction in bus travel time was substantially greater than in the first experiment. The conditions tested corresponded to a volume/capacity ratio of approximately 0.33 for each intersection approach.

The authors concluded that bus signal preemption is most efficient when bus arrivals are less frequent than one per minute and that providing a bus lane should be given strong consideration for periods when bus volume is very heavy.

Ludwick {116} modified the UTCS-1 urban network traffic model to study bus preemption techniques on 18th and 19th Streets in Washington (figure 3.11). Local traffic data was used as input. Bus headways of approximately ½, 1, 2, and 4 minutes were adopted. The results of the simulation runs were given in terms of mean travel time per vehicle-mile and stop per vehicle-mile for different time headways between buses and also for different distances of the bus stop from the intersections.

It was found (figure 3.11) that substantial benefits to buses were provided by the preemption algorithm, regardless of the headway or bus stop location. Nevertheless, bus frequency was confined to a maximum of one per half minute. While non priority vehicles on bus streets were also benefitted, a penalty was imposed to cross-street traffic. The greatest penalty occurred with short headways and near-side bus stops.

Lieberman et al {75} described a study to evaluate the effectiveness of two bus priority strategies using the same microscopic simulation model of urban traffic developed by Muzyka {70} previously described in this section. Their test network included two major arterials, each with a contra-flow bus lane (figure 3.12). The first control strategy consisted of a fixed-time traffic signal pattern generated by the SIGOP-II model, which was designed to minimize passenger delay rather than vehicle delay. The second alternative was a real-time policy which preempted the fixed-time control to provide preferential treatment for approaching buses. The simulated results for each strategy were compared with those reflecting the existing fixed-time signal control.

For this single application, the study indicated that the reduction in delay for bus passengers, as predicted by the simulation program, provided by both strategies, outweighted the additional delay experienced by passengers in private vehicles.

Papacostas {54} described a microscopic interval-scanning simulation model, BUSMALL, that was developed for the purpose of simulating an exclusive central business district bus street. It employed car-following rule similar to that adopted in the UTCS-1 Network Simulation Model {59}. BUSMALL was validated using data collected at Hotel Street, the main transit corridor in Honolulu, and was applied in order to determine the effect of various operational, control and structural strategies on capacity and average system speed at capacity.

The model enabled the simulation of a single bus lane with or without bus stops where bus overtaking was permitted only in the vicinity of bus bays. No bus preemption techniques have been modelled, and the consideration of alternative offset and signal timing patterns was not tested due to time and resource limitations.

Capacity was found to range from 83 to 215 buses per hour with corresponding speeds at capacity varying from 2.4 to 5.6km/h. Evidence was found in favour of adopting mid-block stops over near or far-side stops since they enjoy the dual advantage of affording storage length at both ends of the dwell phase. Among other findings, Papacostas observed that system operation was consistently improved by lengthening bus stops from two to three loading positions.

May et al {79} developed an arterial model, TRANSYT6B, and applied it to assess the impact of different traffic management strategies. Their model consisted of the previously developed TRANSYT6 which was extended to include energy and air-pollution impacts as well as spatial and model demand responses. The strategies investigated included arterial design features (preferential lanes or contra-flow lanes) with or without improved signal settings. The output of the model consisted of short term and long term predictions of travel time, energy, and air pollution.

TRANSYT6B was applied to an 8-km section of an American Boulevard during the afternoon peak period. Table 3.10 presents the results for all selected traffic-management strategies. The exclusive bus lane operation with optimizing signal control on a passenger basis was predicted to significantly increase travel time, fuel consumption and air pollution in the short term. The greatest short-term benefits were due to optimizing signal control on either a passenger basis or on a vehicle basis. Their future research directions included, among others, field validation and further refinement of both spatial and modal demand shifts and energy and air-pollution impacts.

Cottinet et al {80} conducted research related to preemptive traffic signal command by buses on different French cities. It included observation at different sites and theoretical studies with a simulation model. The observations covered isolated intersections with and without bus lanes and a series of five coordinated intersections. The latter permitted comparison of different modes of bus preemption at coordinated traffic lights with fixed time strategies given by TRANSYT 5.

As it was difficult to cover all cases found in practice by observation, an existing microscopic simulation model was adapted. Their model, called SITRA B, was validated by comparing simulated and measured travel times of buses and cars.

By comparing the different strategies at different flow levels, the authors showed that bus preemption was always better for buses. Priority strategies were considered to be valuable when bus demand was light or moderate. In such conditions the improvement in bus travel time was significant and general traffic was not overly disturbed. When bus demand was high (more than 40 buses per hour) they found that priority improvements for buses were not important when compared with the perturbation caused to general traffic. It was also mentioned that, within a network, fixed traffic signal plans taking buses into account might improve bus travel times while only slightly disturbing general traffic.

The Greater London Council used the model by Coombe et al {85} to evaluate bus priority schemes strategies in Inner London. The model attempted to evaluate both localized and far-reaching effects of the measures. The localized effects covered the benefits and disbenefits occurring at the site of the bus lane while the far-reaching effects included the changes in traffic flow due to diversion of traffic around the bus lane. The model structure is shown in figure 3.13.

The link travel times for buses and on-bus traffic before and after the implementation of the scheme were calculated. Several strategies were considered varying from introducing short bus lanes on roads with heavy bus flows to a series of bus and taxi only streets. The model has been used in formulating bus priority policies, despite the weaknesses in its formulation {10}.

Turner and Giannopoulos {86} studied the Oxford Street bus precinct experiment that involved the closure of this London street to all traffic except buses and taxis. In their model, vehicles were assigned to a path through the network at the beginning of a simulation which traced their movement through the network. Their matrix of excess trips was simply the O-D matrix of all non-priority trips originally using the street. Traffic delays and queue lengths were obtained from the model for both before and after conditions.

3.4 Track experiments

Coburn and Cooper {77} described a full-scale experiment carried out on the central area of TRRL's test track in 1970. The experiment was mainly concerned with the effect of reserving the nearside lane for buses and the layout used was a signal-controlled cross-road, as shown in figure 3.14. Tests were confined to one main road through the junction, but sufficient traffic was maintained on the side road to give an air of realism. The bus lane was originally extended to the stop-line on the two main approaches, and subsequently stopped short of the junction in successive stages. Bus flows varied from ½ to 4 per minute; control changes were also made in the turning proportion of cars and buses and the signal settings (15, 30, 45 seconds of green time).

For the conditions tested the results showed that moving the end of the bus lane back from the stop-line increased the saturation flow but tended to increase bus travel times. An example of this effect is shown in figure 3.15. In this case the favourable position for the end of the bus lane is around 60m from the stop line.

An approximate expression for the minimum set-back, D_{min}, of the bus lane, to ensure that buses pass through the junction during the next green period after their arrival was given by,

$$D_{min} = slg - \frac{nL(c-g)}{60}$$

where s is the saturation flow (veh/lane/s), g the green time (s), c the cycle time (s), n the bus flow (veh/min), l the effective length of cars and L is the effective length of bus.

Information was also obtained on the pcu values of laden and unladen buses and about the effect of left turning vehicle (right in UK) on saturation flows. The tests showed the advantage of siting bus bays adjacent to the junction so that they run into the stop-line. Webster {65} mentioned that information was also collected regarding the effect of allowing right-turning (left in UK) cars to use the bus lane and of giving priority to buses by providing an early green time or an advanced stop-line, but the results were not very encouraging. He also mentioned that the experiment was valuable in providing basic data to enable real situations to be studied.

Experiments were conducted during 1963 and 1968 on a 2.5 mile freeway-type straight test track at the General Motors Proving Ground in Michigan, USA. Herman et al {89} reported the results of a series of investigations carried out to determine the transient characteristics of a platoon of buses starting and stopping along an exclusive right of way. Such platoons, or 'bus trains' would start and stop at stations along the way similar to the operation of subway trains. This scheme proposed the operation of buses on an exclusive lane in order to organise and facilitate the movement of buses.

The effects of such factors as platform spacing, station spacing, speed, as well as delay on platoon dynamics were investigated. Figure 3.16 shows the time and motion of a bus operation between two stations. Theoretical car-following mathematical models were found to provide a good representation of the detailed manner in which one bus follows another {66}. Figure 3.17 presents the speed-flow curves obtained from the experimental results for platoons of different sizes. The curves show that {91}:

a. a maximum flow of 1450 buses/h is attainable for a continuous stream of buses operating on an exclusive lane.

b. a saturation effect appears to take place when platoon size is increased beyond about seven buses.

The 1968 experiment demonstrated that capacities ranged from 350-400 buses per hour and system speeds ranged from 13 to 15 mph when platoons of six buses were used at a cruise speed of 30 mph between stations 0.3 miles apart using a 30 second dwell time {92}. It was also found that the transient characterisitcs of a bus platoon on starting are related to the inter-vehicle spacings at the platform, the delays of starting between successive vehicles and the acceleration performance of the buses. However, further experiments would be required to determine the exact trade-off between these factors {91}.

From the summary of the inter-station travel times of the platoons, shown in table 3.11, it is apparent that only small gains in the average speed can be achieved by using larger inter-station spacing. Traffic signals were mentioned for situations where exclusive lanes could not be grade separated from cross-street traffic but they were not included in the experiments.

While discussing bus capacity on busways, Vuchic and Day {94} observed that the General Motors experiments quoted much higher capacity figures than actual systems could ever achieve since:

a. the uninterrupted flow tested did not determine capacity as stops, terminals or ramps form the bottlenecks.

b. the conditions prevailing during the tests were artificial, and did not exist on any freeway.

c. an analysis of the quoted flow of 1450 buses/hour at 35 miles/hour showed, through the application of equations of vehicle traction and dynamic behaviour, that under these conditions safety was well below the minimum required for a transit system.

Table 3.1 Applicability criteria for various priority techniques

(source: ref. 13)

General Applicability			Design Year Conditions			
Type of treatment (1)	Local bus service (2)	Limited-express bus service (3)	Planning period, in years (4)	Ranges in peak-hour one-way bus volumes (5)	Ranges in peak-hour one way bus passenger volumes (6)	Related land-use and transportation factors (7)
(a) Freeway Related						
Busways on speical right-of-way	X	X	10-20	40-60	1,600-2,400	Urban population ~750,000 CBD employment ~50,000 20,000,000 sq ft (2,000,000m²) floor space
Busways within freeway right-of-way		X	10-20	40-60	1,600-2,400	Freeways in corridor congested in peak hour
Busways on railroad right-of-way	X	X	5-10	40-60	1,600-2,400	Not well located in relation to service area, stations required
Freeway bus lanes normal-flow		X	5	60-90	2,400-3,600	Applicable upstream from lane-drop, bus passenger time saving should exceed other road-user delays
Freeway bus lanes contra-flow		X	5	40-60	1,600-2,400	Freeways six or more lanes; where imbalance in traffic volumes permits level of service D in off-peak travel directions
Bus lane bypass at toll plaza		X	5	20-30	800-1,200	Adequate reservoir on approach to toll station
Exclusive bus access ramp to nonreserved freeway or arterial lane	X	X	5	10-15	400-600	
Bus bypass lane at metered freeway ramp		X	5	10-15	400-600	Alternate surface route available for metered traffic, express buses leave freeways to make intermediate stops
Bus stops along freeways		X	5	5-10	50-100 boarding or alighting passengers in peak hour	Generally provide at surface level in conjunction with metered ramp
(b) Arterial Related						
Bus streets	X	X	5-10	20-30	800-1,200	Commercially oriented frontage
CBD curb bus lanes – main street	X		5	20-30	800-1,200	Commerically oriented frontage
Curb bus lanes	X		5	30-40	1,200-1,600	At least two lanes available for other traffic in same direction
Median bus lanes	X	X	5	60-90	2,400-3,600	At least two lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses
Contra-flow bus lanes short segments	X		5	20-30	800-1,200	
Contra-flow bus lanes extended	X	X	5	40-60	1,000-2,400	At least two lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft (150-m) intervals
Bus turnouts	X		5	10-15	400-600	Points of major passenger loadings on streets with more than 500 peak-hour autos using curb lane
Bus pre-emption of traffic signals	X		1-5	10-15	400-600	Wherever not constrained by pedestrian clearance or signal network constraints
Special bus signals and bus actuated signal phases	X		1-5	5-10	200-400	At access points to bus lanes, busways, or terminals or where special bus turning movements must be accommodated
Special bus turn provisions	X		1-5	5-10	200-400	Wherever vehicular turn prohibitions are located along bus routes

Table 3.2 Minimum number of buses per hour justifying a reserved lane

(source: ref. 19)

	A. Same Direction:	Buses Replacing a Normal Traffic Lane			
NUMBER OF LANES FROM WHICH THE BUS-ONLY LANE IS TAKEN	OVER-SATURATED ROAD			NONSATURATED ROAD	
	50–PASS. BUS	70–PASS. BUS	90–PASS. BUS	30–PASS. BUS	50–PASS. BUS
2	60	45	35	45	30
3	45	30	25	40	25
4	40	30	25	35	25
5	40	30	25	30	25
	B. Reserved Lane:	In Same Direction Replacing Parking Lane: 15–20 buses/hr			
	C. Reserved Lane:	In Opposite Direction on One-Way Streets: 15–20 buses/hr			

Table 3.3 Bus volume warrants for exclusive normal-flow lanes on arterial roads

(source: ref. 82)

Number of Lanes (Reserve Lane Included) Running in Same Direction	Thoroughfare Not Saturated (Slack Periods) Bus Load (Number of Passengers)			Thoroughfare Over Saturated (Peak or Other Busy Periods) (Number of Passengers)			
	10	30	50	30	50	70	90
2	-	45	30	60	60	45	35
3	-	40	25	65	45	30	25
4	-	35	25	60	40	30	25
5	-	•30	25	60	40	30	25

Table 3.4 Critical hourly bus flows for a bus lane

(source: ref. 55)

Critical hourly bus flows for a bus lane on a 2-lane approach road
(ie bus flows required for priority benefits to equal disbenefits to non-priority traffic)
Bus occupancy = 60 passengers

	setback of optimum length			no setback provided					
				'easy' diversion			'hard' diversion		
Proportion of green time, λ	0.3	0.4	0.5	0.3	0.4	0.5	0.3	0.4	0.5
Degree of saturation									
0.7	65	65	65	90	105	115	110	130	150
0.8	50	60	70	95	120	135	130	165	190
0.9	25	50	70	85	120	150	130	180	220
0.95	10	20	40	65	100	130	115	165	210
0.97	5	5	15	55	85	110	105	150	195

Critical hourly bus flows for a bus lane on a 3-lane approach road
(ie. bus flows required for priority benefits to equal disbenefits to non-priority traffic)
Bus occupancy = 60 passengers

	setback of optimum length			no setback provided					
				'easy' diversion			'hard' diversion		
Proportion of green time, λ	0.3	0.4	0.5	0.3	0.4	0.5	0.3	0.4	0.5
Degree of saturation									
0.7	55	55	55	90	95	105	90	95	105
0.8	45	50	60	110	125	145	125	150	175
0.9	30	45	60	105	145	175	155	200	240
0.95	15	30	45	90	130	170	140	195	245
0.97	5	15	25	75	115	150	125	185	235

Table 3.5 Critical hourly bus flows for bus lanes (source: ref. 56)

Critical Minimum Hourly Bus Flow for a Bus Lane on a Two-lane Approach with Setback of Optimum Length (see text), and for Various Bus Occupancies and Degrees of Saturation

Degree of Saturation	*Green Proportion*	*Bus Occupancy* 60	50	40	30	20
0.7	0.3	62	68	74	82	92
	0.4	63	69	77	86	98
	0.5	63	70	78	88	102
0.8	0.3	49	54	60	67	77
	0.4	59	65	72	82	94
	0.5	68	76	84	98	111
0.9	0.3	25	28	32	37	44
	0.4	49	55	62	71	83
	0.5	69	76	85	97	113
0.95	0.3	10	12	13	16	19
	0.4	20	23	26	31	37
	0.5	40	45	51	59	71
0.97	0.3	5	6	7	8	10
	0.4	5	6	7	8	10
	0.5	15	17	20	24	29

Critical Minimum Hourly Bus Flow for a Bus Lane in a Three-lane Approach with Setback of Optimum Length (see text), and for Various Bus Occupancies and Degrees of Saturation

Degree of Saturation	*Green Proportion*	*Bus Occupancy* 60	50	40	30	20
0.7	0.3	54	59	67	76	88
	0.4	54	60	68	78	92
	0.5	54	61	69	80	94
0.8	0.3	44	50	56	64	76
	0.4	50	55	63	73	86
	0.5	59	66	75	87	104
0.9	0.3	30	34	39	45	54
	0.4	45	50	57	67	80
	0.5	59	67	76	88	105
0.95	0.3	15	17	20	24	29
	0.4	30	34	39	46	55
	0.5	45	51	56	66	82
0.97	0.3	5	6	7	8	10
	0.4	15	17	20	24	29
	0.5	25	29	33	39	40

Table 3.6 Output of SCOT (source: ref. 70)

Bus route and general traffic performance for 8:00 to 8:15 a.m. peak.

Traffic	Statistic	Base Case	Direct-Flow Bus Lane	Counterflow Bus Lane
Bus	Average travel time per bus route, minutes	8.14	8.00	7.29
	Average dwell time per bus route, minutes	1.28	1.16	1.06
	Average speed, mph	5.8	6.1	6.6
Automobile-truck	Average speed, mph	11.1	12.0	10.9
	Average delay per vehicle, seconds	44	35	46
	Average stops per vehicle	1.12	0.96	1.20
	Stopped delay per total delay	0.71	0.67	0.71
	Cycle failures at link location	7 at 48, 58 6 at 79, 69 1 at 58, 59	1 at 58, 59	3 at 79, 69 4 at 58, 59
	Spillback	None	None	None

Bus route and general traffic performance for 4:30 to 4:45 p.m. peak.

Traffic	Statistic	Base Case	Direct-Flow Bus Lane	Counterflow Bus Lane
Bus	Average travel time per bus route, minutes	9.75	9.91	9.65
	Average dwell time per bus route, minutes	4.02	3.89	4.19
	Average speed, mph	4.9	4.8	5.2
Automobile-truck	Average speed, mph	11.1	9.8	9.7
	Average delay per vehicle, seconds	36	41	46
	Average stops per vehicle	1.16	1.13	1.29
	Stopped delay per total delay	0.73	0.77	0.76
	Cycle failures at link location	1 at 38, 39	2 at 48, 58 4 at 58, 68 2 at 89, 79 10 at 49, 39	3 at 48, 58 2 at 79, 69 5 at 69, 59 1 at 59, 49
	Spillback at link location, seconds	None	24 at 48, 58 10 at 49, 39	70 at 48, 58

Table 3.7 Alternative systems tested by Friesen
(source: ref. 72)

System No.	Busway: Mixed Traffic	Busway: Exclusive Street	Busway: Elevated or Subway	Station Layout: Stops in Through Lane	Station Layout: Stops in Bus Bay	Stopping Configuration and Distance Between Stations: Each Bus at Every Third Block	Skip Stop and 2 Stations for Every 3 Blocks	Skip Stop and 1 Station for Every 2 Blocks	Skip Stop and 1 Station for Every 3 Blocks	Number of Doors: 1 for Each Movement	2 for Each Movement	Fare Collection: Exact Fare When Boarding	No Fare Collection When Boarding	Traffic Signals: Fixed-Cycle Signals	Bus-Actuated Signals	No Signals	Transit Vehicles: Large Bus (50 Seats)	Small Bus (30 Seats)
1	X			X		X				X		X		X			X	
2	X			X			X			X		X		X			X	
3	X				X	X				X		X		X			X	
4	X				X		X			X		X		X			X	
5		X		X			X			X		X		X			X	
6		X			X		X			X		X		X			X	
7		X			X			X[a]		X		X		X			X	
8		X			X			X[b]		X		X		X			X	
9		X			X				X	X		X		X			X	
10		X			X		X				X		X	X			X	
11		X			X		X			X		X			X		X	
12		X			X			X[a]		X		X			X		X	
13		X			X		X			X		X			X			X
14			X	X		X				X		X				X	X	
15			X		X		X			X		X				X	X	
16			X		X			X[a]		X		X				X	X	
17			X		X			X[b]		X		X				X	X	
18			X		X				X	X		X				X	X	
19			X		X		X				X		X			X	X	
20			X		X		X			X		X				X		X

[a] 'A' Stations and 'B' Stations at adjacent blocks. [b] One block between 'A' Stations and 'B' Stations.

Table 3.8 Summary of simulation results from BLOSSIM
(source: ref. 71)

Strategy	Operating Conditions: Bus Stop: Midblock	Bus Stop: Far Side	Automobile Right Turns From Common Section: Yes	Automobile Right Turns From Common Section: No	Traffic Signal Offset (s)	Buses Allowed to Overtake Buses: Yes	Buses Allowed to Overtake Buses: No	Model Results: Buses/h	Passengers/h	Avg Bus Occupancy	Avg Bus Speed (m/s)
Alternating bus stop spacing	X		X		25	X		160	8570	54	2.85
Buses operating in platoons of three	X			X	65		X	174	9100	52	2.14
Bus overtaking allowed, no right turns by other vehicles	X			X	25	X		170	9290	55	1.71
Variations in traffic signal offset	X		X		Various	X		129 to 147	7615 to 8389	59 to 57	1.89 to 1.55
No bus overtaking allowed	X		X		25		X	128	7980	62	1.27

Note: 1 m = 3.28 ft

Table 3.9 Summary of recommendation for bus lane setback
(source: ref. 83)

FLOW CONDITION	RANGE OF SETBACKS*
UNSATURATED FLOW	50m —— increasing degree of saturation ——→ 80m 85% 100%
FLOW WITH PEAK AT FULL SATURATION	Short duration at full saturation 50m —— increasing equilibrium queue length / decreasing bus passenger flow ——→ 80m long duration at full saturation
CONTINUOUS SATURATED FLOW	50m —— increasing equilibrium queue length / decreasing bus passenger flow ——→ 80m 5000 passengers/h 1000 passengers/h

* Setbacks given are for a green time (g) of 30 seconds and a packing fraction (P) of 90 per cent. For other conditions multiply by 3g/P.

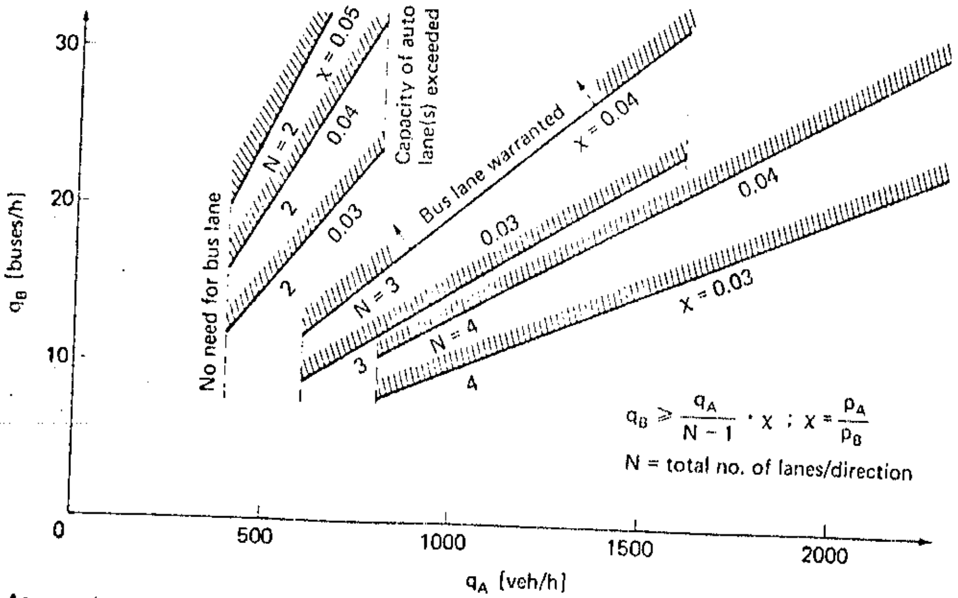
Table 3.10 Effects of arterial traffic-management strategies (source: ref. 79)

Strategy	Vehicle*	Travel Time (h) Vehicle Amount	Vehicle Percent	Passenger Amount	Passenger Percent	Fuel Consumption (L) Amount	Percent	Air Pollutants (kg) HC Amount	HC Percent	CO Amount	CO Percent	NOx Amount	NOx Percent	Total Amount	Total Percent
Signal control															
Short term															
Vehicle basis	Nonpriority	-81.8	-9.4	-97.6	-9.3	-234.0	-5.9	-9.0	-9.3	-109.6	-10.6	-4.5	-9.7	-123.1	-10.5
	Priority	-1.1	-5.0	-49.3	-4.9	-7.3	-6.7	-0.1	-4.8	-1.6	-7.5	0.0	0.0	-1.7	-7.0
	Both	-82.9	-9.3	-146.9	-7.2	-241.3	-5.9	-9.1	-9.3	-111.2	-10.6	-4.5	-9.8	-124.8	-10.4
Passenger basis	Nonpriority	-78.5	-9.0	-93.6	-8.9	-215.8	-5.4	-8.2	-8.6	-98.2	-9.5	-3.7	-8.0	-110.1	-9.4
	Priority	-1.4	-0.9	-65.4	-1.2	-10.0	-9.2	-0.1	-4.8	-2.0	-9.4	-0.1	-11.1	-2.2	-9.0
	Both	-79.9	-8.9	-159.0	-7.9	-225.8	-5.5	-8.3	-8.5	-100.2	-9.5	-3.8	-8.1	-112.3	-9.4
Long term															
Vehicle basis	Nonpriority	8.0	0.8	12.7	0.8	157	3.5	—	—	—	—	—	—	—	—
	Priority	0.1	0.0	6.3	0.3	-2	0.0	—	—	—	—	—	—	—	—
	Both	8.1	0.8	19.0	0.9	155	3.4	—	—	—	—	—	—	—	—
Passenger basis	Nonpriority	7.0	0.7	11.3	0.9	119	2.6	—	—	—	—	—	—	—	—
	Priority	-0.2	-0.7	-11.8	-1.2	-4	-3.9	—	—	—	—	—	—	—	—
	Both	6.8	0.7	-0.5	0.0	115	2.5	—	—	—	—	—	—	—	—
Signal control and design															
Short term															
Bus lanes	Nonpriority	508.1	58.2	607.5	57.6	1338.0	33.6	46.8	49.0	532.9	51.7	4.1	8.9	583.8	49.8
	Priority	-2.9	-13.1	-103.7	-13.4	-24.6	-22.6	-0.3	-14.3	-4.0	-18.8	-0.2	-22.2	-4.5	-18.5
	Both	505.2	56.4	503.8	23.1	1313.4	32.1	46.5	47.7	528.9	50.3	3.9	8.3	579.3	48.4
Reversible lanes	Nonpriority	-66.4	-7.6	-78.6	-7.5	-131.9	-3.3	-6.3	-6.6	-76.0	-7.4	-2.5	-5.4	-84.8	-7.2
	Priority	-0.2	-0.9	-12.8	0.2	-0.8	-0.7	0.0	0.0	-0.4	-5.6	-0.4	0.0	-0.4	-1.1
	Both	-66.6	-7.4	-91.4	-4.5	-132.7	-3.3	-6.3	-6.5	-76.4	-7.3	-2.5	-5.5	-85.2	-7.1
Long term															
Bus lanes	Nonpriority	18.6	2.1	19.8	1.8	168	4.1	—	—	—	—	—	—	—	—
	Priority	-2.9	-13.2	-139.7	-14.0	-25	-23.0	—	—	—	—	—	—	—	—
	Both	15.7	1.7	-119.9	-5.8	143	3.4	—	—	—	—	—	—	—	—
Reversible lanes	Nonpriority	6.4	0.6	9.4	0.8	196.2	4.2	—	—	—	—	—	—	—	—
	Priority	0.1	0.5	2.4	0.2	-2.0	-1.4	—	—	—	—	—	—	—	—
	Both	6.5	0.6	11.8	0.5	194.2	4.1								

Note: 1 L = 0.26 gal, 1 km = 0.6 mile, 1 kg = 2.2 lb.
*Total distance traveled: nonpriority vehicles, 18 554.8 km; priority vehicles, 340.2 km.

Table 3.11 Intersection running times of platoons (source: ref. 93)

Inter-station spacing (miles)		0·3				0·6				0·9			
Speed (mile/h)	*Loading time (sec)*	0	10	20	30	0	10	20	30	0	10	20	30
20	Running time	61·3	71·3	81·3	91·3	112·7	122·7	132·7	142·7				
	Standard deviation	2·2				2·2							
	Average speed	17·6	15·1	13·3	11·8	19·2	17·6	16·3	15·1				
30	Running time	47·0	57·0	67·0	77·0	82·3	92·3	102·3	112·3	118·3	128·3	138·3	148·3
	Standard deviation	2·1				1·7				2·1			
	Average speed	23·0	19·0	16·1	14·0	26·2	23·4	21·1	19·2	27·4	25·3	23·4	21·9
40	Running time					69·3	79·3	89·3	99·3	95·7	105·7	115·7	125·7
	Standard deviation					1·9				1·8			
	Average speed					31·2	27·2	24·2	21·8	33·9	30·7	28·0	25·8
50	Running time									86·6	96·6	106·6	116·6
	Standard deviation									1·3			
	Average speed									37·4	33·6	30·4	27·8



Assumptions: bus lane needed when $q_A \geq 200$ veh/h/lane; lane capacity 800 veh/h; q_A refers to passenger car equivalents.

Figure 3.1 Travel volume warrant for bus lane introduction (source: ref. 23)

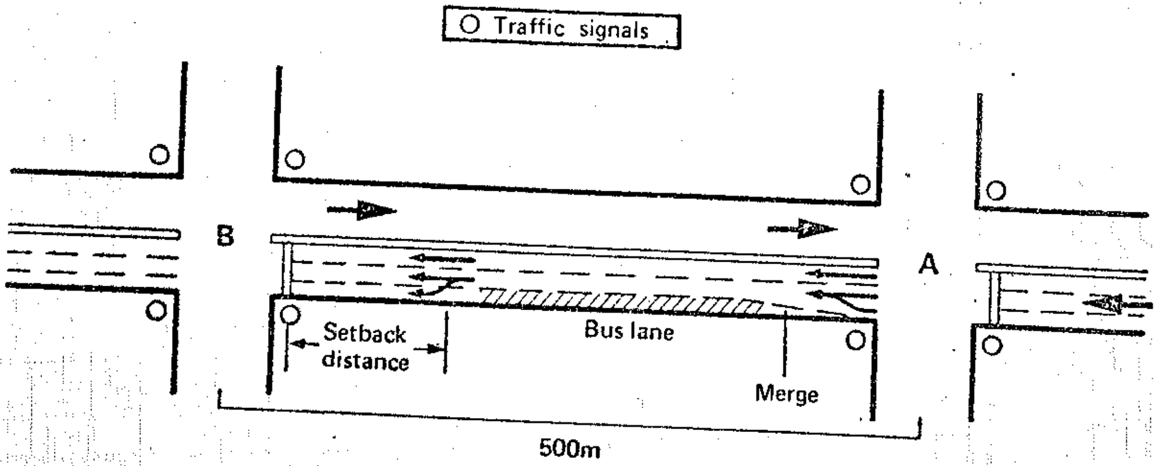


Figure 3.2 Layout of road link modelled at TRRL (source: ref. 55)

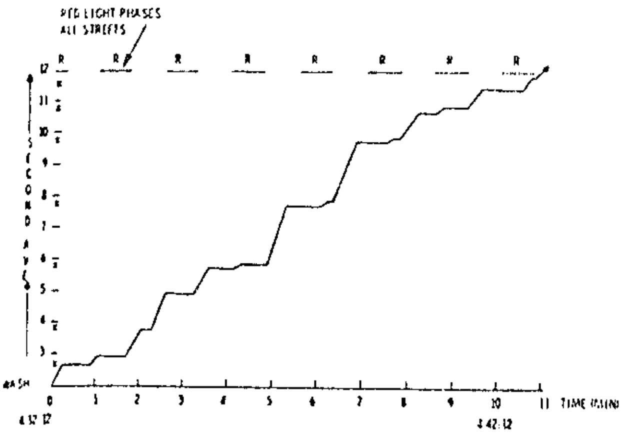


Figure 3.3 Bus trajectory plots - SCOT
(source: ref. 70)

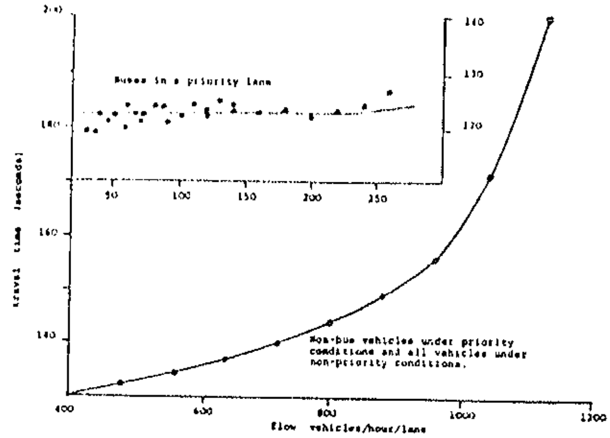


Figure 3.4 Travel time and flow relationship
(source: ref. 67)

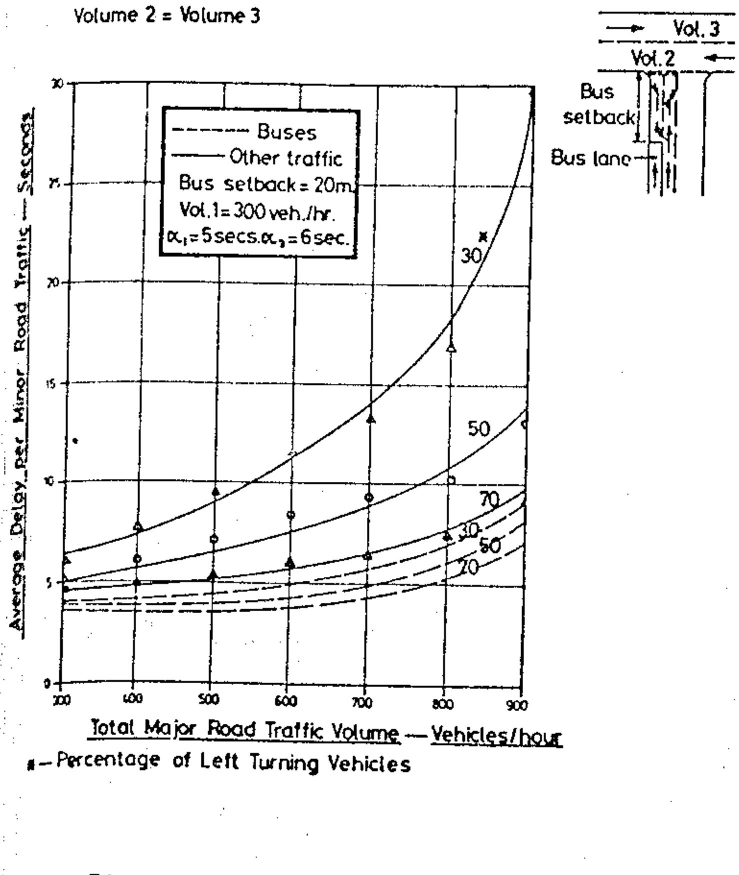


Figure 3.5 Average delay at a priority junction with a bus lane
(source: ref. 68)

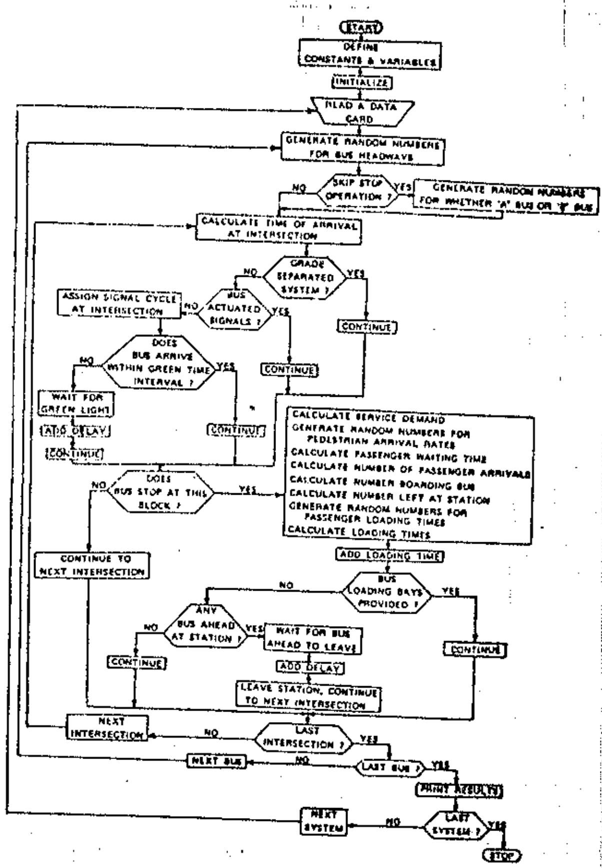


Figure 3.6 Simulation block diagram of Eriksen's model
(source: ref. 72)

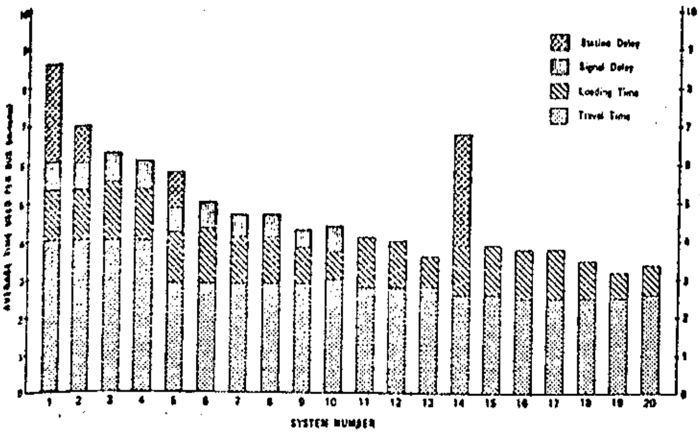


Figure 3.7 Bus time used along route for each system
(source: ref. 72)

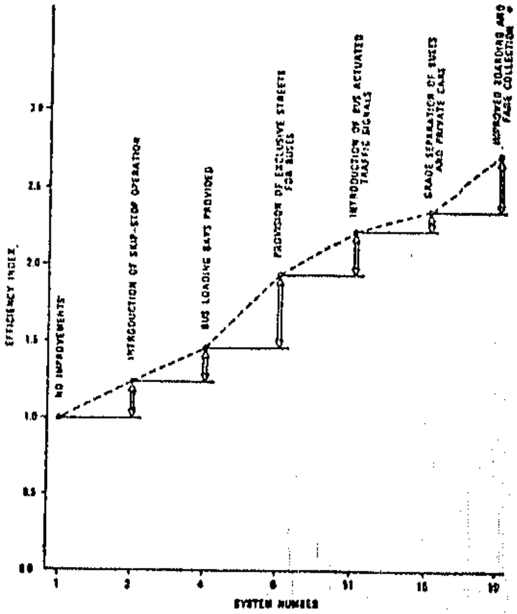


Figure 3.8 Increase in efficiency by introduction of improvements
(source: ref. 72)

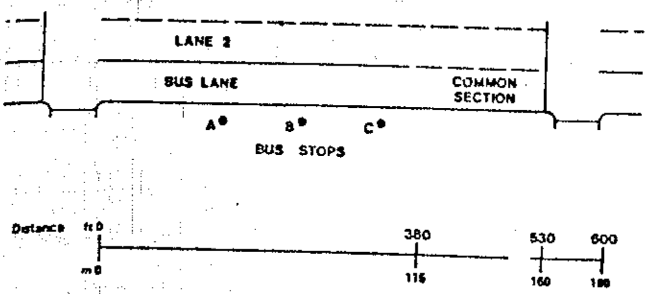


Figure 3.9 Geometry of a block - BLOSSIM
(source: ref. 71)

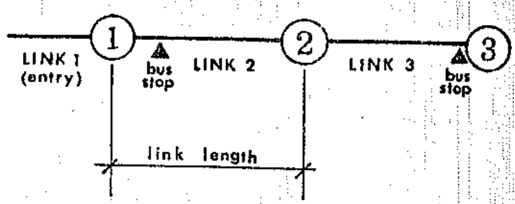
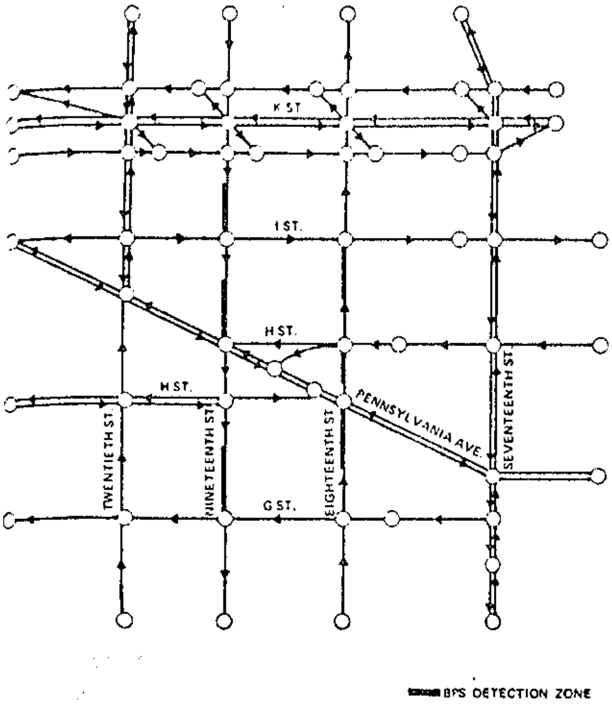
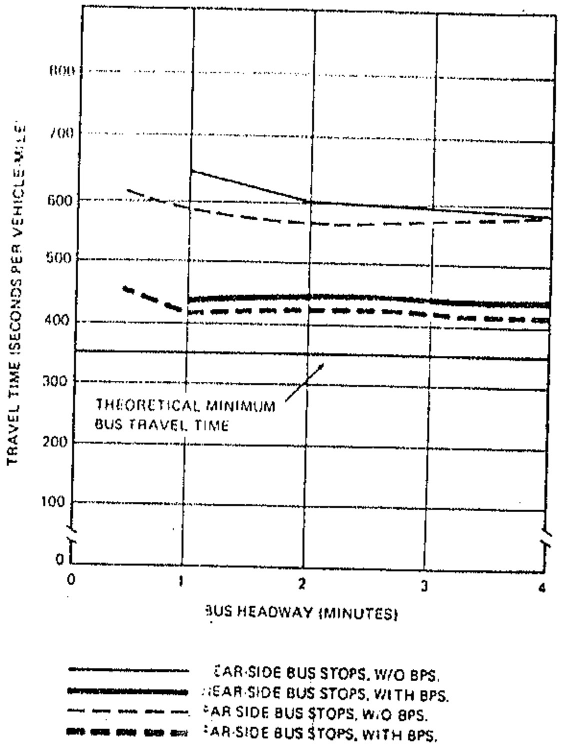


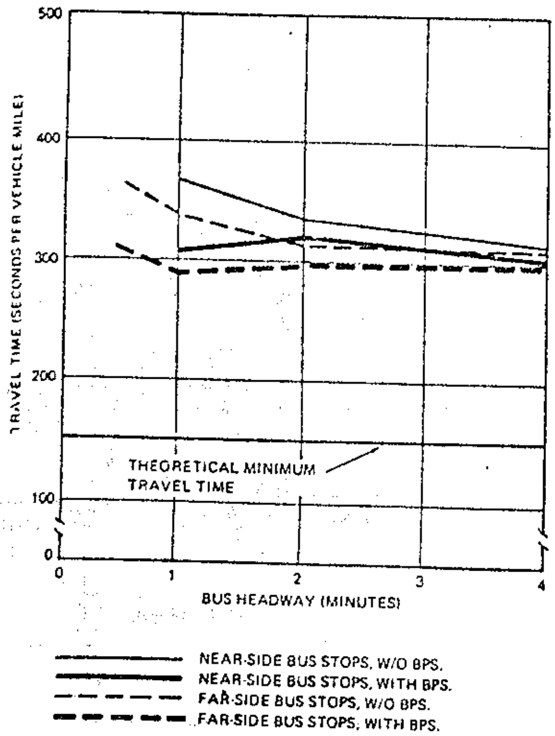
Figure 3.10 Representation of a typical arterial street - SUB
(source: adaptated from ref. 73)



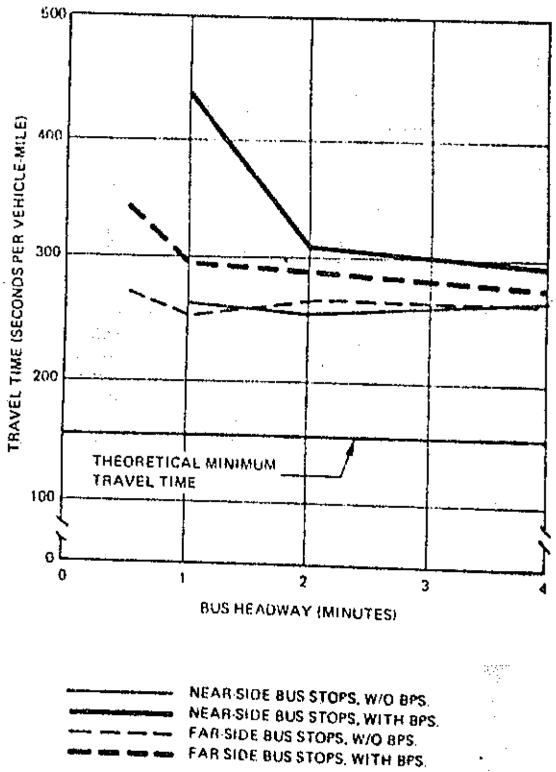
a. simulation network



b. local serv ce,
bus street travel time,
buses only



c. local service,
bus street travel time,
all vehicles



d. local service,
cross street travel time,
all vehicles

Figure 3.11 Ludwick's preemption simulation
(source: ref. 116)

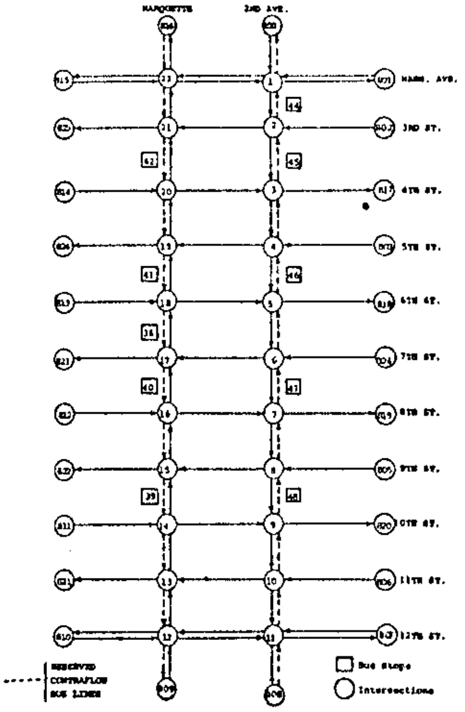


Figure 3.12 Study network - SCOT
(source: ref. 75)

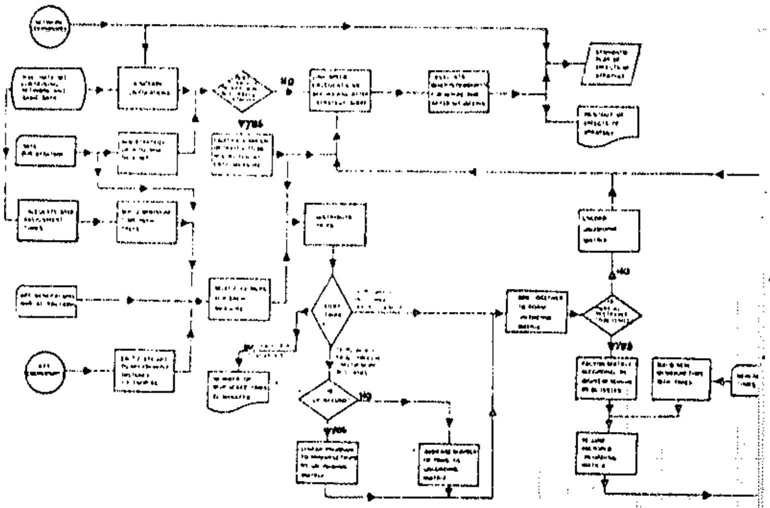


Figure 3.13 Inner London bus priority - model structure
(source: ref. 85)

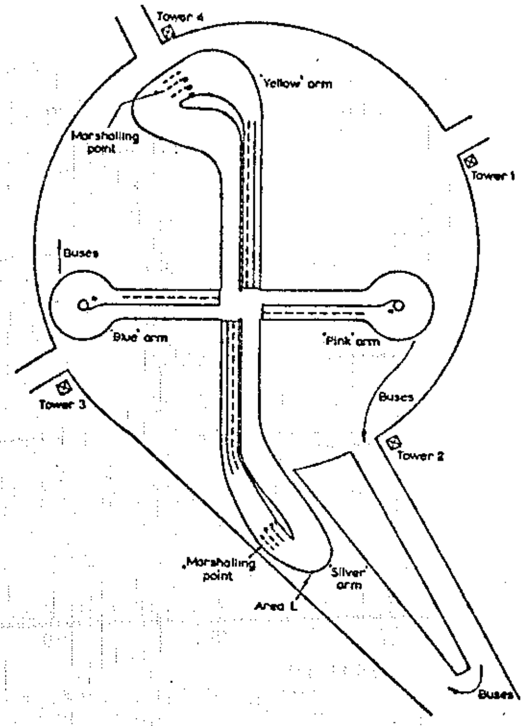


Figure 3.14 Experimental layout at TRRL
(source: ref. 77)

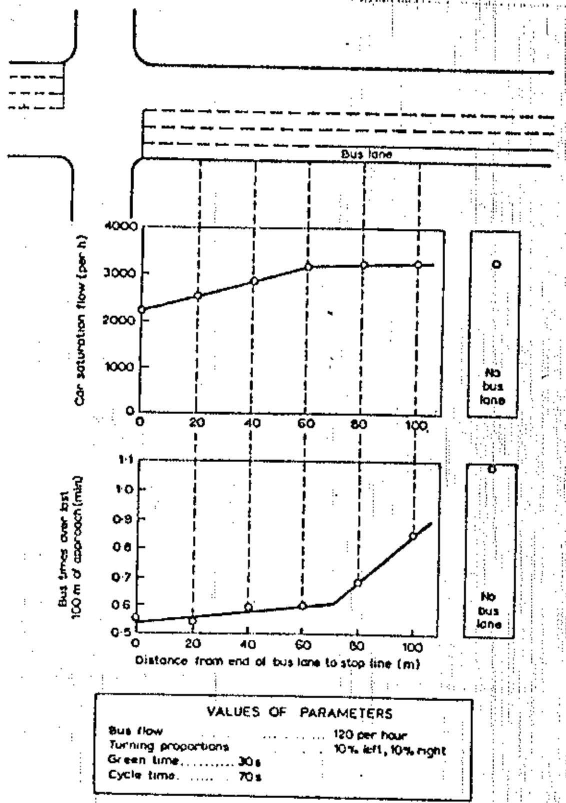


Figure 3.15 Effect of setback on saturation flows and bus journey times
(source: ref. 77)

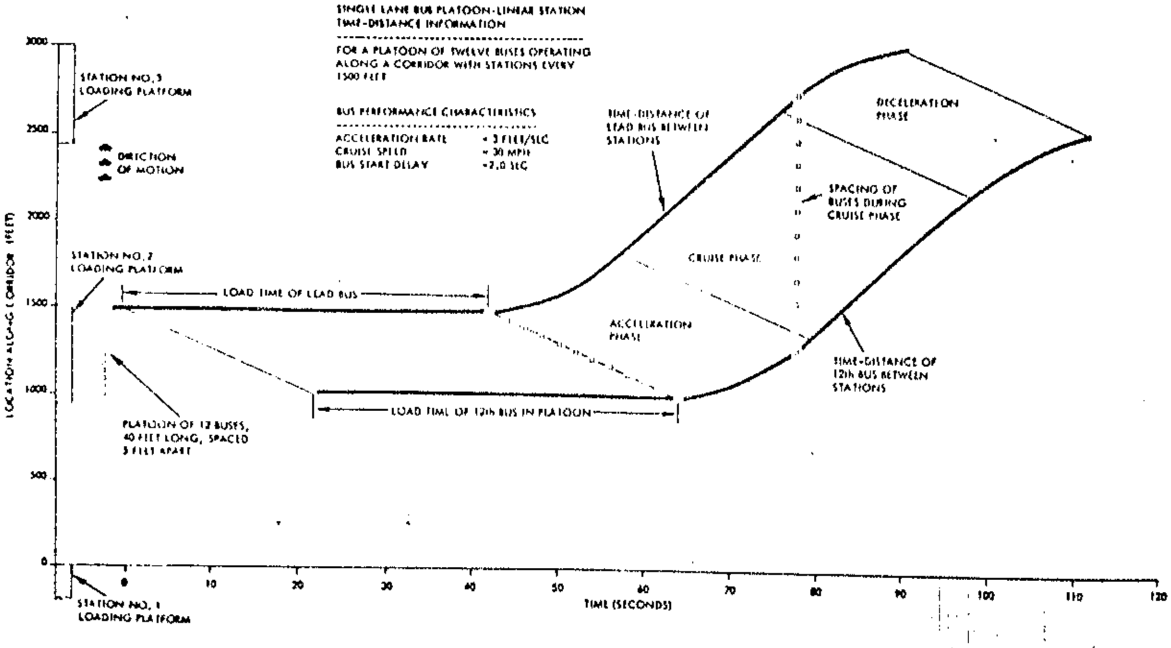


Figure 3.16 Time-distance progress of a bus platoon (source: ref. 90)

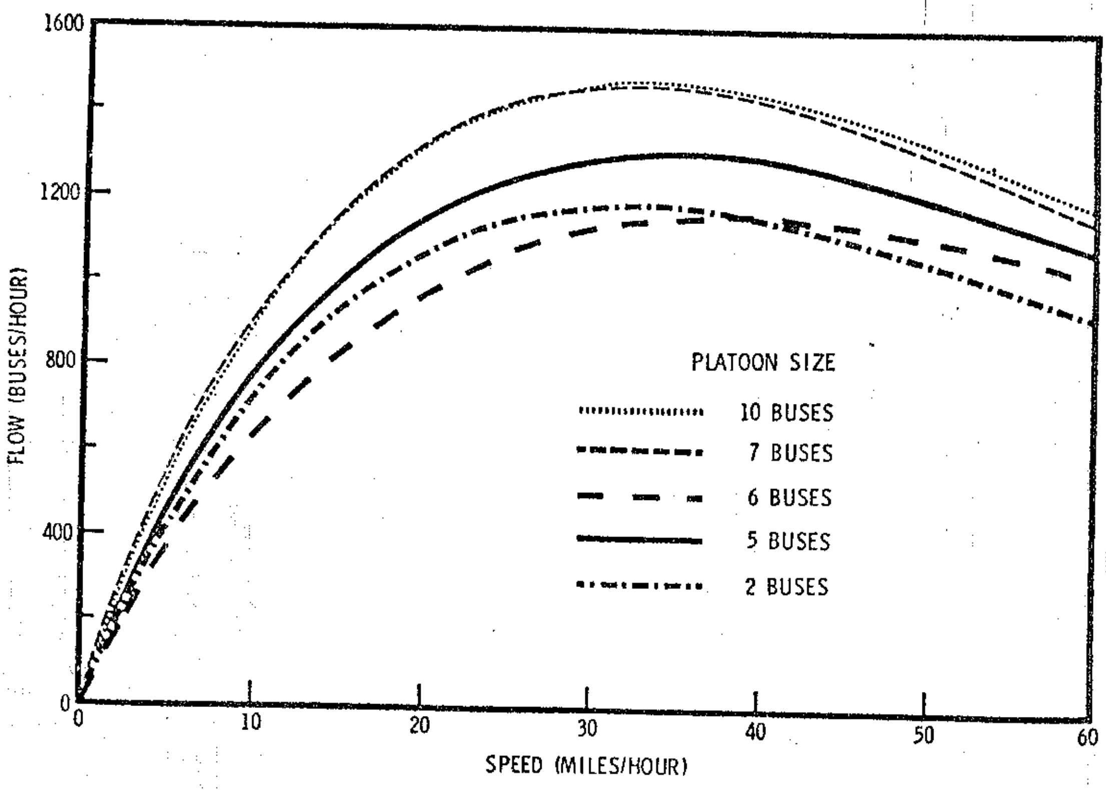


Figure 3.17 Speed-flow relationship for different size platoons (source: ref. 91)

4. EVALUATION OF IMPLEMENTED SCHEMES

4.1 Introduction

It is desirable to monitor priority schemes to assess the extent to which objectives have been met and to determine the extent to which other road users have been affected. Within any evaluation process, benefits are compared with disbenefits, either in money terms or by subjective judgment.

Lane {95} stated that a bus lane is worthwhile when one can be reasonably certain that the benefits sufficiently outweigh the disbenefits to provide a satisfactory economic return. On the other hand, the Report of the International Collaborative Study of the Factors Affecting Public Transport Patronage {96} considered:

> "... public transport ... is now generally treated as a social or community service whose development cannot be left wholly at the mercy of market forces, but which should be moulded, at some public expense, to encourage the spread of its wider benefits ... overall transportation efficiency, protection of the environment, safety, improved mobility for disadvantaged sections of society, and energy conservation."

4.2 Effect of bus priorities

The effects caused by the introduction of a bus priority scheme can be divided into {10}:

a. Economic changes

   i. in operation costs of buses and other vehicles
   ii. in the number of accidents
   iii. in travel times of priority and non-priority vehicles
   iv. in walking and waiting times of bus passengers and other road users
   v. in consumer surplus (benefit from travelling above perceived costs of travel) arising from generated and suppressed journeys.

b. Environmental changes

   i. in atmospheric pollution

ii. in noise levels

iii. in visual scene

c. social and political changes

i. in the distribution of costs and benefits between different sections of the community

ii. in the modal-split

iii. in the fuel conservation

iv. in attitudes towards the bus rank, area or town

v. in job, educational, social opportunities etc. (second-round impacts) directly attributable to the scheme

4.3 Difficulties in costing effects

For the purposes of comparison, it is desirable to express all costs and benefits involved in the implementation of a scheme in monetary terms. However, in some cases this is not practical.

In the economic evaluation of priority schemes, it is a normal procedure to quantify the time saved by the priority vehicles and the losses, if any, to other road users. These time values can then be converted into monetary terms by applying appropriate 'values of time' for each class of vehicle. Another factor usually included in the evaluation is the saving in fuel consumption that may arise from the introduction of a specific scheme. Its inclusion is justified by the present concern over energy conservation. Environmental changes involving the alteration of noise and air pollution levels are very difficult to express in monetary terms although some quantitative analysis can be carried out.

Problems also arise in the assessment of the political and social implications of a proposal. It may well be the case that one group in the community pays for the project while an entirely separate group enjoys the benefits. An example of this is where the cost of a scheme is met from the general taxation while the benefits acrue to commuters to a city centre. It is largely a political decision as to whether benefits to some groups should be valued more highly than benefits to other groups, although it is essential to try to identify the scope and extent of such benefits for a sound political decision to be made.

4.4 Dimension of evaluation

Richardson and McKenzie {82} proposed a framework within which bus priority systems may be evaluated. This evaluation framework, shown in figure 4.1, considers various evaluation methodologies as lying within a three-dimensional space. This space, with dimensions termed breadth, width, and depth, defines the complexity and completeness of the evaluation procedure. Breadth refers to the number of groups in the community included in the analysis. For bus priority systems, appropriate groups might include bus passengers, car drivers and passengers, pedestrians, and non-users of the facility. Width refers to the geographic area over which the evaluation extends and, for bus priority studies, might consist of a link, a route, or a network. Depth refers to the number of effects considered in the evaluation.

The evaluation of an existing scheme can be anywhere within this three-dimensional framework.

4.5 Evaluation methods

The most common methods used for assessing a bus priority scheme is a 'before and after' study. The alternative method is called a 'post-implementation' study and consists of conducting a questionnaire vey after the introduction of the priority measure.

4.5.1 Before and after studies

In these studies conditions which occur after the imple ntation of some priority measure are compared with those which wo have been occurring if the scheme had not been introduced. The ' ore' period must end prior to any material alteration to the location the 'after' period must follow a transition period during which avel habits are adjusted. The more comprehensive the scheme, the more extensive will the assessment need to be and the longer the period allowed for people to adjust to the changes before measuring the effects {14}.

A before and after assessment of a scheme is only valid if its implementation is the only change affecting factors measured as part of the evaluation {82}. However it often happens that the priority scheme is introduced at the same time as other traffic management measures. Even if the implementation is phased, some uncontrolled changes take place during the assessment period, such as changes in income and cost of living, with consequent effect on the modal split and journeys to work.

Table 4.1 presents a summary of the review of some of the relevant before and after studies related to bus priorities in urban areas.

4.5.2 Post implementation studies

They are undertaken by conducting a questionnaire survey, after the implementation of the priority measure, in which respondents are questioned as to their travelling habits before and after implementation of the priority measure. It is a less valid evaluation technique than a before and after study since it is subject to non-response and other bias.

Table 4.1 - Tabulation of before and after studies (literature review)

location	type of scheme	ref. no.	priority vehicles	non-priority vehicles	link specific	area wide	journey time	operation costs	fuel consumption	environment	accidents	modal-split	traffic flows	others
NY 7th Avenue Miami, Florida	i) C ii) A+C	97	X		X		X		X					comfort measures
Dallas, Texas	A	98	X	X	X		X					X	X	lane occupancy, spot speeds, bus patronage
Oxford Street, London	G	99, 10	X		X	X	X	X		X	X		X	passenger waiting times
Bitterne, Southampton	H	53	X	X	X	X	X				X	X	X	route changing, bus patronage, passenger waiting times
Australia	i) C ii) C+D	49	X	X	X		X						X	
Bangkok	A	100	X	X	X		X						X	bus lane violation
Tottenham Rd, London	B	101	X		X		X				X		X	
Glasgow	E	102	X	X		X	X						X	
Louisville, Ky.	I	52	X	X	X		X						X	lane composition
Los Angeles, Ca.	C	38	X		X		X						X	
Tel-Aviv	B	103	X		X		X							
Swansea	C	104	X	X	X		X						X	vehicle occupancy, pedestrian delay
Reading	J	106, 10	X	X		X	X				X		X	bus patronage
Adelaide, Australia	A	108	X	X	X		X						X	bus stop time, bus patronage, pass. waiting times
Dublin	A	76	X	X	X		X						X	vehicle occupancy, pass. waiting times
Marseilles	A	105	X	X	X		X			X			X	bus lane violation, car parking
Bologna	J	10	X			X	X							bus patronage
Besançon, France	J	10	X	X		X	X			X		X	X	walking times, pedestrian counts, bus patronage

Table 4.1 (continued)

location	type of scheme	ref. no.	priority vehicles	non-priority vehicles	link specific	area wide	journey time	operation costs	fuel consumption	environment	accidents	modal-split	traffic flows	others
		area of interest												
Madison, Wisconsin	B	110	X	X	X		X		X	X	X		X	walking distance, bus patronage
Sidney	A	112	X	X	X		X						X	vehicle occupancy
Vauxhall Bridge, London	A	114	X	X	X		X						X	
Camberwell Green, London	B	114	X	X	X		X						X	
Derby	C	117	X	X	X		X						X	

convention:

A - normal-flow bus lane
B - contra-flow bus lane
C - signal preemption
D - signal progression
E - area traffic control
F - bus ways
G - bus street
H - metering
I - bus stop location
J - comprehensive schemes

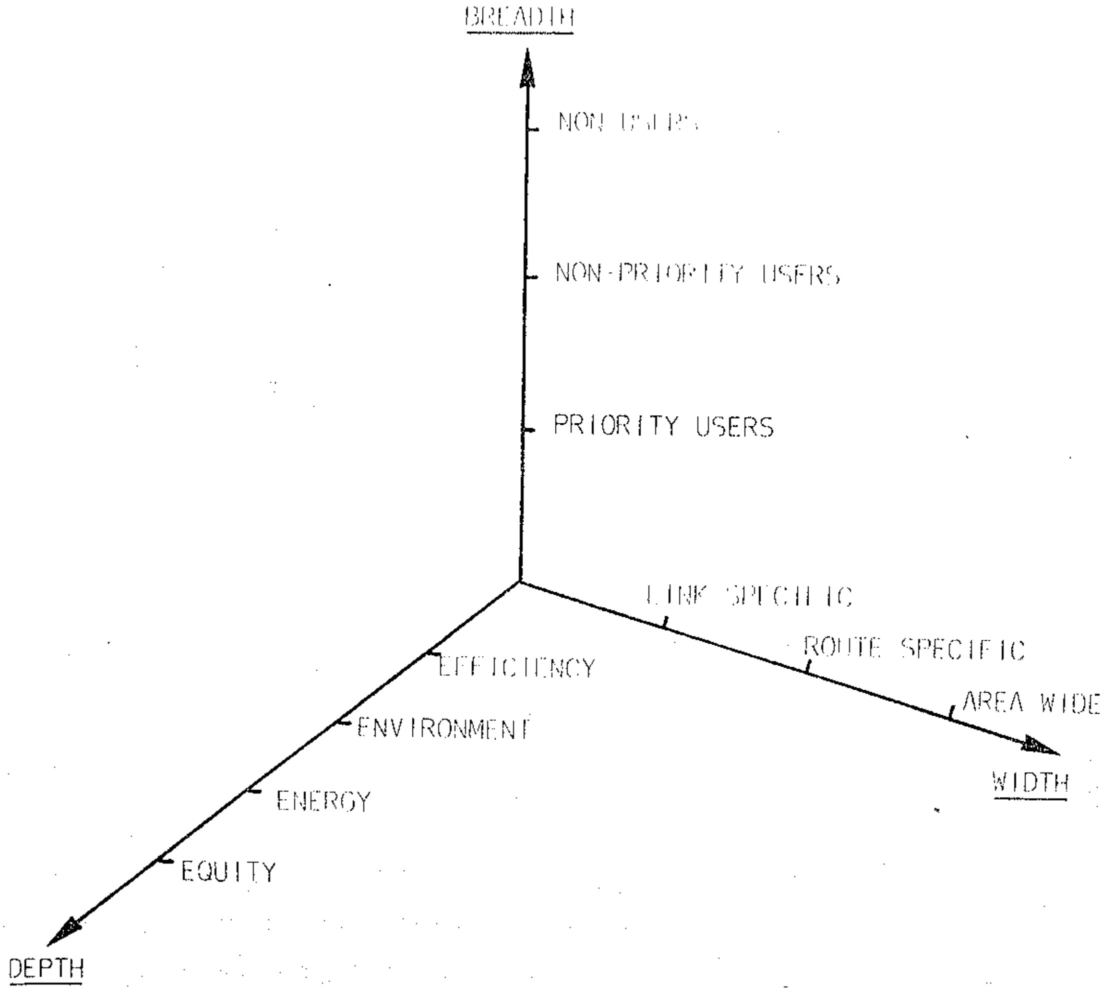


Figure 4.1 Dimensions of Evaluation Methodologies

(adapted from ref. 82)

CONCLUDING COMMENTS OF SECTION I

The objective of this first section has been to review priority measures which may be used to improve the performance of bus operations in urban areas. The procedure adopted in the literature review was to:

a. identify and define the different bus priority schemes (Chapter 2).

b. describe the characteristics of the measures adopted on urban roads with special attention to advantages and disadvantages resulting from the adoption of alternative schemes (Chapter 2).

c. collect information related to the impact of implemented urban priority schemes (Chapters 2 and 4).

d. investigate the different methods of assessing the suitability of urban bus priority schemes (Chapter 3).

e. identify the extent to which the impacts of bus priorities have been evaluated in the past (Chapter 4).

f. identify areas for worthwhile research, particularly those with specific application to the situation prevailing in Brazil.

The review of the available literature showed that a considerable amount of work is stillrequired to fill gaps in the existing knowledge of bus priorities operations. With specific relation to item f above, the following main points were found:

a. Few bus lanes have been thoroughly evaluated {14}. While thousands of schemes have been implemented throughout the world, there have been few scientific studies of the impacts of bus priority facilities, especially 'before and after' measurements pertaining to arterial bus priority treatments {11}. Due to the difficulties in placing a monetary value to environmental, social and political effects, the majority of the studies have been concerned with travel time benefits to users of priority vehicles along a specific road or link. It was also found that most of the studies on the implementation of schemes have not considered the effects of the scheme on non-bus traffic (see tables 2.1 and 2.2).

b. <u>The potential for urban bus lanes has not been fully investigated.</u>

i. This statement is particularly relevant to arterial median bus lanes where applications had not been reported (see figure 2.3 and table 2.4).

ii. Only a few track experiments have been undertaken to study bus priority measures. Although track experiments have enabled traffic and road layout factors to be altered in a controlled manner, there is a practical limitation to the range of experiments which can be made in this way. The interpretation of their results deserves careful consideration since they cannot, directly, predict the effects of providing bus priorities in a 'real life' situation {65}.

iii. The measures simulated by computer programs include combinations of bus lanes and signal priorities. However there is a lack of simulation studies in areas such as the combined use of progression and preemption {118} and the adoption of bus platoons along arterial bus lanes. Moreover, none of the simulation models reviewed have examined high flow median bus lanes.

With regard to the Brazilian conditions this study concentrates in investigating the effectiveness of median arterial bus lanes - the technique that has been recommended, by existing criteria, for locations presenting a high flow of buses and passengers. As median bus lanes are amongst the most expensive priorities to implement, alter and discontinue, apart from being the least common form of urban bus lanes, research effort is required to improve the knowledge of their operational capability before implementation.

5.3 Steps in simulation

The successive steps in the preparation of a traffic simulation program may be summarized as:

a. formulation of the model - define the traffic situation to be simulated, specify the degree of complexity to be included and once having formulated the logic of the problem, reduce it to a language acceptable by the computer.

b. program checkout and internal verification of the model - determine if the program is working and correctly representing the model as defined by checking out each subroutine as it is written. This procedure requires special test routines that supply data and print the output of the subroutine being tested.

c. estimation of parameters - select the best values for model parameters by direct measurement and statistical tests or by indirect techniques in which parameter values are inferred by comparing model outputs and observation of the outputs. The procedure of selecting the best values for model parameters is called calibration of the model {119}.

d. validation - test the agreement between the behaviour of the simulation model and a real system by comparing data generated by the computer with actual traffic data.

e. design of experiments - the objective of an experiment is usually either related to finding the combination of factor levels at which the response variable is optimized or to explaining the relationship between the response variable and the controllable factors in the experiment.

f. analysis of simulation data - the analysis of simulated data consists of the collection and processing of simulated data, computation of test statistics and interpretation of the results.

These steps are further discussed in the following chapters of this study.

6. MODEL FORMULATION

6.1 Introduction

1965 h03

This chapter describes the main features of the traffic simulation model SIBULA (SImulation of BUs LAne) which was developed to represent in detail the operation of priority (buses) and non-priority vehicles travelling along one direction of a section of an arterial road. The primary objective of the simulation model is to test and evaluate the efficiency of exclusive median bus lanes under different configurations. A significant amount of data was collected and used for calibration and validation procedures.

SIBULA was developed in several phases. In the first stage a model was formulated to represent mixed vehicle operation on a single traffic lane featuring a three berth bus stop and one traffic signal. This early model served as basis for the development of the present versions of the vehicle response subroutines described in chapter 9. At that initial stage pilot experiments were conducted by comparing real life and simulated time-distance profiles of successive following vehicles. Traffic data was collected from time lapse films that were analysed using the technique described in Appendix 1. The site selected for the measurements consisted of a traffic signal approach on Bursledon Road, Southampton (UK), where incoming vehicles were restricted to the use of a single lane.

The research effort was then totally concentrated in the investigation of vehicle following behaviour. A variety of assumptions were tested by conducting a large number of computer runs to assess the sensitivity of journey time to the changes in the assumed relationships. Car following procedures were thus developed to enable simulated vehicles to undertake realistic and stable deceleration and acceleration manoeuvres while either approaching the end of a standstill queue of vehicles or starting at the onset of the green period. It was found that a particular combination of free flowing and car following reactions, described in section 9.6, produced headways at the stop line that were in close agreement with site observations (see section 11.2).

The second step of the simulation work comprised the development of the mixed flow multi-lane model. Initially the program was extended to cope with three unidirectional lanes where no lane change was allowed. Turning vehicles were introduced and special subroutines were written to evaluate travel times and process the removal of vehicles from the system. The sensitivity and conceptual validity of the model was checked by observing the direction of change in the output caused by modifications in specific input parameters. The greatest variation in average travel times was caused by increments in input flows. However, no attempts were made, at that stage, to determine which form the variations took (i.e., if response curves were linear, quadratic or cubic in nature). On the same grounds, it appeared that output saturation flows at stop lines were more sensitive to variations in the characteristic speed than to alterations in the magnitude of the free flowing acceleration behaviour of queueing vehicles. This large number of tests, undertaken before data collection in Brazil, enabled the definition of the extent to which the various input parameters needed to be identified from the data. Some parameters had only minor effects on the measures of effectiveness. For example, the average travel time of kerb lane vehicles was almost insensitive to changes in the gap acceptance model as under arterial road conditions only a minor proportion of the total flow is inserted through lateral roads. Such results led to the introduction, in the model, of some distributions and parameters obtained in previous studies.

In the third phase, a lane changing model was incorporated to the program. Several generations of lane changing routines were developed. A sophisticated model had to be formulated in order to cope with complex forced lane changing manoeuvres. Sensitivity tests were carried out to investigate the effect of varying the parameters involved in the determination of the kerb lane vehicle that allows the merging of a forced lane changing unit. For a description of the model and the sensitivity analysis, see section 9.9.

During the fourth stage, the length of road simulated was extended to enable the representation of vehicle movements along a series of arterial blocks. Research effort was also concentrated in developing random generation routines as up to that stage randomness could only be incorporated by using alien NAG libraries. Such extra subroutines added flexibility to the model by turning the program coding totally independent of the computing system being used.

This was achieved with no significant increment in program processing time. A fuel consumption model was also developed in order to increase the extent of evaluation that could be conducted by the model. Individual characteristics were assigned to vehicles based on distributions and parameters (see chapter 8) obtained from the traffic data collection conducted in Brazil.

In the fifth and final stage, the main framework of SIBULA was altered as to allow the simulation of both the 'do nothing' and the 'priority' situation.

The model is written exclusively in FORTRAN IV and runs on an ICL 2970 computer. It is set in a modular format, incorporating the following major features:

a. microscopic simulation of individual vehicles by type, utilizing a car-following model and time-scanning methods.

b. representation of a 3 lane section of an artery with up to 6 traffic signals together with associated input (4) and output (5) links. It is possible to extend the study section to any desired length. However any alternative configuration may be restricted by available computer facilities.

c. provision of a series of output printouts including both detailed information after each time increment, i.e. the dynamic characteristics of any particular vehicle, queue length during red phases, link volumes and bus stop occupation, and overall results such as average journey times per class of vehicle and fuel consumption.

d. detailed and equal treatment of both intersection and link traffic behaviour including queue discharge, turning performance, free-flow acceleration and deceleration, traffic response to stop signs and traffic signals, gap-acceptance and free/forced lane changing manoeuvres.

e. detailed treatment of bus traffic including bus-stop dwell times, bus/vehicular traffic interaction ('do nothing' situation) and response to alternative bus stop location and configuration.

f. simulation of both bus priority and non-priority situations. While in the 'do-nothing' situation buses interact with the other vehicles, one lane may be reserved for the exclusive use of buses durign the 'priority' situation.

6.2 Overall structure of the model

This sub-section describes the model in broad terms including its overall structure.

The model specifies vehicles entering the simulated system at entry lanes. Traffic is discharged from the system via exit lanes. Each vehicle being inserted into the system is uniquely identified in terms of its performance characteristics. These characteristics are randomly drawn from specific distributions and influence the selection of reactions such as turning performance, lane change and free-flow acceleration and deceleration. Car-following routines are employed to update constrained vehicles. Such procedures enable the model to generate microscopic vehicle trajectories sensitive to changes in the traffic composition, to the impedance caused by other vehicles and to changes in the traffic signal control policy.

A driver may change lanes when his lane is obstructed by buses halted at a bus stop or an excessively long queue in the lane in which he is travelling. He will also attempt to change lanes if a higher speed can be achieved in the adjacent lane. The actual completion of a lane change manoeuvre is conditional upon the availability of an acceptable lag in the adjacent lane.

As a vehicle approaches an intersection, it may turn, proceed through or stop. The response of a moving vehicle to the onset of the amber phase is based on its speed and proximity to the intersection. The model also caters for the effects of vehicles blocking entry lanes.

Buses are generated according to pre-specified flows and are processed along the system stopping at their assigned stations. Their dwell times are based on the number of passengers boarding obtained from a statistical distribution. Provision is made for evaluating the effects of adopting different bus-stop configurations and a variety of alternative high-flow bus operation techniques.

6.3 Components of the model

The traffic simulation model, which was developed, is formed by two main and two secondary processors (fuel consumption and random number) as shown in figure 6.1. A pre-simulation processor is used to define the traffic stream. Vehicle units are generated based on traffic parameters, and the results stored for subsequent use by the other processors. Other functions of the pre-simulation processor include obtaining, processing and storing all the geometric and traffic details that are held constant throughout the simulation run.

The traffic simulation processor carries out the repetitious computations that are required for simulating the movement of each vehicle through the main lanes of the system. It also caters for the insertion and removal of vehicles from the system.

Most of the calculations performed by the pre-simulation processor involve the generation of random variates of defined probability distribution functions. The random number processor i[illegible] lso used by the traffic simulation processor. The fuel consumption pr[illegible]cessor is linked to the traffic simulation processor, evaluating t[illegible]e total fuel consumed during each simulation run.

The following four chapters describe in detail each of these processors.

6.4 Simulation modules

The four processors are formed by computer modules. The operational relationships of all subroutines are schematically illustrated in figure 6.2 and a glossary of module names is provided in table 6.1. The listing of the program is included in appendix 2.

Table 6.1: Glossary of simulation modules

name	description
COMPOS	set vehicle type according to input lane
VEHCHA	assign characteristics to vehicles
TEMOFF	determine generation times and calculate signal offsets
SIMPRO	perform time sequencing and periodic scanning
RORDER	update main list of vehicles
ELACHA	evaluate possibility of lane change
WCHLA1	check forced lane change and lane changing conflicts
WCHLA2	check time gaps and lane changing conflicts
LACHDE	calculate decelerations involved in lane changing manoeuvre
LACHAN	perform lane changing
LALIST	assemble ordered list of vehicles and control amber reaction
PROUPD	process updation in a per lane basis
LINKPO	determine number of units in each main link
WVEHRE	determine the insertion time for next main lane vehicle
UPDATE	update the dynamic characteristics of each vehicle
STOPOS	determine turning or stopping position
BSTIM1	select bus stop time (conventional bus service)
BSTIM2	select bus stop time (buses operating in platoons)
TSPAHE	determine the position of next signal ahead
KSPACC	keep vehicle speed or accelerate it
WDECST	determine if deceleration to stop is required
RELVEH	release main lane vehicle through origin
WDECLE	determine if deceleration to leader is required
DECSTO	decelerate vehicle to stop
WDSTLE	decide if vehicle reacts to stop or to leader
DECLEA	decelerate vehicle according to car following
INSVEH	check insertion of new units through origin
WDECTU	determine if deceleration to turn is required
WDTULE	decide if vehicle reacts to turn or to leader
DECTUR	decelerate vehicle to turn
REMOTU	remove turning vehicle
REMOST	remove straight vehicle
SIGIND	determine traffic signal indications
UPDELA	update minor 'T' lane vehicles
EVAGAP	evaluate existing gaps in major traffic stream

Table 6.1: continued

name	description
EVALAG	evaluate existing lags in major traffic stream
INSERT	insert minor lane vehicles into main traffic stream
UPDSIL	update and release minor signal lane vehicles
UPDSIG	update the dynamic characteristics of minor signal lane vehicles
POOLTR	transfer vehicle characteristics to smaller arrays
WINCON	write initial geometric and flow conditions
FUELCO	determine instantaneous fuel consumption
NORMAL	obtain a normally distributed random deviate
RANDNU	generate a random number (0,1)
SHNEXP	obtain a shifted negative exponential deviate
NEGEXP	obtain a negative exponential deviate

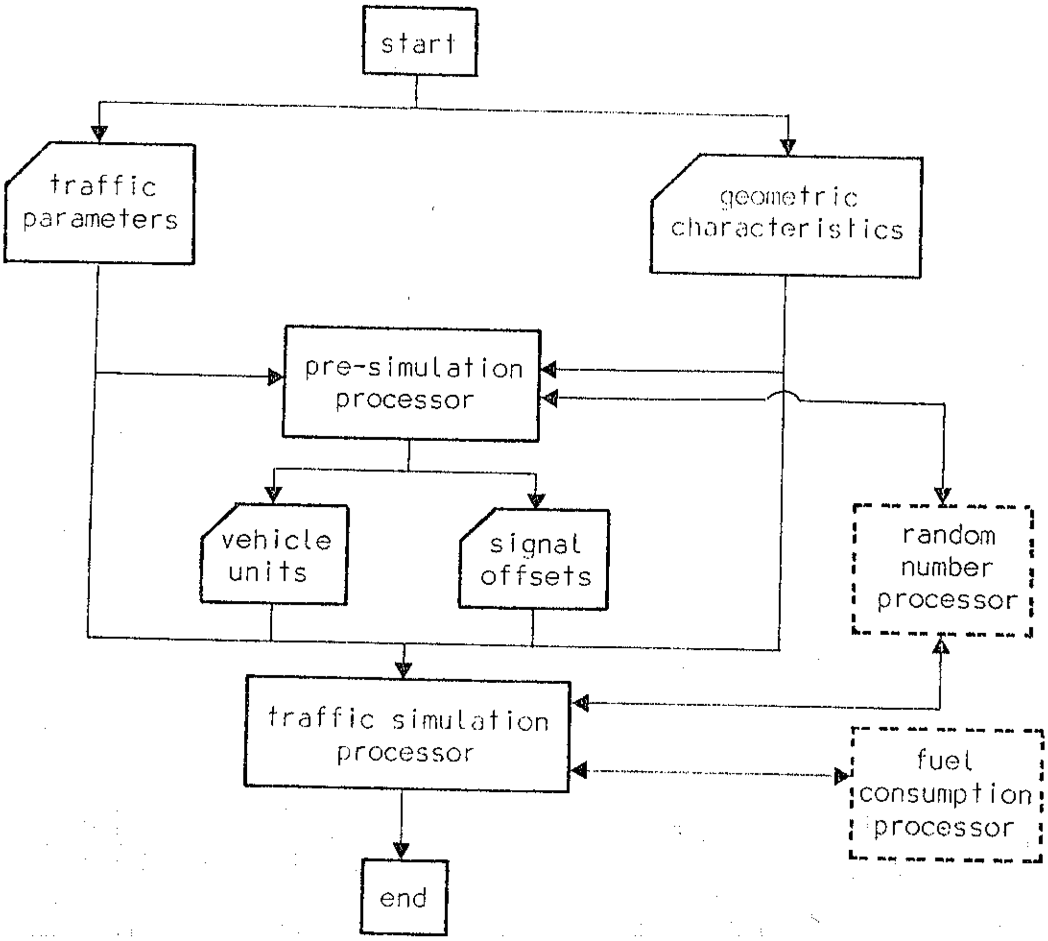


Figure 6.1: Components of SIBULA

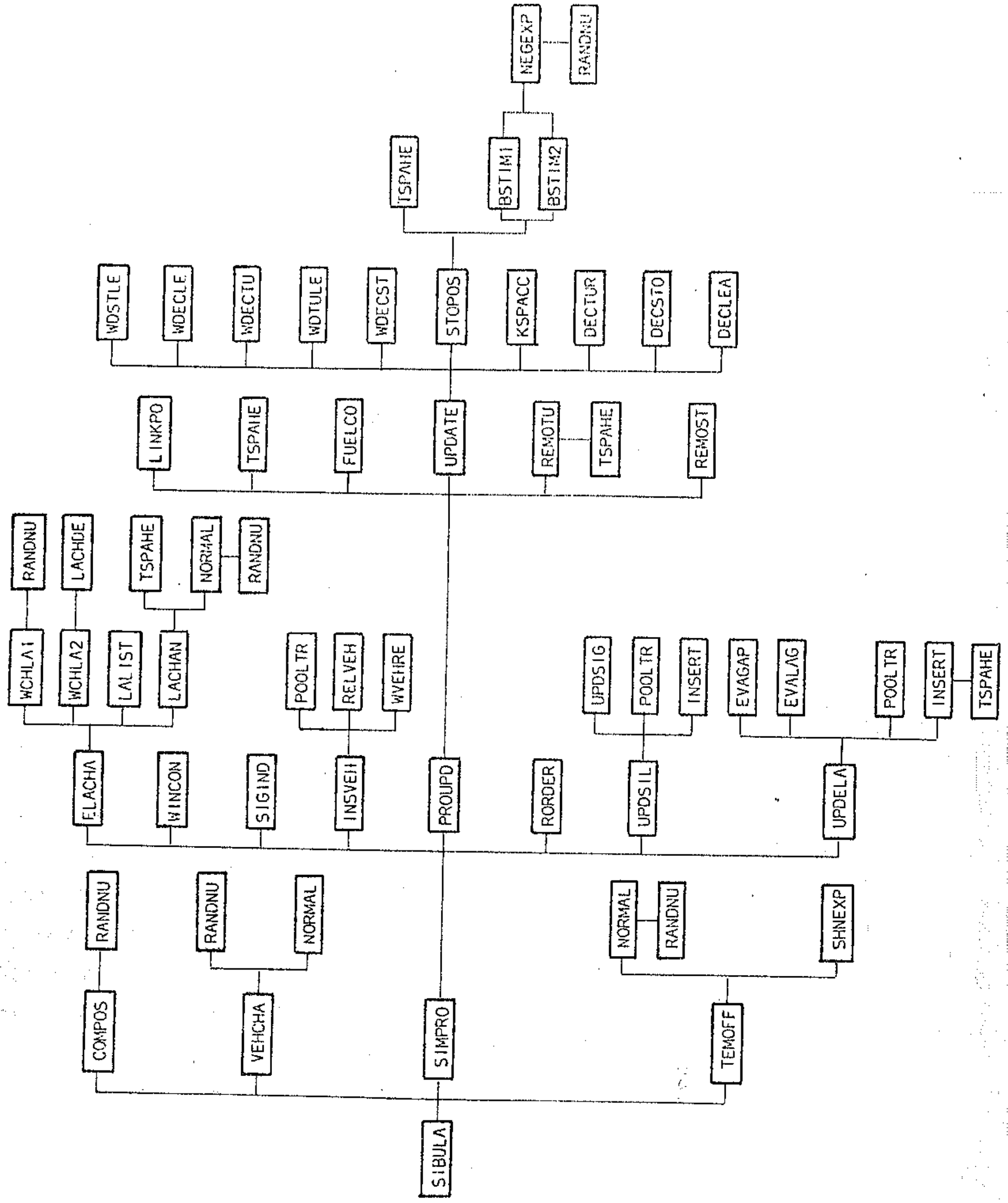


Figure 6.2 Flowchart of SIBULA modules

7. RANDOM NUMBER PROCESSOR

7.1 Introduction

The simulation requires a mechanism for generating random events from a variety of continuous and discrete probability distributions. Variates can be generated for a wide variety of distributions provided only that a sequence of random numbers, uniformly distributed on the interval (0,1), can be generated. These values are then associated with both continuous and discrete distributions to provide the required random variates. Figure 7.1 presents the flowcharts of the modules used by the random number processor.

7.2 Generation of random numbers

An adequate method of producing random numbers should satisfy statistical tests designed to evaluate the randomness of the sequence. It is also desirable to have a minimum utilization of computer storage. The efficiency of a particular algorithm is also related to the computer time it requires to produce a sequence of numbers. In practice, some compromise must be made between the several requirements.

One form of generating random numbers on a digital computer is to prepare and store a table of random numbers {196}. Apart from computer storage requirements, the main disadvantage of using such a method is the possibility of exhausting the table.

The most commonly employed random number algorithm produces a sequence of numbers where each number is determined by its predecessor and all numbers determined by an initial number. Such random numbers, due to their nonrandom nature, are called pseudo-random numbers. The use of a pseudo-random number generator should thus be dependent on its first passing a series of diverse statistical tests.

The pseudo-random technique is usually stated as,

$$Z_i = a\, Z_{i-1} + c \pmod{m}$$

where a, c and m are chosen in accordance with the characteristics of the computer being used and Z_i is the i^{th} random number distributed on the interval (0,1). Generators of this form are called congruential generators. Generation is allowed to be interrupted and restarted without loss of order in the sequence simply by saving the last number. Fishman {197} pointed out some theoretic inadequacies in the utilization of the congruential generators and suggested the use of an 'almost full period multiplicative congruential generator',

$$Z_i = a\, Z_{i-1} (\mathrm{mod}\ m)$$

where $a = 14^{29}$ or 7^5 and $m = 2^{31} - 1$ satisfies the condition for maximum period on a system of 31 bits available for computation. These parameters have performed favourably on a variety of statistical tests {198, 199}.

The initial random number, or seed, is provided as input data to the model. The generation of the i^{th} random number is performed by module RANDNU.

7.3 Statistical tests for the seeds

The series of numbers produced by each selected seed has to be checked against eventual departures from randomness.

7.3.1 The frequency test

A chi-square goodness-of-fit test is used to check the uniformity of a sequence of n consecutive pseudo-random numbers Z_1, Z_2, Z_3, ..., Z_n. The unit interval (0,1) is divided into r equal subintervals so that the probability that a number Z_i falls in a particular interval is 1/r.

If Z is a sequence of independent, uniformly distributed random variables, the statistic,

$$X_1^2 = \frac{r}{n} \sum_{j=1}^{r} (f_j - \frac{n}{r})^2$$

has a chi-square distribution with r-1 degrees of freedom, where f_j is the frequency which numbers fall in the interval $[(j-1)/r, j/r]$. In large samples, X_1^2 has mean r-1 and variance 2(r-1). When r is sufficiently large the quantity,

$$Q' = \frac{X_i^2 - (r-1)}{\sqrt{2(r-1)}}$$

approximates to the

normal distribution with mean zero and unit variance so that,

$$\text{Prob}\left[|Q'| < P_{1-\alpha/2}\right] \sim 1-\alpha$$

where $P_{1-\alpha/2}$ is the point on the normal curve corresponding to probability $1-\alpha/2$.

The result of the frequency test carried out by Lewis, Goodman and Miller {199}, for ten different seeds, using a multiplicative congruential generator, is shown in table 7.1. A test size of $\alpha = 0.05$ gives $P_{0.975} = 1.96$. Since the largest deviation gives $\max|Q'| \sim 1.92$, Fishman {197} indicated that the hypothesis of Q' being normally distributed N(0,1) was accepted for each of these 10 seeds.

7.3.2 Other tests

The numbers generated in the interval (0,1) were also tested against the requirements that,

$$\frac{1}{n}\sum_{i=1}^{n} Z_i = 0.50$$

and

$$\frac{1}{n}\sum_{i=1}^{n} Z_i^2 = 0.33'$$

The results of these tests are also presented in table 7.1. The seeds used in the program were selected from these 10 values.

7.4 Obtaining random deviates

The inversion technique is the usual procedure adopted to convert random numbers into random deviates that satisfy the desired frequency distribution. The method relies on the possibility of integrating the probability density function, f(x), that describes the distribution of a variable x. An analytical invertion of the resultant cumulative distribution is also required.

The point-distribution method may be used in situations where probability density functions are difficult to integrate and the inversion is either impossible or impractical.

In order to generate deviates from $N(\mu,\sigma^2)$, u_j and u_{j+1} are generated and a random deviate is obtained by either,

$$x = \mu + (-2\sigma^2 \ln u_j)^{\frac{1}{2}} \cos 2\pi u_{j+1}$$

or

$$x = \mu + (-2\sigma^2 \ln u_j)^{\frac{1}{2}} \sin 2\pi u_{j+1}$$

Usually it is desired to generate a random deviate from a specified interval (a,b) although the probability density function is defined over a larger interval. This process involves the truncation of x. One approach to sampling from a truncated distribution is to generate deviates from the unrestricted distribution and to accept only the variates that fall in (a,b). This process is most appealing for truncating the tails of a distribution {197}. A loss of 0.1 probability in the tails raises the expected number of iterations to only 1.11; a loss of 0.2 raises the number to 1.25.

Module NORMAL produces normally distributed random deviates.

7.5.4 Lognormal random deviates

If the logarithm of a random variable has a normal distribution, then the random variable has a positively skewed continuous distribution known as the lognormal distribution. Suppose that x is drawn from $N(\mu_x, \sigma_x^2)$. Then $y = e^x$ has the lognormal distribution with mean and variance,

$$\mu_y = e^{\mu_x + \sigma_x^2/2}$$

$$\sigma_y^2 = e^{2\mu_x + \sigma_x^2}(e^{\sigma_x^2} - 1)$$

respectively. Whenever μ_y and σ_y^2 are specified, instead of μ_x and σ_x^2, the equations above yield,

$$\mu_x = \frac{1}{2} \ln \left(\frac{\mu_y^4}{\sigma_y^2 + \mu_j^2} \right)$$

and

$$\sigma_x^2 = \ln \left(\frac{\sigma_y^2}{\mu_y^2} + 1 \right)$$

No special module is employed for the generation of lognormal random deviates. Module NORMAL, already described, is used in order to sample a normally distributed logarithm and the exponential function calculates the deviate.

7.5.5 Discrete random deviates

In the case of a discrete variable, the probability distribution gives the probability of each value occurring, p(I). When the summation of the probability distribution is taken over all possible values of the variables the result is,

$$\sum_{I=1}^{n} p(I) = 1$$

where n is the number of discrete classes. The discrete probability density function is,

$$f(I) = p(I)$$

The cumulative density function for the discrete distribution is expressed by,

$$F(J) = \sum_{I=1}^{J} p(I)$$

where F(J) is in the range from 0 to 1.

The cumulative density function is not represented by an equation but by tabular data. As the function cannot be analytically solved, the generation of a deviate is performed by a 'table-look up' operation. In figure 7.2 tabular values of the distribution are indicated by points. A random fraction, Z, is compared with the ordinates of the various points until the first point satisfying the following conditionis found,

$$F(J-1) \leq Z < F(J)$$

This procedure is performed in the program whenever necessary.

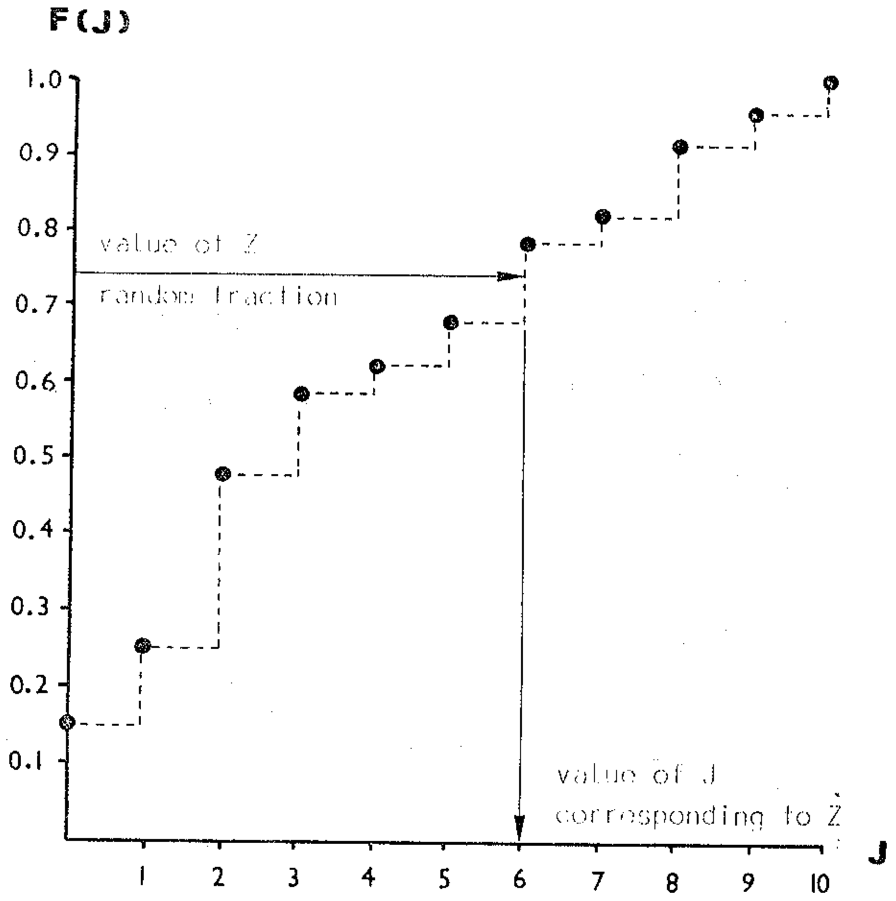


Figure 7.2 Generating deviates from the cumulative density function

8. PRE-SIMULATION PROCESSOR

8.1 Introduction

The purpose of the pre-simulation processor is to generate individual vehicles by assigning them characteristics taken from traffic stream distributions. The input parameters of such distributions were, in the majority of the cases, obtained from data collected on site. The pre-simulation processor also requires, as input, engineering information describing the physical layout of the system being simulated. The output of the pre-simulation processor consists of a series of stored arrays for subsequent use by the other processors. A random number processor, described in Chapter 7, is employed in sampling vehicle characteristics. The flow chart of the pre-simulation processor is given in figure 8.1.

8.2 Input requirements

The traffic stream and physical layout data required by the pre-simulation processor consists of:

a. geometric data
   - i. stop line position at traffic signals (main lanes)
   - ii. position of bus stops
   - iii. number and stop line position of entry and exit lanes
   - iv. length of main traffic lanes
   - v. exiting path radii
   - vi. entry path lengths and radii

b. entry lane information
   - i. traffic flow
   - ii. traffic composition
   - iii. lane distribution
   - iv. percentage of turning vehicles
   - v. headway distribution

c. traffic signal data
   - i. cycle time
   - ii. phase splitting
   - iii. signal offsets

d. vehicle characteristics

i. type, length and width

ii. desired speed

iii. desired acceleration

iv. desired deceleration

v. maximum deceleration

vi. stopping error

vii. gap acceptance

8.3 Geometric data

The road system being simulated is typical of an urban arterial in Brazil. Along the road system, shown in figure 8.2, there are major, minor and auxiliary lanes. A lane is defined by painted carriageway markings spaced in such a way as to allow the passage of only one row of vehicles. Lanes are numbered according to their functions within the simulated system. The lanes along the main flow of traffic (no. 1 - 3) are called major lanes. Major lanes are used both for insertion and removal of vehicles. Each minor lane (no. 4 - 12) performs a unique function: some are used for insertion (no. 4 - 7) while others are used for vehicle removal (no. 8 - 12). An auxiliary lane (no. 20) stores data on vehicles that leave the system. In the 'do-nothing' situation buses and other road vehicles share the use of the 3 main lanes. The median lane (no. 3) is reserved for the exclusive use of buses in the priority situation. The number of traffic signals is dependent on the circumstances being studied. If mid-block bus stops are adopted in the priority situation, it is necessary to insert extra traffic signals to cater for the pedestrian crossing movements. Further discussion related to vehicle operation is found in Chapter 12.

All positions are expressed in terms of distances from the main generation point, defined as the origin. The current version of the program allow a maximum number of 6 traffic signal lights to be introduced. The model was also built to cater for traffic arrivals through 2 minor entry lanes located at 2 different road intersections with traffic signal lights and through 4 other stop signed minor entry lanes. Although traffic removal is allowed to occur along 5 different minor exit lanes, the majority of the simulated vehicles, including all buses, are both inserted and removed through the major lanes. The number of bus berths in a bus stop is related to the bus operational situation being tested. Further details are also presented in Chapter 12.

Site observation indicated that the average path radii of vehicles leaving the system through minor exit lanes did not coincide with the geometric radii of the curves, since drivers tended to alter their lateral displacement in relation to the kerbside between the beginning and the end of the turning manoeuvre. Estimates of the average paths were obtained by measuring these displacements. By approximating circular paths to the estimates, the path radii were determined from,

$$R = \frac{T}{\tan \frac{1}{2} \alpha}$$

where the variables are as shown in figure 8.3. The input radii values influence the selection of the desired turning speed (section 9.4.3).

A simplifying procedure is used in the model to simulate vehicles entering the main lanes through minor entry lanes at signalized intersections. Entering vehicles travel, in reality, along a non-linear merging path, b, as shown in figure 8.4. However, for practical purposes, insertion through these types of lanes can only be performed through section AA, defined by the location of the stop line of the traffic signals at the main lanes. Therefore, entering vehicles must travel an extra few metres, x, before insertion occurs. These extra distances are also required as input by the pre-simulation processor. A curvilinear approximation of the average path radius is used in determining the dynamic characteristics of the entering vehicles. Further details about vehicle updation along minor entry lanes are described in section 9.10.7.2.

8.4 Entry lane information

8.4.1 Traffic flow, composition and lane distribution

In order to simplify the data input requirement of each different run, it was decided to express the entering flow of each main traffic lane, no. 1 - 3 in figure 8.2, in terms of the hourly total number of buses. Classified hourly flow counts during the 'do nothing' situation provided means of estimating the relative proportions (in percentage) of vehicle types, k_i, along the main entry lanes. Figure

8.5 shows the observed average variation in the traffic stream composition along different periods of the day. The results presented in table 8.1 were considered to be representative of the artery road conditions and were kept constant during all simulation runs. Therefore, once a desired bus flow, v_b, is input, the total number of a given type of vehicle, t_i, being inserted through the main lanes is calculated by,

$$t_i = \frac{k_i}{k_3} v_b$$

where i is the index of the vehicle type, i=1 represents a car, i=2 a taxi, i=3 a bus and i=4 indicates a lorry.

The typical lane distribution of major lane vehicles is shown in matrix form, c_{ij}, in table 8.2, for both the 'priority' and the 'do-nothing' situations. The total flow of each of these lanes, f_j, for each of the operational situation being studied, is obtained by,

$$f_j = \sum_{i=1}^{4} t_i \, c_{ij}$$

with

$$\sum_{j=1}^{3} c_{mj} = 1, \text{ for } m=1 \text{ to } 4$$

where index j represents the main lane number, i indicates the vehicle type, and c_{ij} represents the percentage of vehicles i in lane j.

The composition of each main entry lane, l_{ij}, is determined by,

$$l_{ij} = t_i \, c_{ij}/f_j$$

The composition of the remaining entry lanes (no. 4 - 7) is given in table 8.3.

8.4.2 Assigning exit lanes

The following procedure is adopted in order to determine the exit lane of a turning vehicle:-

a. check if the possible destinations of the vehicles in the lane being evaluated include one of the minor exit lanes; vehicles being inserted through a minor entry lane always leave the simulated system through one of the major lanes and turning movements are never assigned to vehicles entering the system through the median lane (no. 3).

b. if the vehicle is a turning one, select its minor exit lane.

The percentage of turning vehicles, y, is another input value required by the pre-simulation processor. The parameter y is expressed as a percentage of the total main flow. If a vehicle is being generated through one of the main entry lanes where turning movements are defined (lane no. 1 or 2), a random number within the interval (0,1), r_1, is sampled (chapter 7) and compared to z_j,

$$z_j = w_j \left[\sum_{m=1}^{3} f_m \right] y/u$$

with $\left[\begin{array}{l} u = f_j, \text{ bus traffic is restricted to the median lane} \\ u = (1-l_{3j}) f_j, \text{ all vehicles share the use of the main lanes} \end{array} \right.$

where z_j is a number within the range (0,1), w_j is obtained from table 8.4, representing the distribution of turning vehicles along each of the main entry lanes, and j is the index of the lane where the vehicle is being inserted. The parameter y is usually input as 0.10.

If r_1 is smaller or equal to z_j the vehicle is considered as a turner and a second random number, r_2 (0,1) is generated to determine its exit lane (no. 8 to 12). The exit lane, n, will be the one that satisfies the expression,

$$r_2 \leq \sum_{n=8}^{12} g_{nj}$$

where g_{nj} is the percentage of turning vehicles of lane j leaving the system at lane n (table 8.5).

8.4.3 Headway distribution

There are two possible ways of generating traffic headway data as input to a simulation model:

a. by reading real data collected from the observed range of volumes.

b. by allowing the computer to generate its own data from a mathematical description of headways.

The first method not only demands more computer storage but also does not permit the simulation to investigate situations different than the ones observed.

Headway distributions in the traffic stream can be described by a wide range of equations. However, in most of the cases these equations yield the estimation of complex parameters in order to provide some improvement in the overall goodness-of-fit. Moreover, as Buckley {120} pointed out, headways observed from the roadside, regardless of the traffic homogeneity, can be extremely dissimilar, even during a short period of observation. While most the headway studies concentrate on uninterrupted flow conditions, the headway pattern of urban traffic is bound to be influenced by interruptions caused by nearby traffic signals.

In this study headways were collected in a per lane basis from time lapse films at sites approximately 200 metres downstream of a signal controlled junction. An initial observation of the headway data showed that the traffic stream could be regarded as composed by a mixture of free (unimpeded) vehicles and constrained (impeded) vehicles. This non-random nature of traffic arrivals on arterial roads was also observed by Ritchie {56} while collecting headways 250-600m downstream from traffic signals. The formulation of a mixed headway distribution model incorporating the distributions of both free-flowing and constrained vehicles was therefore attempted.

Considering a lane of traffic as a succession of moving gaps, a stream of vehicles influenced by traffic lights is composed by gaps between impeded/unimpeded vehicles and gaps between successive 'green phase queue leaders', as shown in figure 8.6. Adopting a criteria for defining which vehicles in a lane are unimpeded and which are impeded would involve examining the association between successive vehicle speeds and/or using properties of the headway distribution {121}. As such details would be outside the scope of this study, a distinction was made, for data collection purposes, between 'green phase queue leaders' and vehicles in general. Therefore, two distinctive distributions of the headways were obtained from the analysis procedures.

The data analysis showed that the average headway value between consecutive 'green phase queue leaders' was very close to that of the cycle time for the observed range of flows. Table 8.6 and figure 8.7 also indicate that a normal distribution is a good approximation to the headway distribution of successive 'green phase queue leaders'.

Shifted negative exponentials and log-normal distributions were tested for goodness-of-fit against real distributions of the headways between the remaining vehicles of the traffic stream in a per lane basis since:

a. they are amongst the easiest distributions to reproduce digitally on electronic computers.

b. each requires the estimation of only two parameters, the displacement and the average headway for the shifted negative exponential and the average of the natural logarithm of the headways and its standard deviation for the lognormal distribution (chapter 7).

c. there are acceptable grounds based on the nature of driver behaviour within platoons to consider the lognormal distribution {122 and 123}.

Although none of the distributions tested produced acceptable results by the chi-square test standards, the best fits were obtained with the lognormal distribution. Reasonable visual fits resulted by the application of the lognormal distribution to data collected along the exclusive priority lanes as demonstrated by figure 8.8. Nevertheless, as stated by Wohl and Martin {64}:

> "... it may still be better to use some approximation, even though it may not be as good statistically as one would like, than to do no analysis at all."

The combined use of the normal and lognormal distributions is employed in order to generate headways for vehicles entering the system through the major lanes. In one hour N bunches of vehicles are formed according to the total number of cycles of the signal downstream. The average size of each bunch is determined by dividing the total lane flow by N. Each bunch leader, i.e., a 'green phase queue leader', obtains its headway, relative to the last generated vehicle of its kind, from the normal distribution described before with maximum and minimum values separated by two standard deviations from the mean. Otherwise, a headway is obtained by sampling a value from the normal distribution of the natural logarithms of the headways.

This procedure has, as advantage, the capability of allowing cyclic bunches of vehicles to be input through the main generation point, as it is found in a network of closely situated traffic signals. Any discrepancy between observed and simulated headway data should be dissipated by the adoption of a settling down distance as described in chapter 12.

The pre-simulation model also allows vehicles to be generated according to shifted negative exponential distributions. This provision is particularly useful to cater for the insertion of light traffic flows through the major lanes. The shifted (1 second) negative exponential is also adopted in the representation of the distribution of minor road vehicle headways, since this distribution has been previously shown to provide satisfactory fits to observed vehicle arrival patterns on side roads {46}.

In order to limit the maximum headway allowed between consecutive vehicles, x_m, sampled by the shifted negative exponential, a truncation {124} at 97% is introduced by the pre-simulation processor,

$$p_x = e^{-\frac{(x_m-\alpha)}{(\beta-\alpha)}} = 0.03$$

where β is the mean headway and x is the shift. Under such conditions, the value of β to be used in the determination of x (section 7.5.2) is expressed by,

$$\beta = \alpha + \beta_f + \left((x_m p_x - \alpha)/(1 - p_x)\right)$$

where β_f represents the mean headway based on a particular rate of arrival. An interactive process is employed until both equations are satisfied.

8.5 Traffic signal data

A traffic signal installation regulates the traffic flow by displaying green, amber and red indications. In the control of traffic at signalized intersections, traffic conflicts are prevented by a separation in time. The procedure by which the streams are separated is known as phasing. A phase has been defined as the part of the traffic signal time cycle allocated to any combination of traffic movements receiving right of way simultaneously {125}.

It is desirable to reduce the number of phases employed at any intersection to a minimum compatible with safety {39}, otherwise the flow of traffic can be seriously retarded. The arterial roads being investigated are characterized by normal cross intersections where only two major traffic conflicts occur. In such conditions traffic stream movements are solved by two phases.

The period between one phase losing right of way at the termination of green and the next phase gaining right of way at the commencement of green is termed the intergreen period {39}. In every intergreen period there is a loss of running time for both approaches where the signal aspects are changing. Therefore such periods are kept to a minimum consistent with safety.

An arterial signal system consists of several individual signal installations functioning under either unlinked or linked control. Unlinked systems allow each intersection to function under isolated control. Linked systems are used to reduce overall vehicle delays and/or vehicle stops. Several types of signal-control systems are used for solving linking systems, including the simultaneous system, the alternate system and the progressive system:

Simultaneous system. With a simultaneous system, all signals along the coordinated length of the artery show the same indication at the same time. It requires an identical cycle length for all signals along the road. This system is considered useful for closely spaced intersections where turning traffic is light since it offers advantage for pedestrian movements {126}. Advantages may also occur under extreme loading conditions, when the progressive system often breaks down, since the traffic at all blocks moves together {64}. The relationship between the progression speed (in both directions) and signal spacing in a simultaneous system can be expressed as,

$$S = \frac{D}{0.278C}$$

where S is the speed of progression in km/h, D is the spacing of signals in metres and C is the cycle length in seconds {127}.

Alternate system. With an alternate system each traffic signal or group of signals along the road shows opposite indication to that of the next signal or group. A single alternate system occurs where each signal alternates with those immediately adjacent. If pairs of signals alternate with adjacent pairs, the system is termed double alternate, etc. Under heavy loading, an alternate system may operate more effectively than progressive systems {64}. The best results arise if the road present equal distances between signals. The progressive speed in a single alternate system is given by,

$$S = \frac{D}{0.139C}$$

where in a double alternate system D is the distance between mid points of adjacent pairs {127}.

Progressive system. With a progressive system, green indications at adjacent intersection are displaced relative to each other according to the desired speed on the road. This time displacement in relation to some fixed point in time is termed the offset. The operational efficiency of the progressive signal system increases in proportion to the increase in the mean operating speed {128}. Newell {129} observed that the usual progressive timing of lights may cause greater delays than a random synchronization, for long distances between traffic lights and under low traffic density.

The signal light indications, generated by the simulation model, follow the pattern green, amber and red that is characteristic of the study sites. The program requires, as input, the specification of a common cycle time and signal indication times for each traffic signal. Within the pre-simulation model the signal offsets for a particular run can be calculated by selecting one of the following alternatives:

a. progressive system for two-directional flow. The signals along the arterial are assigned offsets to maximize bandwidth, the amount of green time available to a platoon of vehicles travelling along the road. In the earliest form of this method, green bands were constructed by a graphical procedure. Except in the simplest cases, this manual production of a signal setting plan may become a very laborious procedure. A detailed description of this method is given in the Transportation and Traffic Engineering Handbook {127}. With the advent of the electronic computer a number of computational algorithms were developed for this process. Morgan and Little {131} first computerized the setting of arterial signals for maximum bandwidth. The widely distributed program of Little, Martin and Morgan {130} is efficient for finding offsets for maximal bandwidth given cycle time, red times, signal spacing, street speed, saturation flow headway and average traffic volume in each direction. Although their approach allows the total bandwidth attained to be allocated between directions on the basis of flow, in this study only bands of equal width are used.

Consider a two-way arterial having n traffic signals. The traffic signals are denoted P_1, P_2, ..., P_n, according to figure 8.9. The red times, r_1, r_2, ..., r_n are specified in fractions of the common cycle, C. The outbound speed, v_i and the inbound speed, $\overline{v_i}$, are defined either by the journey time of free light vehicles or the journey time taken by free heavy vehicles while travelling between P_i and P_{i+1}. The latter case occurs when progression is used to favour the movement of buses. The average bus running time, $w_{i,i+1}$, is the component of the journey time that allows for acceleration and deceleration time losses caused by buses stopping at bus stops. It is evaluated from,

$$w_{i,i+1} = \frac{x_{i+1}-x_i}{v_i} \text{, for } b = 0 \text{ (no bus stop)}$$

$$w_{i,i+1} = 16 + \frac{(x_{i+1}-x_i-60)}{v_i} \text{, for } b > 0$$

where x_i is the position of P_i in metres, b is the average time spent stationary at a bus stop and where both b and w are expressed in seconds {132}. The bus speed is calculated by,

$$v_i = \frac{x_{i+1} - x_i}{w_{i,i+1} + b}$$

The calculation steps that lead to the determination of the signal offsets are described in detail by a MIT report (130). This model was incorporated into the main framework of the current version of SIBULA due to its free availability and computer coding simplicity. However the bandwidth method for signal progression presents shortcomings when compared to the more comprehensive area-wide signal optimization techniques which minimize the overall cost of traffic congestion. The introduction of signal offsets calculated by specially developed computer optimization packages (see section 2.3.2.1.1) would therefore provide a more realistic indication of the optimum signal progression. However, an enormous number of simulation runs would be required in order to achieve the 'true' optimum of each alternative system tested. As such extensive optimization experiments were regarded as being outside the scope of this present study, a decision was made to adopt the equal bandwidth method to evaluate signal offsets during the comparative analyses described in chapter 12.

b. progressive system for one-directional flow. When the model is applied to simulate traffic movement along one-way roads, the traffic signal offsets can be determined by the speed of progression along each link and the distances between the signals. The computation procedure consists of calculating the link speed, v_i, of the type of vehicle being favoured (item a above). The offset between successive traffic signals, $\theta_{i,i+1}$, is expressed by,

$$\theta_{i,i+1} = \frac{x_{i+1} - x_i}{v_i}$$

where x_i is the position of signal i.

c. other systems. The program allows traffic signal offsets to be input as data. The purpose of this facility is to enable the investigation of alternative systems such as those previously described. A random determination of offsets is the last of the permitted configurations offered by the current version of the program.

8.6 Vehicle characteristics

Vehicular traffic streams are usually composed of two broad classes of vehicles, those carrying people and those carrying goods. Passenger vehicles are bicycles, motorcycles, cars, taxis and buses. Commercial vehicles may include the full range of vehicles designed to carry goods of any sort.

For the purpose of this study, the vehicles were divided into four representative vehicle groups, taken as:

a. Type 1 - passenger car and vans
b. Type 2 - taxi
c. Type 3 - bus
d. Type 4 - lorry

8.6.1 Type, length and width

A survey undertaken by the local traffic authorities determined the proportion of the different vehicles within each group (table 8.7). Once the vehicle type has been determined according to its entry lane composition, its length and width are generated using an empirical discrete probability distribution. Chapter 7 describes the technique used to generate empirical discrete random variates.

8.6.2 Desired speed

The desired speed is the speed a driver would prefer to travel in the absence of traffic. Each driver/vehicle combination in the model is assigned a desired (free) speed randomly sampled from a distribution according to vehicle type. In order to obtain an estimate of both distributions and parameters, it was assumed that desired speeds could be approximated by the speeds at which free flowing vehicles and leaders of platoons travel.

The manual timing of vehicles over a specified distance was thought to be the most appropriate method of collecting speed data as radar speed-meters would be difficult to conceal from the view of drivers. Electronic stopwatches were used during the data collection procedure.

It was necessary to determine a section of where vehicles travel, on average, at their maximum free speeds. During a preliminary survey, three sections were marked on the road pavement. A baseline length of 20 metres {133} was adopted for each section. The section selected for the final survey was determined based on the comparison of the results obtained at each of the preliminary sites.

It is often assumed that desired speeds are normally distributed {126}. Observations carried out by Leong {134} have indicated that although speeds at a given site may vary considerably, the distribution of speeds for different vehicle types could be represented by a normal distribution. Results provided by chi-square (χ^2) and Kolmogorov-Smirnov (K-S) tests confirmed the assumption that the observed speed distributions may be represented by normal distributions. The values of the parameters used in the simulation model are found in table 8.8 and figures 8.10 and 8.11. Maximum and minimum input values have been limited by the mean plus two standard deviations and by the mean minus two standard deviations respectively.

8.6.3 Desired acceleration

The acceleration behaviour of a queue leader discharging from a traffic signal is an important factor in any urban microscopic simulation. A comparison of existing acceleration models {135} showed that:

a. the uniform acceleration model, which is frequently used, does not accurately match observed behaviour on a microscopic scale.

b. the linear acceleration model indicated excellent agreement with observed data (figure 8.12).

While the uniform acceleration model assumes a constant acceleration rate until the desired speed is reached, the linear acceleration model hypothesizes use of maximum acceleration when vehicular speed is zero, zero acceleration at desired speed, and a linear variation of acceleration over time (figure 9.1).

A microscopic investigation of vehicular acceleration was demanded in order to obtain average acceleration slopes for local drivers of both heavy and light vehicles. The intersection selected for data collection had the median lane reserved for the exclusive use of buses. The sample included only the leading vehicles (51 lights and 40 heavies) of each approach queue accelerating at the onset of green. The distances travelled by these vehicles during each one second increment of time were obtained by analysis of time-lapse films as described in appendix 1. Average accelerations, a, were extracted from the data by a process of numerical differentiation {136},

$$a_{n-0.5} = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

where V is the increment of distance during unit time in m/s, t is the time in s and n is a positive integer. Plots of average acceleration-time values are shown in figure 8.14. A linear regression line was fitted for each main class of vehicles being studied. The resulting equations were:

i. for heavy vehicles

$$a = 1.11 - 0.08t \ (m/s^2)$$

ii. for light vehicles

$$a = 1.91 - 0.17t \ (m/s^2)$$

By assuming the average acceleration-time linear slope, s, as constant for each type of vehicle, the initial acceleration value, a_i, was determined as function of the desired speed of the driver by the equation (figure 9.1),

$$a_i = \left(a_f^2 - 2s(v_f - v_i)\right)^{\frac{1}{2}}$$

where both the final acceleration, a_f, and the initial speed, v_i, are equal to zero and v_f represents the desired speed of the driver.

The validity of these assumptions is demonstrated by the good agreement obtained between the observed and the predicted headways at the stop-line as shown in chapter 11.

8.6.4 Desired deceleration

It was concluded in previous study {135} that the uniform deceleration model does not reproduce the observed behaviour of actual drivers when considered on a microscopic scale. A comparison between data points and both uniform and the linear deceleration models as plotted in figure 8.13, demonstrated that the uniform deceleration model yields a higher speed during the initial stages of the deceleration manoeuvre and, as the speed approaches zero, the values become less than those observed. The linear deceleration model assumes a linear variation of deceleration over time while deceleration varies from zero at desired speed to the maximum value at the moment the vehicle stops.

The deceleration performance of free vehicles stopped by the traffic lights has been also measured at an urban intersection site. The method of approach adopted for collecting time-deceleration data for vehicles stopping first in queue at the intersection is basically the same as that used for obtaining the acceleration performance. A filming speed of 2 frames per second was adopted since these same films were also used for analysing amber reactions. Every vehicle in the sample (37 heavies and 38 lights) had its travelled distance recorded at one second intervals. Average decelerations were evaluated from changes in the average increment of distance. Plots of average time-deceleration values, d, are presented in figure 8.14. Regression lines were fitted to each group of data. The resulting equations, by vehicle type, were:

i. for heavy vehicles

$$d = -0.87 + 0.09t \ (m/s^2)$$

ii. for light vehicles

$$d = -1.31 + 0.15t \ (m/s^2)$$

The desired deceleration value assigned to each vehicle inserted in the simulation model is also calculated by assuming the average deceleration-time slope, s, as constant for each type of vehicle. The procedure adopted for the calculation is similar to the one described in the previous section. The final deceleration value, d_f, is isolated from,

$$d_f = -\left(d_i^2 + 2s(v_i - v_f)\right)^{\frac{1}{2}}$$

where both final speed, v_f, and initial deceleration, d_i, are equal to zero and v_i represents the desired speed of the vehicle.

8.6.5 Maximum deceleration

Studies have shown that deceleration rates of $2.5m/s^2$ were subjectively accessed as comfortable whereas a deceleration of $4.2m/s^2$ would be regarded as an emergency stop {137}. Hammond {138} and Wilson {139} suggested that deceleration rates up to $4.8m/s^2$ could be used without severe discomfort to the drivers. Dramatic changes in deceleration, in a short period of time, are restricted within the simulation model to $4.2m/s^2$.

8.6.6 Stopping error

When a vehicle is required to stop at an intersection or when it approaches the end of a queue, it decelerates up to a certain stopped position. As vehicles do not all stop at the same position, a stopping error is introduced. The stopping error is defined either as the distance back from the stop line by queue leaders or as the safe distance between the rear and front bumpers of successive vehicles.

Stopping error data was collected at a signalized intersection of RU60 (appendix 1). A normal distribution was developed from the analysis of these field measurements (figure 8.15). For simulation purposes, the parameters of the distribution are shown in table 8.9 where maximum and minimum values are limited from the mean by 1.5 times the standard deviation.

8.6.7 Gap acceptance

Gap acceptance is an important characteristic of the reaction of drivers wishing to merge into the major traffic stream at the stop signal controlled intersections. The decision made by the driver to either proceed or wait at the priority junction will depend on the size of the gap between successive vehicles in the major stream. The gap acceptance approach used within this model is based on the hypothesis that the driver is able to make a precise estimate of the arrival time of the approaching vehicle. Consistent driver behaviour is also assumed, i.e., each driver has a fixed gap and he will always accept gaps larger than this and always reject smaller gaps. Different drivers, however, may have different critical gaps.

The variation of gap acceptance is usually described by trapezoidal, normal, exponential or lognormal distributions. Observations carried out by Bissel {140}, Ebbesen and Haney {141} and Uber {142} indicated gap acceptance to be lognormally distributed. Salter {143} found out that the best fit to his data, collected at a number of priority intersections, was obtained by a cumulative lognormal distribution. The majority of observations noted by him where lags, where a lag is defined as the time interval that is available to a minor road vehicle approaching a priority junction before the arrival of the next major road vehicle. A lognormal distribution was chosen to be used in the selection of a fixed gap for each minor inbound lane vehicle. The parameters of the distribution are given by an average of 4.27 seconds, with a standard deviation of 1.4 seconds, according to Salter {143}, where maximum and minimum values were also limited by two standard deviations from the mean.

8.6.8 Desired turning speed

The speeds of vehicles negotiating turns at urban intersections are influenced by the radii of the intersections. A simple speed-radius relationship used in previous studies {144, 145 and 146} assumes the form,

$$s = k\sqrt{R}$$

where s is the average turning speed, k is a constant and R is the radius.

For the purpose of this study it has been assumed that vehicles decelerate up to the start of a turn and then maintain a constant speed through the turn until discharged from the system. Details of how to determine the turning speed for a particular vehicle and intersection are presented in section 9.4.3.

Field measurements were conducted at urban signalized intersections. Speeds were obtained by using stopwatches and by painting reference marks on the pavement. As the speed of each vehicle variates while it moves along the curve {147}, the baselines allowed the collection of average turning speeds. Only free-moving turning cars approaching each intersection during the green signal indication were included in the sample. The observations were also limited to vehicles negotiating the curves according to average turning paths. Table 8.10 indicates that the average speeds obtained at each site compared favourably with the speed-radius relationship where the constant k is equal to 1.61, following the value recommended for urban intersections by the Ministry of Transport {144}.

8.7 Pre-simulation modules

The pre-simulation processor is formed by three modules: COMPOS, VEHCHA, TEMOFF. The simplified flowcharts of these subroutines are shown in figure 8.16. As an alternative to reading a data file, most of the parameters required by the processors are inserted through a block data routine. Subroutine COMPOS determines the flow of each lane for the period of time being simulated. It also performs the function of selecting an exit lane, a bus stop group and a type for each vehicle that will be inserted during the run of the simulation processor. Other vehicle characteristics, such as vehicle length and width, desired speed, stopping error, desired free flow acceleration and deceleration rates, are assigned through VEHCHA.

Module TEMOFF uses headway distributions to calculate a proposed time of generation for each particular driver, in a per lane bases. TEMOFF is also employed for evaluating traffic signal offsets and for assigning gaps to vehicles arriving through minor 'T type' inbound lanes.

Table 8.1 Average traffic stream composition (k_i)

type of veh	car	taxi	bus	lorry	total
%	55	22	21	2	100

Table 8.2 Lane distribution of main lane vehicles (c_{ij})

'PRIORITY'

type of veh \ lane (i ↓, j →)	1	2	3	total
car	0.49	0.51	-	1.00
taxi	0.60	0.40	-	1.00
bus	-	-	1.00	1.00
lorry	0.50	0.50	-	1.00

'DO NOTHING'

type of veh \ lane (i ↓, j →)	1	2	3	total
car	0.15	0.45	0.40	1.00
taxi	0.10	0.60	0.30	1.00
bus	0.93	0.07	-	1.00
lorry	-	0.70	0.30	1.00

Table 8.3 Composition of minor entry lanes (l_{ij})

BOTH 'PRIORITY' & 'DO NOTHING'

type of veh (i) \ lane (j)	4	5	6	7
car	0.83	0.83	0.83	0.83
taxi	0.12	0.12	0.12	0.12
bus	-	-	-	-
lorry	0.05	0.05	0.05	0.05
total	1.00	1.00	1.00	1.00

Table 8.4 Distribution of the origin of turning vehicles (w_j)

situation \ lane	1	2	3	total
'priority'	1.00	-	-	1.00
'do nothing'	0.70	0.30	-	1.00

Table 8.5 Distribution of the destination of turning vehicles (g_{nj})

'do nothing'

exit lane (n) \ entry lane (j)	1	2
8	0.35	-
9	0.35	-
10	0.15	0.35
11	0.10	0.35
12	0.05	0.30
total	1.00	1.00

'priority'

exit lane \ entry lane	1	2
8	0.245	-
9	0.245	-
10	0.21	-
11	0.175	-
12	0.125	-
total	1.00	-

Table 8.6 Headways between consecutive 'green phase queue leaders'

cycle time(s)	sample size	average (s)	standard deviation	minimum (s)	maximum (s)	degrees of freedom	χ^2	K-S
60	68	59.7	3.1	53.5	65.9	4	1.9	0.51

Table 8.7 Size and percentual characteristics of simulated vehicles

Type 1

type of vehicle	length (m)	width(m)	percentage	cumulative percentage
car (small)	4.03	1.54	40.36	
	3.64	1.55	5.28	45.64
car (medium)	4.13	1.57	6.18	
	4.47	1.62	5.75	
	4.19	1.60	4.62	
	4.13	1.54	1.65	63.84
car (large)	4.70	1.76	4.52	
	4.52	1.66	3.17	
	4.56	1.79	1.52	
	4.96	1.81	0.76	
	4.69	1.69	0.36	
	5.41	2.00	0.33	74.55
van	4.40	1.77	10.67	
	4.01	1.60	8.32	
	5.16	1.98	2.25	
	4.47	1.62	1.75	
	4.32	1,58	1.39	
	4.63	1.76	1.12	100.00
Type 2				
taxi	4.03	1,54	100.0	100.0
Type 3				
bus	9.40	2.73	80.0	
	10.70	2.73	20.0	100.0
Type 4				
lorry	10.70	2.73	100.0	100.0

Table 8.8 Desired speeds

type of vehicle	sample size	average (m/s)	standard deviation	minimum (m/s)	maximum (m/s)	degrees of freedom	χ^2	K-S
light vehicles	301	15.6	2.6	10.4	20.8	11	22.2	1.04
heavy vehicles	118	10.5	1.4	7.7	13.3	6	3.6	0.55

Table 8.9 Stopping error

sample size	average (m)	standard deviation	minimum (m/s)	maximum (m/s)	degrees of freedom	χ^2	K-S
104	1.52	0.63	0.57	2.46	6	10.4	1.04

Table 8.10 Desired turning speed

site	average (m/s)	radius (m)	no. of observations	Kolmogorov/ Smirnov	$s = 1.61\sqrt{R}$ (m/s)
1	5.7	11.5	151	0.96	5.5
2	6.2	15.5	155	0.62	6.3

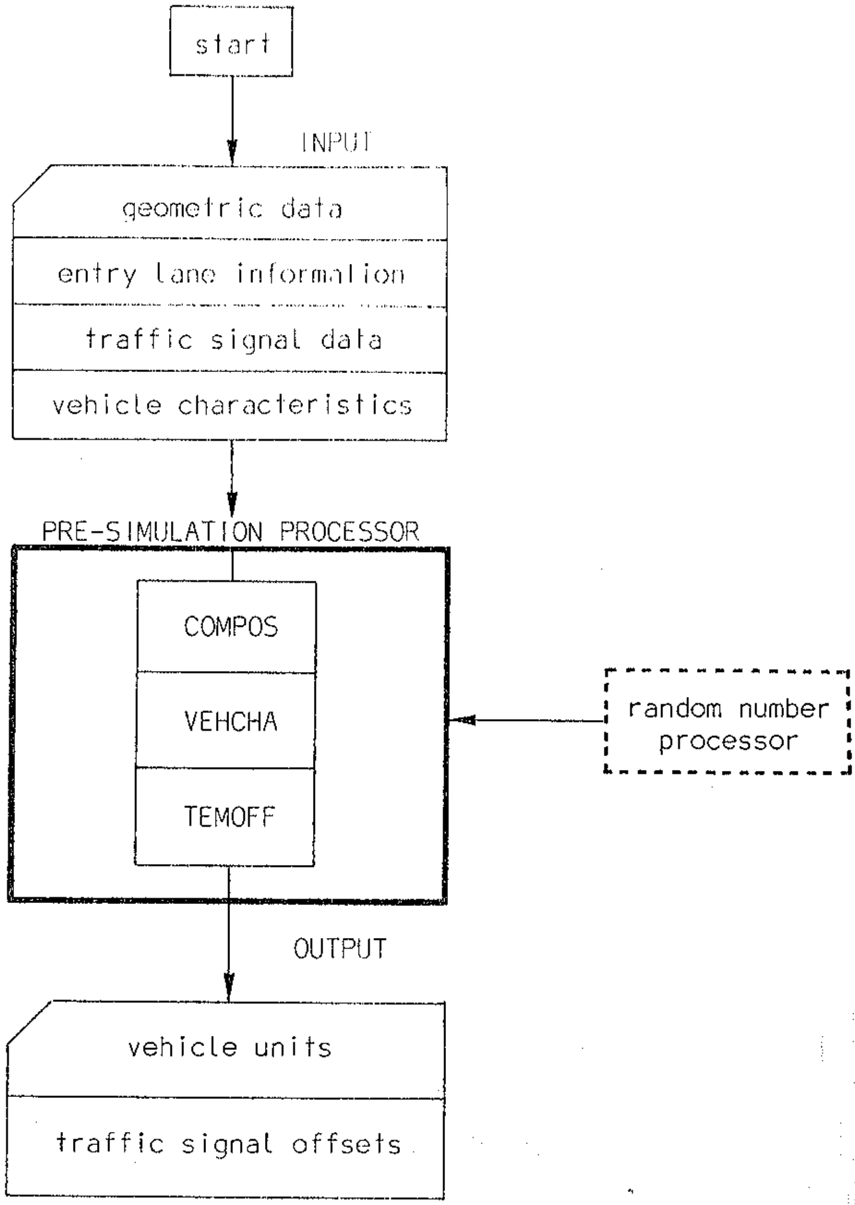


Figure 8.1 Flow chart of the pre-simulation processor

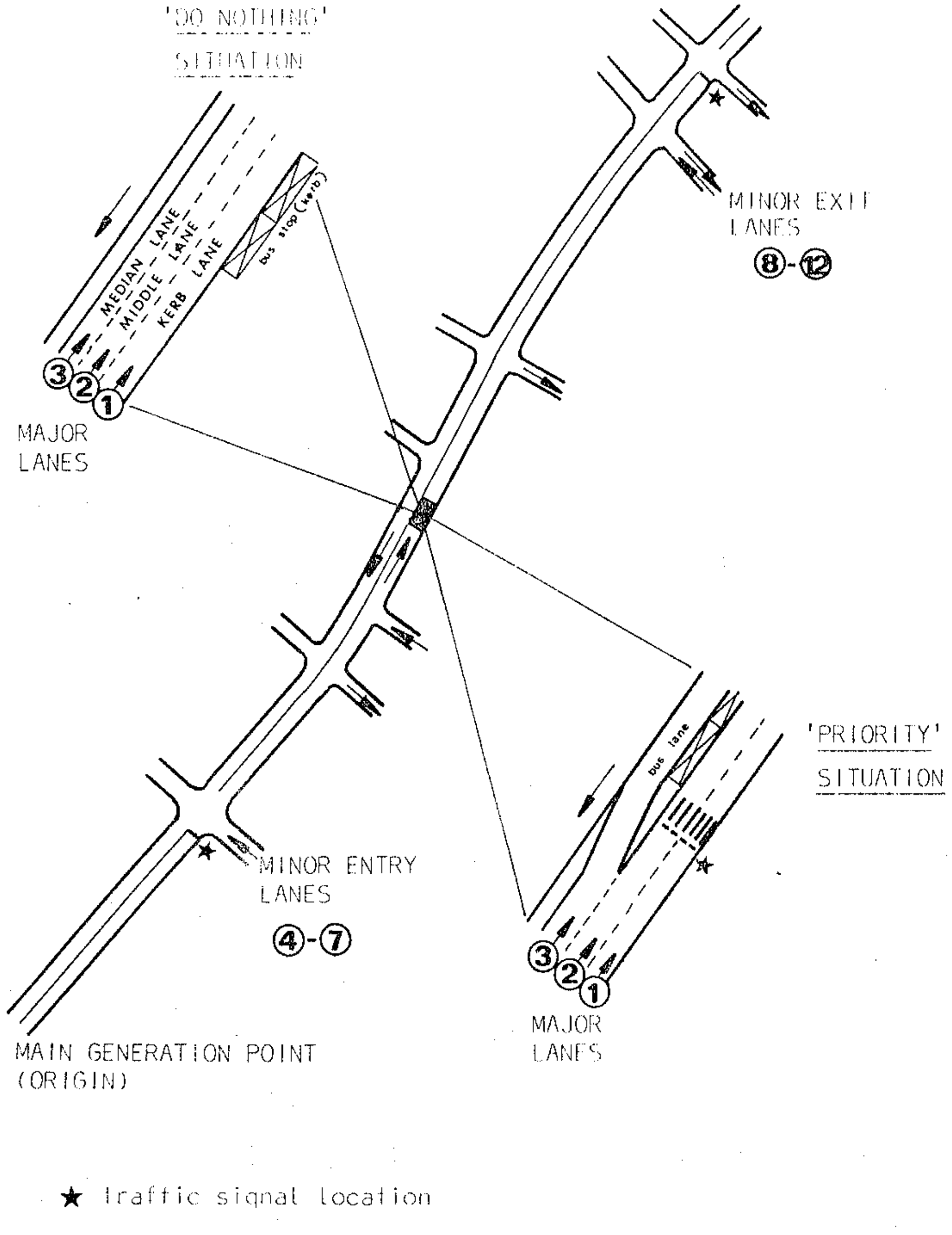


Figure 8.2 Layout of a road system, an example

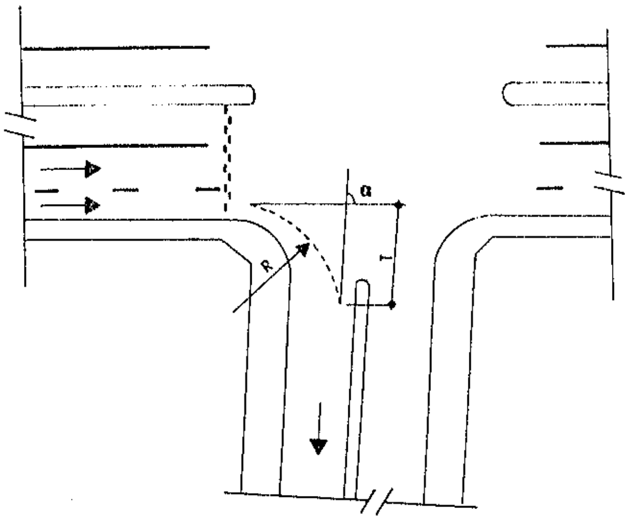
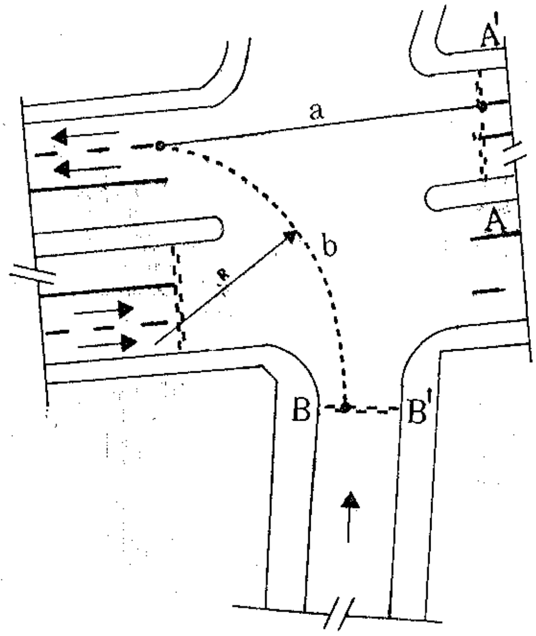
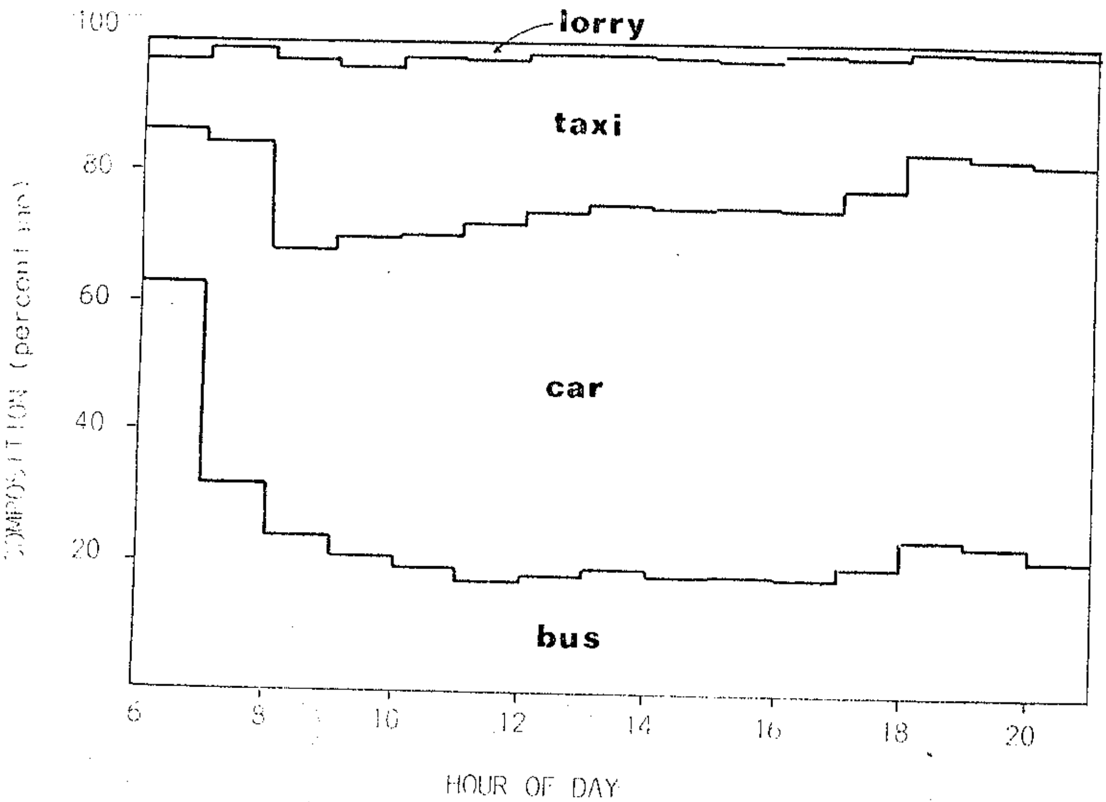


Figure 8.3   Turning path



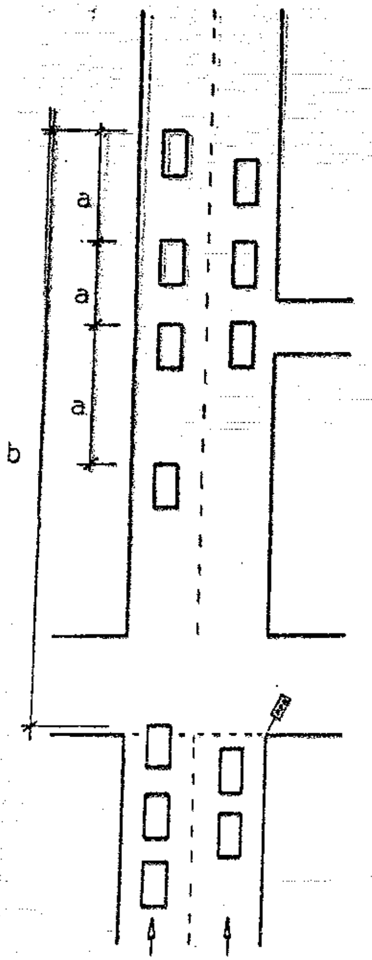
$$\begin{cases} x = b-a \\ x \geq 0 \end{cases}$$

Figure 8.4   Path of entering vehicles



5 major lanes ('do nothing ' situation)
location: RH6 (see appendix I)
vehicles with 4 or more wheels leaving the CBD

Figure 8.5 Variation in traffic stream composition



a = gap between impeded/
unimpeded vehicles

b = gap between successive
'green phase queue leaders'

Figure 8.6 Gaps in the traffic stream

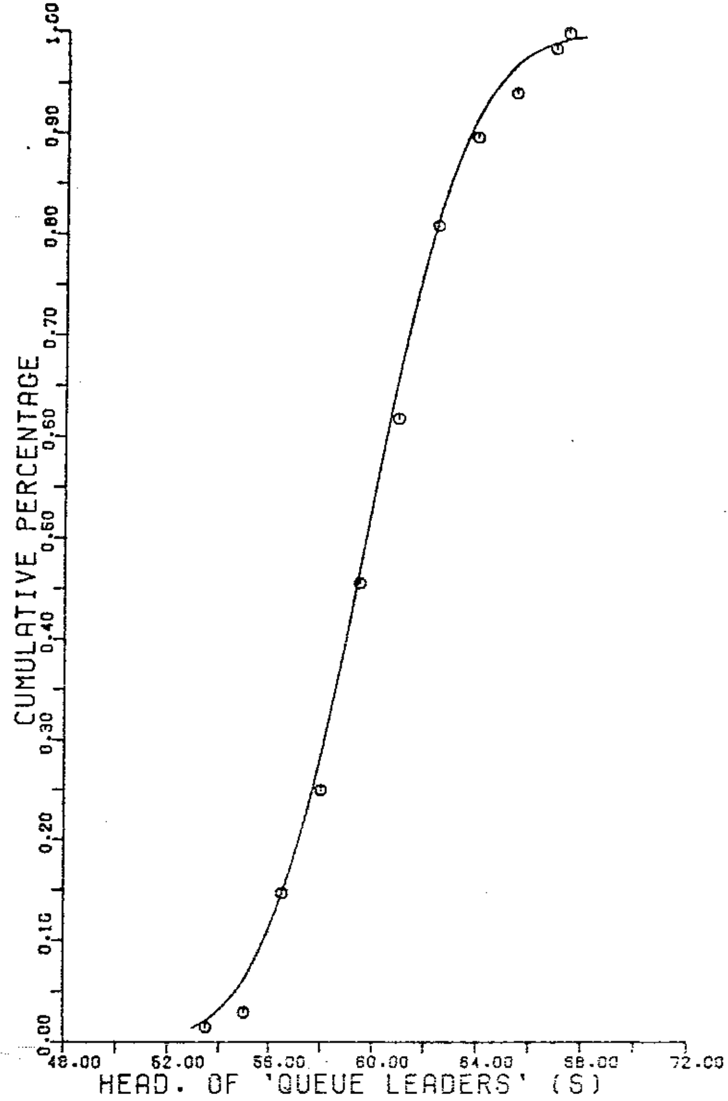


Figure 8.7 Headways between consecutive
'green phase queue leaders'

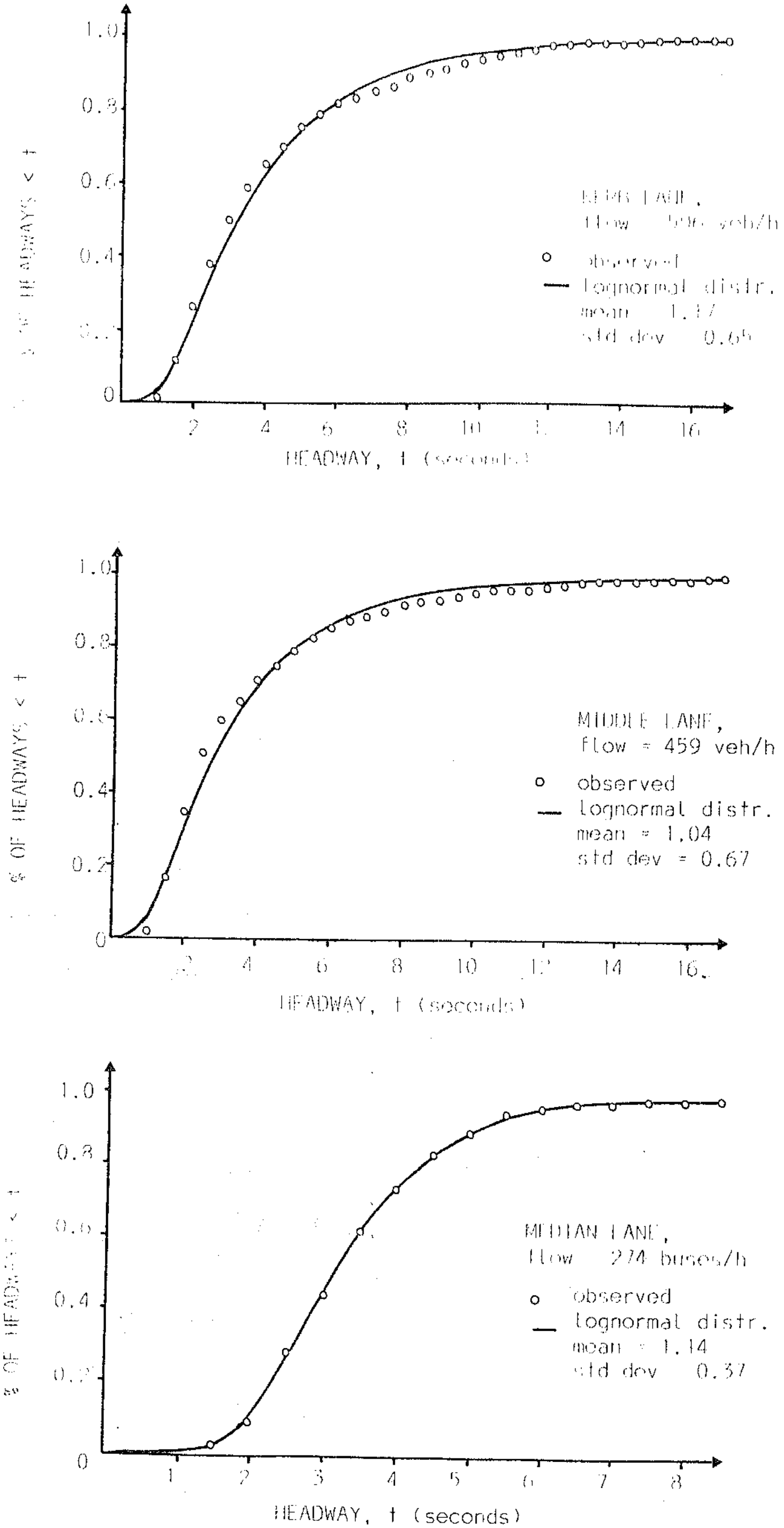


Figure 8.8 Cumulative distributions of headways

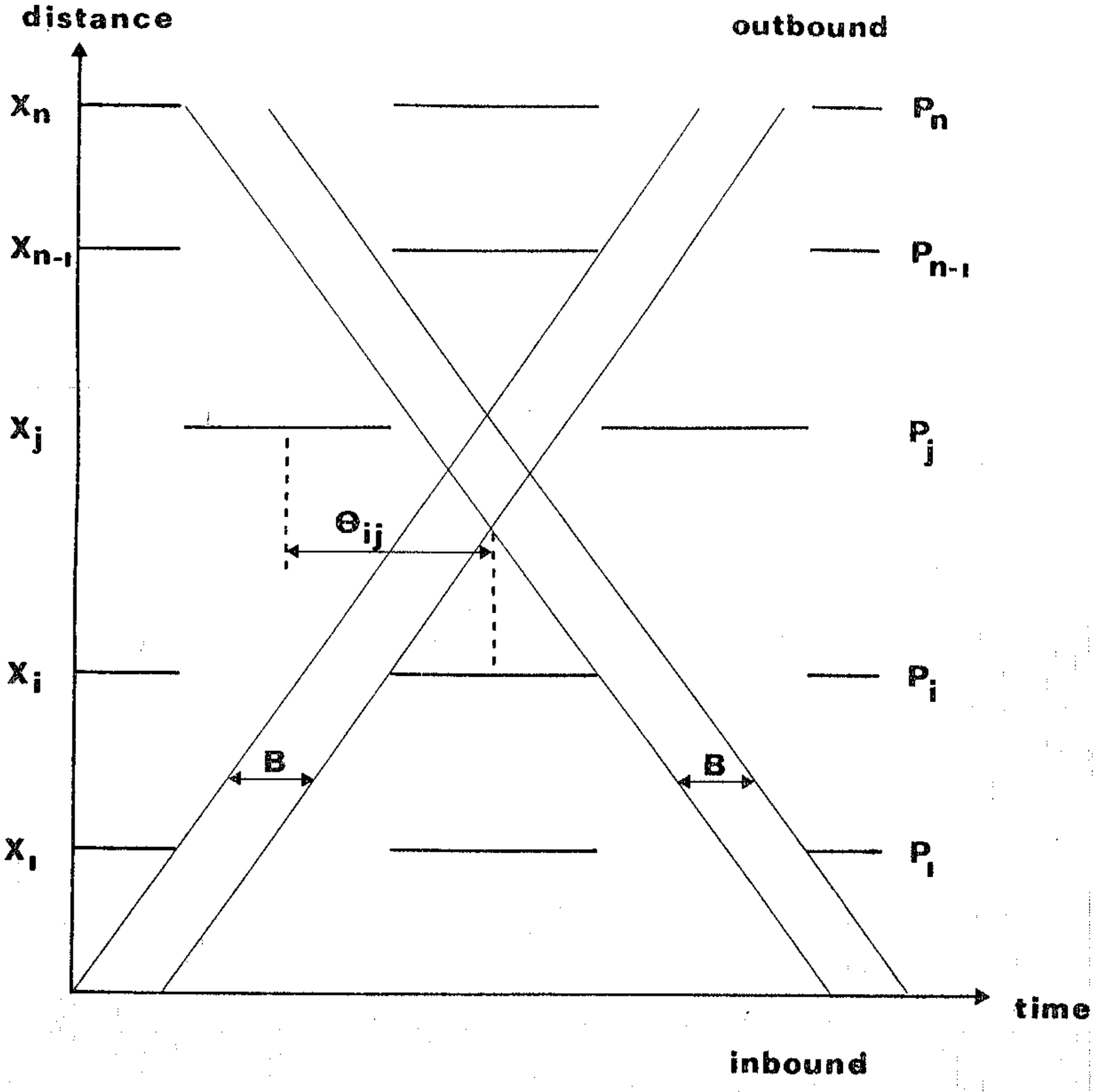


Figure 8.9 Space time diagram showing green bands

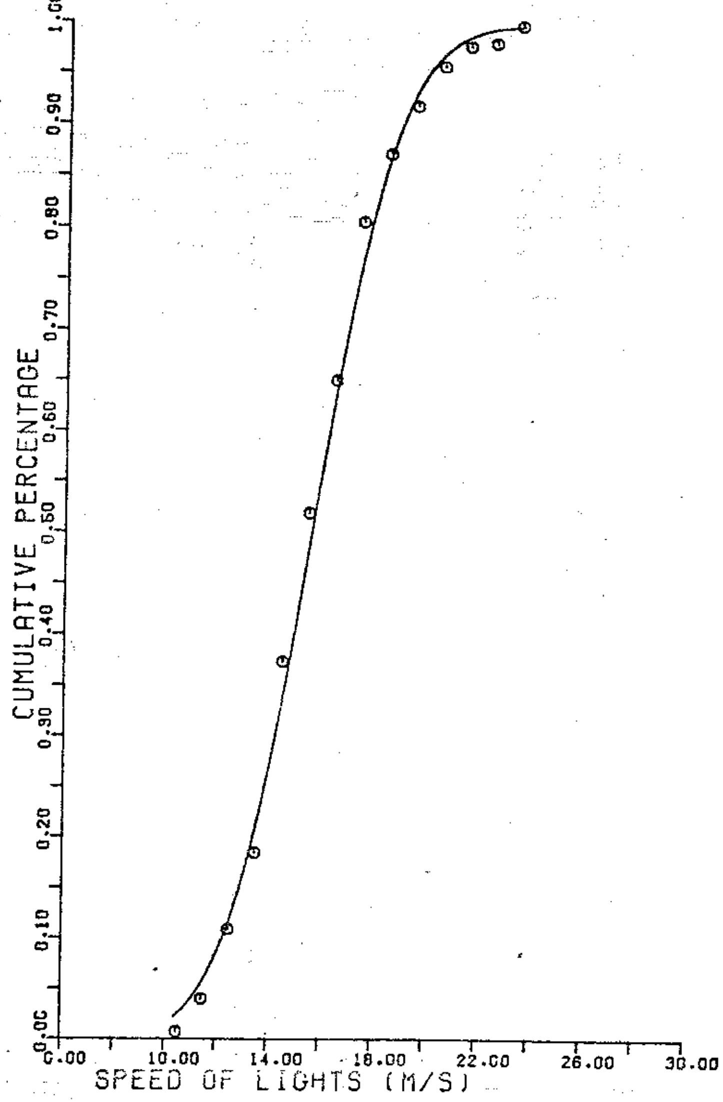


Figure 8.10 Desired speed of light vehicles

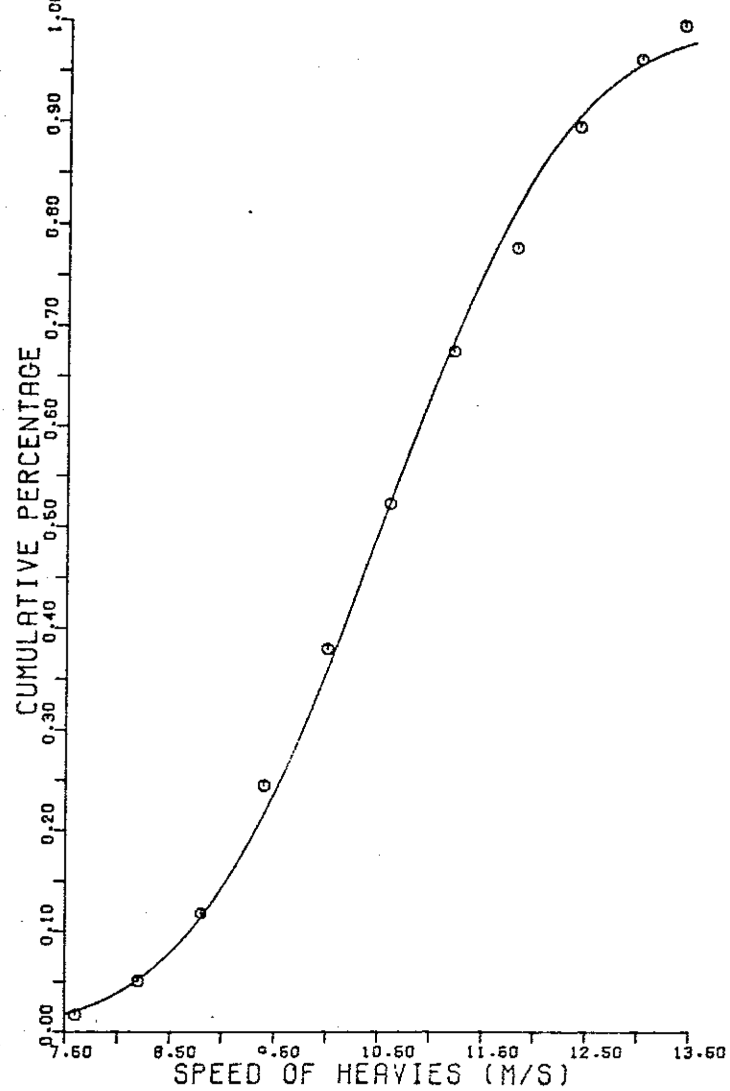


Figure 8.11 Desired speed of heavy vehicles

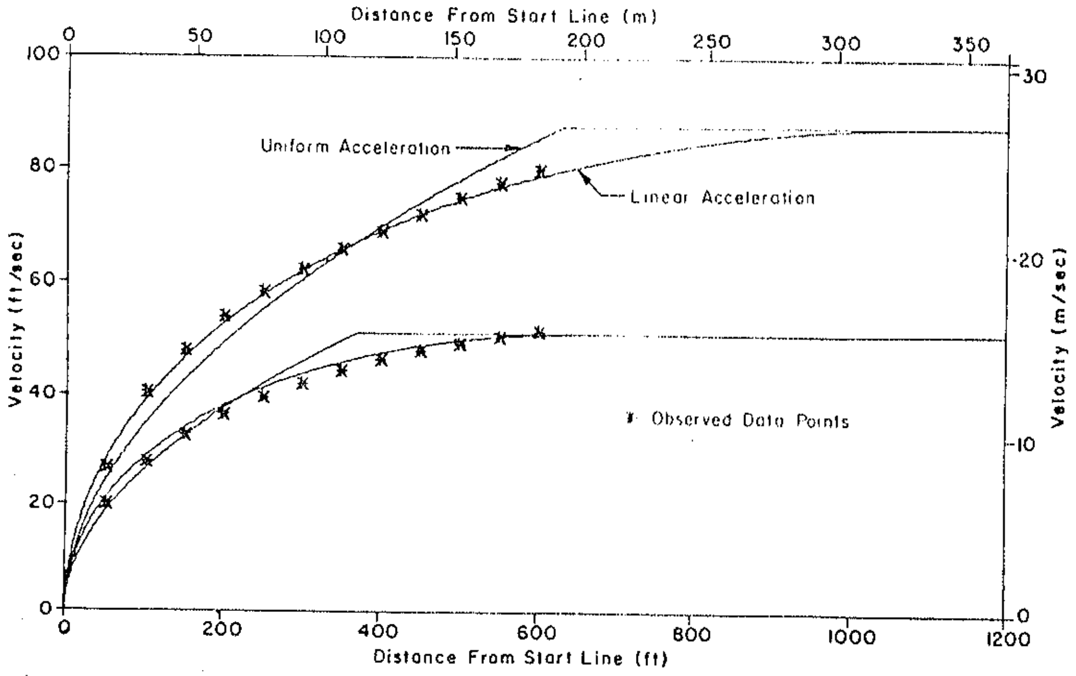


Figure 8.12 Uniform and linear acceleration model for observed data (source: ref. 135)

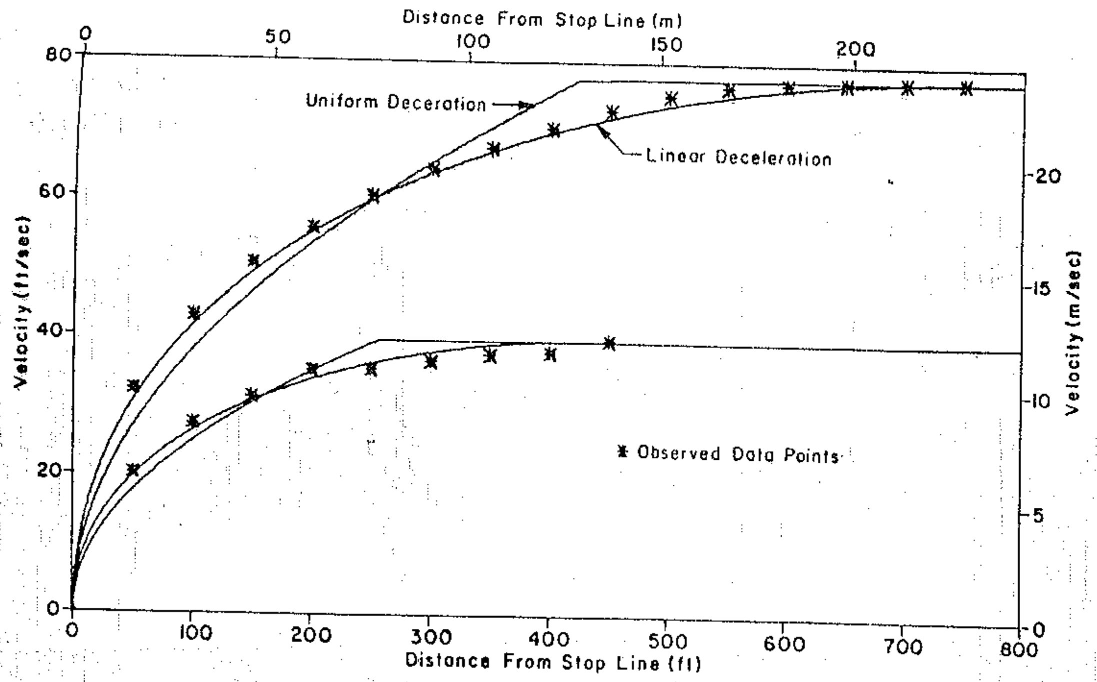


Figure 8.13 Uniform and linear deceleration model for observed data

(source: ref. 135)

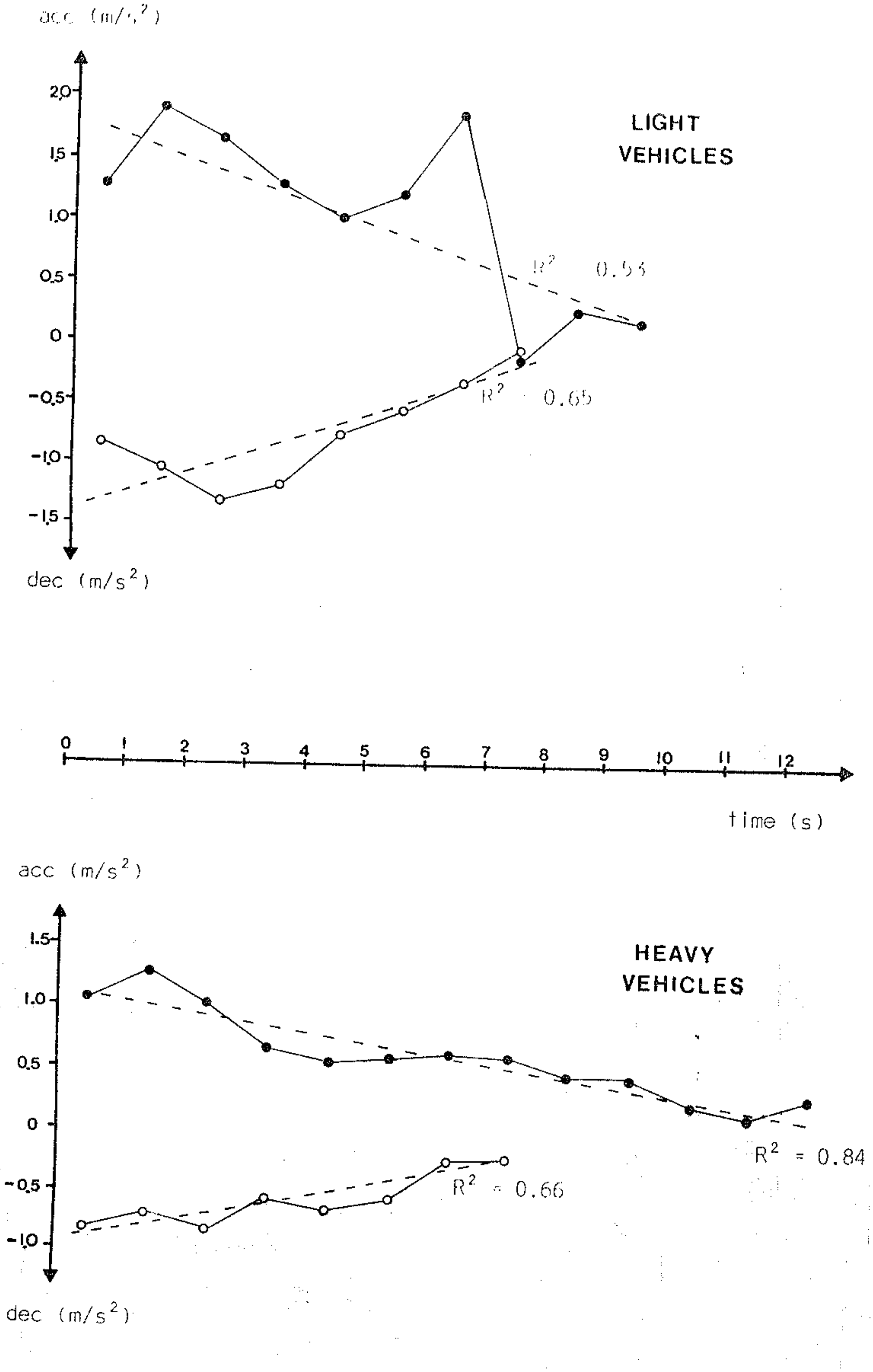


Figure 8.14 Desired acceleration and deceleration

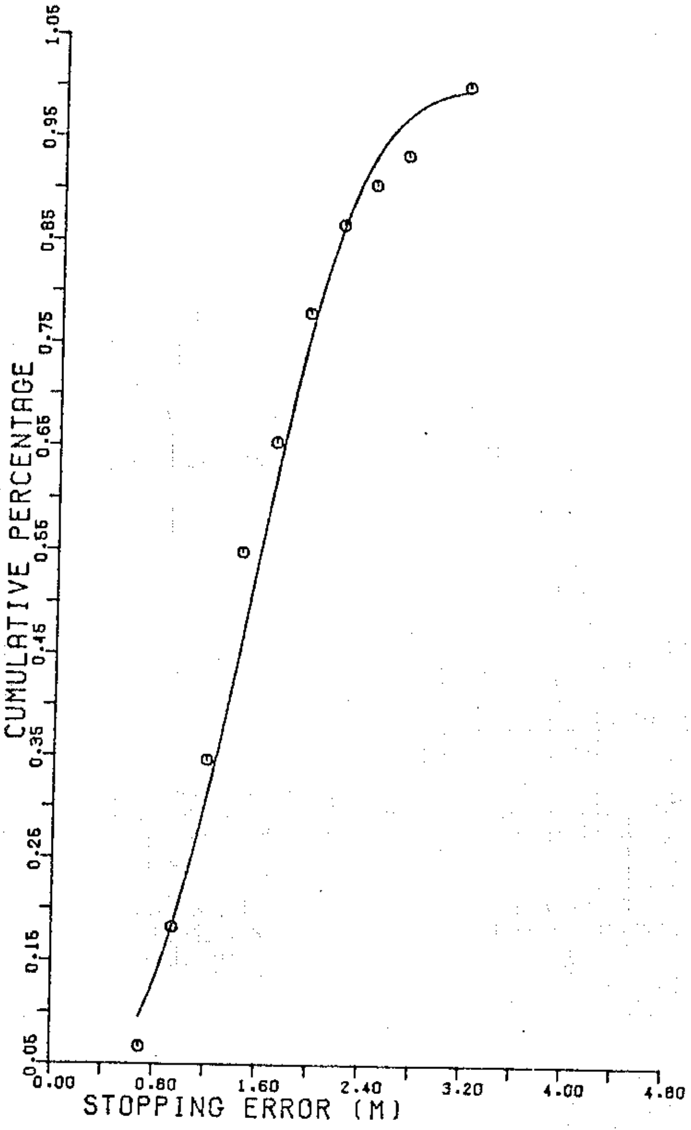


Figure 8.15 Stopping error

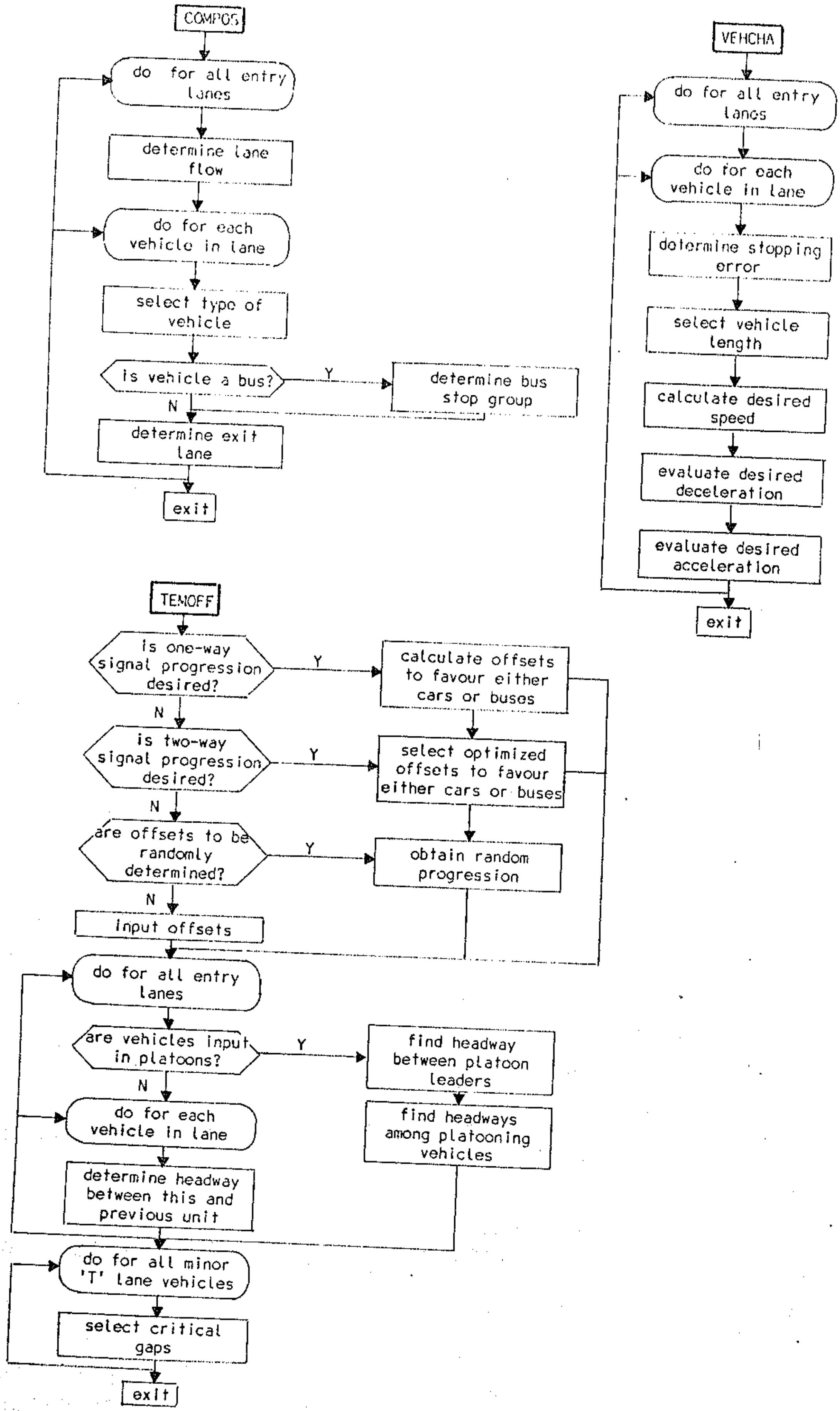


Figure 8.16 Pre-simulation modules

9. TRAFFIC SIMULATION PROCESSOR

9.1 Introduction

Drivers are constantly required to make decisions regarding changes of action. Besides the unavoidable interrelation between vehicles in the road there is also the interaction between pedestrian movements and vehicle flow. Actions and reactions related to pedestrian activities are usually inconsistent and therefore difficult to predict. While in some situations drivers adapt to the presence of pedestrians, in others pedestrians must adapt to the drivers. Due to the local conditions and to the existence of signal controlled pedestrian crossings, unpredictable mid-block pedestrian crossings are not taken into consideration by this study.

The computer can make only one single logical choice at a time. Therefore, it must process all decisions sequentially, i.e., it must process each decision for every vehicle in every lane for every elapsed interval of time. This dynamic activity of the traffic simulation model is performed by the traffic simulation processor.

9.2 Time increment

At each time increment all vehicles within the system have their position, speed and acceleration parameters evaluated. In selecting the time increment, some considerations must be taken into account:

a. a too large time increment may lead to the impossibility of simulating all events that are occurring.

b. a small time increment causes additional computations to be undertaken to represent a given event.

A time increment of 1 second was adopted in the model since:

a. reaction time was stipulated as 1 second in accordance with the range (0.75 to 1.0s) recommended for design purposes in urban traffic {148}, and with an estimated brake reaction time of 0.9s {149}

b. traffic signal settings are multiples of 1 second.

c. a 'start wave' speed in the region of 1 vehicle per second is compatible with previously observed starting delays within platoons {150}.

9.3 Driver response

The basic premise of the model is that all drivers have a desired speed at which they would like to travel, although this may be constrained by the interaction with other vehicles and environmental factors. The speed of the driver may be affected by:

a. the characteristics of the vehicle
   acceleration performance
   stopping performance
   turning performance

b. road geometry
   obstruction to lane changes
   bus stop requirements

c. traffic signals
   reaction to amber/red indications

d. the presence of other vehicles.

9.4 Free-flow reaction

A driver moving along a single-lane traffic stream is normally found to be either influenced by a leading vehicle (car following reaction) or travelling freely, i.e., adopting an acceleration/ deceleration rate as function only of his own characteristics (desired acceleration, deceleration and speed). This second possibility leads to free-flow reactions.

The following equations of motion were derived for free-flowing vehicles based on the linear acceleration and deceleration models (see chapter 8):

$$a_f = a_i + st \qquad (9.1)$$

$$v_f = v_i + a_i t + \frac{st^2}{2} \qquad (9.2)$$

$$x_f = x_i + v_i t + \frac{a_i t^2}{2} + \frac{s t^3}{6} \qquad (9.3)$$

where a is the acceleration/deceleration, v is the speed, x is the distance, t is the time, s is the acceleration/deceleration slope and the indexes i and f represent initial and final values respectively. These relationships are illustrated in figure 9.1.

9.4.1 Acceleration

A free flow driver will try to reach his desired speed by accelerating at his desired acceleration rate. Assuming that at desired speed, v_d, the acceleration is zero, equations 9.1 and 9.2 will enable the free-flow acceleration slope to be determined,

$$s = -0.5\, a_i^2 / (v_d - v_i) \qquad (9.4)$$

The initial acceleration rate of a vehicle is reset to,

$$a_i = \left(-2\, s\, (v_d - v_i)\right)^{1/2} \qquad (9.5)$$

whenever conditions allow it to start pursuiting its desired speed.

9.4.2 Deceleration to stop

Desired deceleration slopes are also obtained from the equations of motion 9.1 and 9.2,

$$s = 0.5(d_i^{\,2} - d_d^{\,2})/v_i \qquad (9.6)$$

where d_d is the desired deceleration rate attained at the moment the vehicle stops.

A vehicle reacts to a free-flow stop whenever distance from the required stop position is shorter than x_s, the value obtained by substituing equation 9.6 in equations 9.1 and 9.3 and solving for x_f minus x_i,

$$x_s = -0.667\, v_i^{\,2}(d_i + 2d_d)/(d_i + d_d)^2 \qquad (9.7)$$

This equation can also be written as,

$$x_s = -0.667 v_i^{\,2}\left(2 - d_i/(d_i + d_d)\right)/(d_i + d_d) \qquad (9.8)$$

If the vehicle is accelerating at the time it is required to start a 'decelerating to stop' manoeuvre, a reaction time, equal to one time increment, is included in the calculations during which acceleration is reduced to zero.

The final deceleration rate, d_m, is obtained from equations 9.7 and 9.8 where d_m replaces d_d,

$$d_m = -d_i - \left(4v_i^2 + 2v_i(4v_i^2 + 6x_f d_i)^{\frac{1}{2}}\right)/(6x_f) \qquad (9.9)$$

and the required deceleration slope is now obtained by inputing d_m as d_d in equation 9.6.

This deceleration to stop procedure is limited to drivers not required to decelerate at higher rates dictated by car-following rules. If a deceleration to stop is demanded at a time a driver$_i$ is decelerating at a 'higher than desired' rate for his current speed, his initial deceleration is reset to,

$$d_i = -(d_d^2 + 2sv_i)^{\frac{1}{2}} \qquad (9.10)$$

the equation that expresses the speed deceleration relationship of the linear deceleration model.

9.4.3 Deceleration to turn

A driver will check if a deceleration to turn manoeuvre is required only when all the conditions below are fulfilled:

a. his exit approach is one of the minor lateral roads
b. he is close to his exiting position, p_t, situated at a point approximately midway through the turn.
c. his approaching speed is greater than his desired turning speed, v_t, obtained from

$$v_t = (v_d/\overline{v}_d)\overline{v}_c \qquad (9.11)$$

where $\overline{v}_d$ is defined as the average desired speed of the type of vehicle under consideration and $\overline{v}_c$ is the average desired speed for the curve obtained as function of the radius path (section 8.3). This assumption is based on the fact that a fast moving vehicle is also a fast turning vehicle.

The final deceleration to turn rate, d_t, assumed by the vehicle at p_t, is obtained as a function of its free-flow desired deceleration rate, d_d. Based on equation 9.10,

$$d_t = -(d_d^2 + 2\,z\,v_t)^{\frac{1}{2}} \qquad (9.12)$$

where z is the deceleration slope of the type of vehicle being examined (section 8.6.4).

By evaluating the deceleration slope, y, required to bring the vehicle from v_i to v_t and by calculating the time, t_t, required to achieve d_t, it is possible to determine if a deceleration to turn is required. After the necessary substitutions, y is obtained from equations 9.1 and 9.2. Thus,

$$y = 0.5(d_i^{\,2}-d_t^{\,2})/(v_i-v_t) \qquad (9.13)$$

The time, t_t is isolated from equation 9.1,

$$t_t = (d_t - d_i)/y \qquad (9.14)$$

A critical distance, x_c, is determined based on equation 9.3,

$$x_c = p_t - v_i t_t - \frac{1}{2} d_i t_t^{\,2} - \frac{1}{6} y\, t_t^{\,3} \qquad (9.15)$$

A vehicle will decelerate to turn if its position is greater than x_c. When this condition is satisfied, the real time, t_p, that the vehicle will take to reach p_t is isolated from 9.2 and 9.3,

$$t_p = \left(-b+(b^2-4ac)^{1/2}\right)/(2a) \qquad (9.16)$$

with

$$a = \frac{1}{6} d_i$$

$$b = \frac{2}{3} v_i + \frac{1}{3} v_t$$

$$c = d_i - p_t$$

The slope for the manoeuvre, s_t, is obtained from 9.2,

$$s_t = 2(v_t-v_i-a_i t_p)/t_p^{\,2} \qquad (9.17)$$

If a vehicle is accelerating at the time a 'deceleration to turn' is required, its acceleration is reset to the rate given by equation 9.12, in one time increment.

9.5 Car following reaction

Car following models attempt to describe the reaction of a driver to the motion of the vehicle immediately preceding him in the traffic stream. The following driver is taken to respond by either accelerating or braking in proportion to the magnitude of the stimulus.

The general form of this relationship is,

$$\text{response}\ (t+T) = \lambda(t)\beta(t)$$

where λ represents the sensitivity and β is the stimulus both at time t, and T is the response time lag, a combination of the time taken by the driver to observe, process the information, decide and act.

Early car-following models were based on a simple linear relation with driver response dependent only on relative velocity {151},

$$a_{n+1}(t+T) = \lambda\left(v_n(t) - v_{n+1}(t)\right)$$

in which $a_{n+1}(t+T)$ represents the response (acceleration) of vehicle n+1 after T, $v_n(t)$ is the speed of vehicle n (the lead vehicle) at time t, v_{n+1} is the speed of vehicle n+1 (the following vehicle) and where λ is the sensitivity taken as constant in the linear car following model. The corresponding macroscopic model is expressed by {152},

$$q = q_m(1-k/k_j)$$

where q is the flow, q_m indicates the maximum flow, k represents the mean traffic density and k_j is the jam density or density at which all vehicles are stopped. As the model assumes maximum flow when density is zero, a situation which is not observed in real world operations, its adoption is considered to be inadequate {153}.

In order to make the vehicle following models more accurate, a number of nonlinear models have been formulated in which sensitivity is taken to be a function of mutual separation and speed of the vehicles being studied. The generalized form of the non-linear car following equation was proposed by Gazis et al {154},

$$a_{n+1}(t+T) = \frac{c\ v^m_{n+1}(t)}{\left(x_n(t) - x_{n+1}(t)\right)^l}\left(v_n(t) - v_{n+1}(t)\right)$$

in which $x_{n+1}(t)$ is the coordinate of the following vehicle n+1 at time t, $x_n(t)$ is the coordinate of the leading vehicle at time t and c, m and l are constants.

A wide range of flow equations can be derived for the entire m, l plane based on several expressions of macroscopic speed-density relationships {155}. The fundamental difference between models is the weight given to relative speeds and distances.

Greenberg's model {156}, based on a macroscopic fluid flow analogy approach, expresses speed and density by the following relationship,

$$q = k\,c\,\ln\left(\frac{k_j}{k}\right)$$

with $c = v_m$, the speed at which flow rate is at the maximum {164}. Since speed, flow and density are related,

$$q = Vk$$

the maximum flow occurs when,

$$q_m = \frac{c\,k_j}{e}$$

Van As {157} assumed 30km/h as the speed at which flow rate is at the maximum. Inserting this value in the previous equation and replacing k_j by the density of a stopped queue of cars, a maximum flow of the order of the saturation flow for a single 3.65m traffic lane width, i.e. 1900 veh/h {39} is obtained.

The results of an experimental evaluation conducted by Ceder and May {158} in 1976, gave significant support to the earlier work of Greenberg {156}. Greenberg's equation was also given a valid connection with vehicular traffic flow by the work of Gazis et al {159} in studying equations of interaction between two vehicles when one is following the other at a close enough distance to be affected by the velocity changes of the leader. Furthermore Rothery et al. {66}, when applying vehicle following theory to the analysis of single lane flow of buses, showed that the best fit to their data was achieved by the reciprocal spacing model (m = 0 and l =1). An inspection of the generalized vehicle following model revealed that Greenberg's model is also obtained by m = 0 and l = 1 {155}.

Greenberg's model has thus been considered satisfactory for use in this study to describe vehicle following behaviour. The response stimulus relationship can then be written as,

$$a_{n+1}(t+T) = c\frac{v_n(t)-v_{n+1}(t)}{x_n(t)-x_{n+1}(t)}$$

Car following equations usually have to be modified in order to describe processes such as the rapid approach of a vehicle towards the preceeding vehicle, the starting up from standstill of a queue of vehicles, and the forced slowing down to a standstill of a line of vehicles {160}. Then, in order to keep with physical reality, a stabilization constant, α, is introduced to modify the sensitivity factor in the response equation {157},

$$a(t+T) = \alpha\lambda(t)\beta(t)$$

Assuming the stabilization constant to be independent of the reaction time, this relationship may also be expressed as,

$$\frac{dv(t)}{dt} = \alpha\lambda(t)\beta(t)$$

Multiplying both sides of the equation by d_t and differentiating, the stabilization equation is solved for α,

$$\alpha = (v_t - v_i) / \int_{t_i}^{t_t} \lambda(t)\beta(t)d_t$$

where v_i is the speed of the following vehicle (initial speed), v_t is the speed of the leader (target speed), t_i is the time at the start of manoeuvre and t_t represents the time at the end of the manoeuvre.

By inserting the reciprocal spacing equation and by integration {161}, the stabilization constant is determined,

$$\alpha = \frac{v_n(t) - v_{n+1}(t)}{c \ \ln\left[\frac{x_t}{x_n(t) - x_{n+1}(t)}\right]}$$

with

$$x_t = x_j e^{v_n(t)/c}$$

where x_j is the individual jammed spacing between vehicles n and n+1 and x_t is the desired spacing at the prevailing condition also referred in the text as the zone of influence of vehicle n. The modified car following equation is therefore expressed as,

$$a_{n+1}(t+T) = \frac{\left(v_n(t) - v_{n+1}(t)\right)^2}{\ln\left[\frac{x_t}{x_n(t) - x_{n+1}(t)}\right]\left(x_n(t) - x_{n+1}(t)\right)}$$

Fox and Lehman {162} stated that in actual driving experience people do not continuously adher to acceleration and deceleration rates obtained by car-following rules. It was suggested {163} that a driver cannot even detect relative velocity until the rate of change of angular motion of the image across the retina is above a minimum threshold value. Considering the diagram of figure 9.2, the visual angle, θ, between vehicles n and n+1 is expressed by,

$$\theta = 2 \tan^{-1}\left(w/2(x_n - x_{n+1})\right)$$

where w is the width of the car being followed. The rate of change of the visual angle, θ_r, is obtained by differentiating this expression with respect to time {164},

$$\theta_r = \frac{w(v_{n+1}-v_n)}{\left[1+\left(w/2(x_n-x_{n+1})\right)^2\right](x_n-x_{n+1})^2}$$

and as in practical cases,

$$\left(w/2(x_n-x_{n+1})\right)^2 \ll 1$$

the equation is simplified to

$$\theta_r = \frac{w(v_{n+1}-v_n)}{(x_n-x_{n+1})^2}$$

As a result of a carefully controlled experiment in human perception of motion, Michaels and Cozan {165} indicated that it is reasonable to use 6×10^{-4} rad/sec as a mean value for the threshold θ_r. Whenever a driver is found to be reacting to a leading vehicle his dynamic characteristics are computed by the equations of motion for constant acceleration,

$$v_f = v_i + a_c t$$
$$x_f = x_i + v_i t + \frac{a_c t^2}{2}$$

where a_c is determined by either the generalized or the modified car following equation.

9.6 Vehicle reaction

The vehicle reaction logic, used in SIBULA, assumes that a driver may face six possible alternatives while selecting his own acceleration/deceleration rate with regard to the front vehicle. The development of such a 'six-state' configuration, best represented by figure 9.2, was based on a long series of computer runs in which traffic was confined to a single lane and dynamic characteristics of vehicles were printed at each time increment. The adequacy of its application is further demonstrated by the results obtained by comparing observed headways at stop lights with simulated conditions (chapter 11).

The determination of the follower's state is based on the relative speed and distance between the vehicle under consideration and its leading unit, on the speed of the leading vehicle, and on the rate of change of the visual angle. A driver travelling in states A, B or C is allowed to accelerate. In state A, his acceleration rate is limited to the minimum value obtained by applying either the modified car following equation or his free flow acceleration behaviour. If found to be in either state B or C, a vehicle is allowed to accelerate to its desired speed according to its own free-flow acceleration capability. The boundary between regions C and D, i.e. between acceleration and deceleration, is given by the rate of change of the visual angle that enables the driver to detect relative velocity. In states D and E a decision is made between adopting the generalized or the modified car following equation. The modified car following equation may be used in state D where the distance between vehicles is greater than the distance determined by the zone of influence of the leading vehicle. State E is characterized by the application of the generalized car following equation.

The modified car following equation will either reduce or increase the speed of the follower to the speed of the leader while approximating or separating both vehicles. A merging situation, i.e., a follower travelling at the same speed of its leader is said to be achieved whenever,

$$|v_{n+1}-v_n| \leq 0.2\text{m/s}$$

and

$$x_n-x_{n+1} \leq x_t \pm 1\text{m}$$

This situation is represented by state F in figure 9.2.

9.7 Amber reaction

In traffic signals, the amber phase is used to alert drivers to the imminent change of phase. A driver approaching an intersection is faced with the binary decision of stopping or continuing through the intersection upon observing the onset of amber. A review of previous research {166} suggested that the percentage of drivers stopping depends on their approach speed and distance from the intersection when the signal changes. It is assumed, in the model, that a driver will stop at the intersection if the time to arrive at the stop line, at the onset of amber, is smaller than a critical time.

Data was collected to provide the probability of drivers stopping as a function of the 'potential time'. 'Potential time' is that required for a vehicle to reach the stop line after the signal turns amber, assuming that it keeps a constant velocity. This time is not necessarily the actual time, due to acceleration (in case of a decision to go through) and deceleration (in case of stopping). Similar investigations were also conducted by Olson and Rothery {167} and Williams {168}.

An urban intersection along RU60 (appendix 1) provided a good view of the approaching traffic and the stop line. Time-lapse films exposed at a rate of 2 frames per second enabled the determination of the speed of the first approaching vehicle on each lane at the onset of amber.

Assuming that both time perception and critical time are normally distributed, a probit analysis was conducted, in order to evaluate the mean critical time and its standard deviation. The analysis of the small sample of 216 observations where 95 vehicles stopped, yielded a mean value of 3.75 seconds. A figure of the order of 4 seconds, the length of the prevailing amber period, was expected to be obtained since the mean critical time was previously defined {169} as the average driver's expectancy of the length of the amber period. The observed mean critical time was also close to the value obtained in a recent and comprehensive study undertaken in USA {169} under similar conditions. Therefore, the amber reaction parameters, i.e. the mean critical time and its standard deviation, were adopted as 3.47 and 1.28 seconds respectively, according to these American results. Maximum and minimum values were limited to the mean plus and minus one standard deviation.

9.8 Bus stop-time

There are two ways of studying the stopped time of buses. The first, and most widely used, employs field surveys of buses in daily operation. In the second, experimental studies are undertaken in simulated conditions in which variables that affect boarding and alighting events can be separately investigated.

The objective in this study was to obtain a means of simulating the time spent by buses at a bus stop. Only two-door buses, where a flat fare is paid to a seated conductor, have been used. The typical internal layout of a bus is shown in figure 9.3. Both morning and afternoon peaks are characterized by boarding and alighting events. The great majority of the stop time occurring during the afternoon peak was governed by boarding passengers, while the opposite situation was found during morning peak hours. As boarding consumes more time than alighting, only boarding events occurring during the afternoon peak were investigated.

A linear regression technique was applied to the measured stop times, the time spent by buses at a bus stop between wheel stop and wheel start, and the number of passengers boarding. The observations were carried on a typical stop of RU60 (appendix 1). Figure 9.4 shows the results obtained for a total of 206 observations. The resulting equation was,

$$T = 6.02 + 1.55N$$

where T is the stop time in seconds and N is the number of passengers boarding. Similar linear relationships have been applied before by several authors including Cundill and Watts {170}, Oliver and Uren {171}, and Bowes and Mark {71}.

The constant term of the linear regression is usually associated to the dead time, the time spent between the wheel stop and the boarding of the first passenger plus the time spent between the boarding of the last passenger and the wheel start. The marginal boarding time, i.e., the average time taken by an extra passenger to board, is related to the slope of the line. A review of studies conducted by Chapman {172} indicated a variation in reported marginal boarding times for on-bus ticketing between 1.2 seconds for one door London buses {173} and 6.3 seconds for one man operated buses with electric ticket issue {174}. Cundill and Watts {170} found that dead time varied between 1 second for single doorway buses without interlock and 6.5 seconds in the case of a two door bus with more restrictive interlock.

In June 1981, the local traffic authority conducted a survey in which the number of boarding passengers at one of bus stops of RU60 was recorded. This data base was used in order to provide parameters for the determination of the number of passengers boarding a simulated bus. The resulting probability of picking up passengers is shown in figure 9.5.

Two relationships were fitted to the data on figure 9.5. The first was an empirical relationship between the probability, P, and the number of persons boarding, N, described by Cundill and Watts {170}. They obtained a good fit to data collected in Reading. It is expressed by,

$$P = \frac{a}{(b+N)^2}$$

where both a and b are constants. The two constants are obtained by equalling to one the sum of the probabilities, i.e.,

$$\sum_{N=0}^{x} P = a \sum_{N=0}^{x} \frac{1}{(b+N)^2} = 1$$

where x is the maximum number of passengers boarding and by expressing the mean number of persons boarding, M, as,

$$M = \sum_{N=0}^{x} PN = a \sum_{N=0}^{x} \frac{N}{(b+N)^2}$$

From the expressions above a give value of M defines the two constants a and b. From the observations, a maximum value of 30 was given to x. Table 9.1 was then constructed for the determination of the constants. The second distribution fitted was a negative exponential of the form,

$$P = \frac{1}{M} \exp^{-\frac{N}{M}}$$

The latter provided a better fit to the data and was therefore selected to be used in the model. By generating a random number, R, within the interval (0,1), the number of passengers boarding a simulated bus is obtained by,

$$N = -M \ln(R)$$

where the parameter M is fixed as 5.62, the average value based on the observation of 1542 bus boarding events, and N is expressed in a non integer format.

9.9 Lane changing

The desire to achieve a higher speed, local traffic density, the proximity of interchanges and bus stops, and lane preference are among the variety of reasons used to explain why a driver changes lanes. The formulation of a lane changing model including all the causes for a lane change is, therefore, a very complicated process. The microscopic lane changing procedure used distinguishes between forced and optional lane changes. A driver will attempt an optional lane change if one of the following conditions is satisfied:

a. the speed of the vehicle is being constrained by a slower moving leader and one of the lane changing gap leaders is moving faster.

b. the queue length of one of the adjacent lanes is shorter than the lane under consideration.

c. the vehicle is not a bus and is travelling at the kerb lane while approaching a bus stop.

A forced lane change will be considered if:

a. the vehicle is a bus travelling at the middle lane and close to its bus stop.

b. the vehicle is a turning one close to its exit intersection and where the current lane, different from the kerb one, does not provide access to its exit lane.

A driver attempting to change lanes will make his decision based upon speeds and positions of the lead and lag vehicles of the gap into which he considers merging. The elements involved in the procedure are shown in figure 9.6. A lane changing manoeuvre is subject to the availability of a gap between the vehicles in the adjacent lane which can accommodate the lane change vehicle. It is very difficult to formulate a lane-change gap acceptance function since it is not possible to identify a rejected gap in this situation. Limited information exists for minimum acceptable lead and lag times. Field observations have given values of 1 and 3 seconds respectively {175}. Matson {176} suggested a value of 3 seconds as the minimum gap into which a lane change vehicle should enter, allowing 1.5 seconds for both lead and lag gaps after the completion of the manoeuvre. Within the model developed in this study, a lane changing opportunity may be considered if lead and lag gaps at the adjacent lane are greater than 1.5 seconds.

Lane changes are further constrained by the deceleration rates imposed on the vehicles involved in the lane changing process. The model checks if a fast vehicle is able to reduce its speed to the current speed of the slower leader within the distance that separates them. The procedure adopted is similar to the one used by vehicles decelerating to turn (section 9.4.3). Once the time that will take to the fast vehicle to reach both the current position and speed of the front vehicle is determined, the deceleration slope is obtained. The maximum deceleration rate required is then calculated. If this deceleration value does not exceed the desired deceleration rate of the driver under consideration, the condition is satisfied and the lane changer is allowed to move into the adjacent lane.

When a forced lane change is rejected, the driver starts slowing down according to its desired free-flow deceleration while continuing to check for a possible lane change. Occasionally, especially under high flow conditions, the vehicle is unable to move to a lane from which its turning movement is allowed or boarding and alighting events take place. The driver is then forced to stop some distance before the intersection or the bus stop until a lane changing opportunity is available. The lower limit of the lane changing length {176}, 30 metres, determines this stopping position. When this situation occurs, a vehicle is chosen in the kerb lane according to a cumulative density function. This selection is limited to kerb vehicles whose relative distance from the forced lane changer is less than 60 metres.

This selected vehicle decelerates in order to allow the forced lane changing unit to merge in front of it. The sensitivity of this assumption during the 'do nothing' situation is demonstrated in figure 9.7.

Once all the required conditions are met, the vehicle is immediately transferred to the adjacent lane. Also, a particular vehicle is allowed to undertake only one lane changing manoeuvre per reaction time. These simplifications of the real lane changing process eliminate the need for evaluating many interactions between all the vehicles involved during the transient period of manoeuvre completion. Such procedures are commonly used in simulation programs, based on the fact that a perfect simulation of lane changing would little contribute to the realism of a model.

9.10 Structure of the traffic simulation processor

The main subroutine of the traffic simulation processor is SIMPRO, shown in figure 9.8. SIMPRO is used for time sequencing and controlling the periodic scanning of the model. It prepares the necessary parameters by initializing both simulation and time related variables. This module also controls the writing of intermediate and final reports on vehicle and system characteristics and on measures of effectiveness.

By calling a series of key modules, SIMPRO ensures that during each sacnning of the system, the following activities are performed:

a. SIGIND selects the indications of all traffic signals.
b. RORDER order main lane vehicles according to their position in relation to the origin.
c. ELACHA performs all required lane changing activities.
d. PROUPD evaluates, in a per main lane basis, the new dynamic characteristics of the vehicles (position, speed, acceleration/deceleration), determining bus stop times and removing from the system the units that have travelling further than their respective exit coordinates.
e. UPDETL inserts minor "T" entry lane vehicles.
f. UPDSIL updates and inserts vehicles through minor signal controlled entry lanes.

g. INSVEH inserts in the system, through the origin, the vehicles whose generation time is within the boundaries of the last time increment interval.

h. WINCON writes initial geometric and flow conditions.

The simulation run ends when time is greater than the specified total simulation time.

9.10.1 Vehicle and lane lists

The arrays that contain the characteristics of the vehicles to be inserted during the simulation run are formed during the previous run of the pre-simulation processor, described in chapter 8. Each vehicle is identified by an order number that relates to its inbound approach. This number is the key for joining, from different arrays, all the characteristics of a particular vehicle. In order to reduce data storage within the traffic simulation processor, active and latent pools are used in the model. Active pools contain data arrays of vehicles currently within the boundaries of the simulated roadway, while latent pools hold all data arrays of vehicles outside the system. An index number, ranging from the value one to the maximum number of vehicles likely to be found inside the network at a given time interval, is assigned to a vehicle once it is due to be inserted in the system.

When the vehicle enters the system, its file is taken from the latent and inserted in the active arrays under its index number. As soon as the vehicle leaves the network, through any of the outbound approaches, its index number is made available to another incoming driver. Both the transfer procedure and the selection of an index number is performed by module POOLTR, shown in figure 9.9.

For each major lane of the roadway there is a list of vehicles where vehicle index numbers are kept ordered according to the distance between each vehicle and the main generation point (origin). Therefore, the vehicle sequence in each of these lists is identical to the sequence on the actual lane of the road. The first vehicle in each list is the one positioned further away from the origin in the particular lane. Whenever a vehicle leaves the system, either by a major or a minor outbound lane, the total number of vehicles using the major lanes, at that particular time, is decreased. The opposite consideration applies when a vehicle is inserted either through a minor or a major inbound lane.

Once the time is incremented all major lane list values are set to zero and a special vehicle list, that includes all indexes of vehicles currently in the major lanes, is re-ordered, according to the updated positions of the vehicles, by subroutine RORDER, also shown in figure 9.9. The application of such time consuming procedure of data movement is restricted, within the model, to this special list.

The re-ordering process is followed by the evaluation of lane changing reactions.

9.10.2 Lane changing modules

Five modules, ELACHA, WCHLA1, WCHLA2, LACHDE and LACHAN are used for the development of lane changing desire, the evaluation of conflicts and the transfer of a vehicle from one lane to the adjacent lane. The function of the modules is demonstrated in figure 9.10.

The lane changing process is the first reaction assessed by the model after the simulation time is incremented. The desire for this manoeuvre is available to vehicles travelling along the main lanes. The procedure is initialized by ELACHA, where starting with the first vehicle, each vehicle on the special list re-ordered by RORDER, evaluates and performs, whenever possible, a lane changing manoeuvre. ELACHA starts by checking if the vehicle is allowed to change lanes. If this is the case, it searches for the lane leader and the front lead gap vehicles at the adjacent lanes. Module WCHLA1 caters for the forced lane changed process apart from checking if a lane change is both possible and necessary. Module WCHLA2 starts by searching for the adjacent lag followers and continues by examining if right and/or left movements are allowed. Deceleration rates required by lag and lead gap followers are calculated by LACHDE. If one of these vehicles is not able to reduce its speed within its desired deceleration rate, the lane changing processor to the lane under consideration is interrupted.

If a lane change is indicated for a particular vehicle, LACHAN performs the transfer by ncreasing or decreasing the lane index of the vehicle. Before moving to the next vehicle on the special list, the index of the last vehicle to consider lane changing is placed, by module LALIST, on its correspondent destination lane list. LALIST also controls the reaction to amber associated with the lane changing process by keeping track of the first vehicle of each major lane due to stop by the amber/red traffic lights. The flowchart of LALIST is included in figure 9.11.

At the end, after all the main lane vehicles have been investigated for lane changing purposes, all major lane lists of vehicle indexes are automatically completed and ordered for the time interval under consideration. The main advantage of adopting this procedure is obtained in simplyifying the logic within the simulation model. Also, less data storage is required since no special computer arrays are employed for storing leading and following indexes of adjacent lane vehicles for each driver.

9.10.3 Traffic signal indications

The traffic signal indications, for main lane vehicles, are determined once the time is incremented. Subroutine SIGIND performs the calculation based on the signal offsets and green times provided by the pre-simulation processor. The flowchart of SIGIND is shown in figure 9.11.

9.10.4 Traffic reaction modules

As the lane changing process is isolated from the actual updating of the vehicles, subroutine PROUPD is able to deal with ordered vehicles in a per lane basis. Therefore, starting with the furthest vehicle from the origin (main generation point) on the median lane until the nearest to the origin travelling on the kerb lane, all main lane vehicles have their dynamic characteristics re-evaluated. The flowchart of PROUPD is shown in figure 9.12.

When updating a vehicle, a decision has to be made as to whether it reacts to the leading vehicle, stops by the traffic lights (or bus stop if the vehicle is a bus), undertakes free flow reaction or decelerates to turn (if the vehicle leaves the system by one of the minor outbound lanes). Subroutine UPDATE (figure 9.13) decides which of these actions is taken by the driver. Module STOPOS (figure 9.14) is called by UPDATE in order to determine the exact position, x_r, where the vehicle being examined is required to stop. Figure 9.14 also illustrates the range of values that x_r may assume. STOPOS uses either BSTIM1 (for conventional bus service) or BSTIM2 (when bus platoons are adopted) in the selection of the length of time a bus remains stopped at its bus stop. The flowcharts of these two modules, represented in figure 9.15, are similar in their general structures.

While a bus is being serviced at its bus stop, the value of x_r remains equal to the bus position and the number of the bus is kept in an array of queued buses. A default value is assigned to x_r when there is no obstruction or desire requiring the vehicle to stop. An obstruction is likely to be either a vehicle already stopped downstream or a red/amber light requiring a stop at the traffic signal position. A desire includes stopping at a bus stop as well as the necessity to allow or to accomplish a forced lane change.

After a position to stop is determined, UPDATE makes use of one of the following modules, in deciding the reaction of the driver under consideration (figure 9.16):

a. WDECST - calculates if a vehicle will be required to react to stop (section 9.4.2). It is used when x_r indicates that the vehicle is the first to stop at a bus stop or at a traffic light.

b. WDECLE - checks whether the driver is constrained by a slower moving front vehicle. A reaction will be indicated if the driver is travelling within the zone of influence of the leading unit or if the rate of change of the visual angle is perceived (section 9.5).

c. WDECTU - determines whether the vehicle requires a deceleration to turn (section 9.4.3). It is applied only for vehicles that leave the system through one of the minor intersections.

d. WDSTLE - decides whether a driver reacts to a stop or to a front vehicle,

$$d_f = \min (d_s, d_v)$$

where d_f is the deceleration adopted, d_s is the deceleration required to stop and d_v is the deceleration required by the front vehicle, all negative values. This situation may occur under the following circumstances:

i. a bus reacting to a leading vehicle also requiring to stop at its bus stop,

ii. a driver reacting to a leading vehicle and either required to allow a forced lane changer merge in front of him or unable himself to perform a forced lane change.

e. WDTULE - selects a deceleration value from the deceleration required to the turning manoeuvre and the deceleration required by the slower moving front vehicle,

$$d_f = \min(d_t, d_v)$$

where d_t is the deceleration required to turn. This decision is restricted to turning vehicles already close to their outbound approaches (section 9.4.3).

Once the reaction of the driver is determined, the action procedure in UPDATE, i.e. the updation of the dynamic characteristics of the vehicle, is performed by one of the following modules:

a. DECSTO - uses the value of required stop position, x_r in order to calculate a deceleration slope for the next time interval (section 9.4.2).

b. DECLEA - computes the deceleration rate that will be applied to a vehicle travelling in either state D or E (section 9.6). It incorporates the decision between using the generalized, the modified form or both of the car following equations. The deceleration rate is limited to the maximum allowed deceleration rate (section 8.6.5). DECLEA also investigates if a merging situation, state F, has been achieved.

c. DECTUR - applies the deceleration value previously calculated by WDECTU in the updation of the dynamic characteristics of the turning vehicle.

d. KSPACC - takes into consideration all the vehicles which are not required to decelerate, including:

i. vehicles travelling at their desired speed, a situation where both the acceleration rate and the slope remain equal to zero.

ii. a leader of a stopped queue of vehicles accelerating during the given phase of the cycle. The acceleration rate is evaluated according to the desired acceleration slope of the vehicle (section 8.6.3).

iii. a vehicle positioned within the zone of influence. The acceleration rate is obtained from the rules that govern state A (section 9.6).

iv. vehicles travelling at a distance where they do not suffer interference from their respective leaders. Desired acceleration is used in evaluating the value of the acceleration slope.

Merging situations, i.e. state F conditions, are also taken into account by KSPACC.

Module TSPAHE is used in order to determine which is the next traffic signal ahead of the vehicle. Module LINKPO, was introduced in the model to keep track of the number of vehicles travelling along each link of the main lanes.

9.10.5 <u>Vehicle removal</u>

After PROUPD has called UPDATE, it checks whether the vehicle under investigation has left the system. There are two possible alternatives to leave the simulated roadway:

a. by one of the major lanes
b. by performing a turning movement into one of the minor outbound lanes.

Whenever a vehicle reaches the end of the major lanes, it must be removed from the system. This is accomplished by placing its vehicle number on a ficticious lane. The real time taken by the vehicle while inside the boundaries of the system is calculated and stored. The same basic procedure is used for vehicles whose destination is one of the turning outbound lanes. A turning vehicle is considered to be out of the simulation system whenever its position is greater than a point approximately midway through the turn. The required checks and transfer activities are undertaken by modules REMOST for straight vehicles, and REMOTU for turning vehicles. Both flowcharts are represented in figure 9.15.

9.10.6 Inserting vehicles through the origin

The insertion of new major lane vehicles through the origin (main generation point) is the last procedure to be evaluated after the time has been incremented. It is performed by a main subroutine INSVEH (figure 9.17) that commands three modules: POOLTR, WVEHRE and RELVEH. A vehicle is due to enter the traffic simulation system when its proposed generation time, t_g, previously obtained by the pre-simulation processor from headway distributions with parameters described in section 8.4.3, is within the last time interval, i.e.,

$$t_{s-1} \leq t_g < t_s$$

where t_s is the actual simulation time.

The dynamic characteristics of the last vehicle, travelling in the lane where the vehicle under consideration, n+1, is due to arrive, are calculated for the proposed time of generation by module WVEHRE. This module also evaluates the minimum headway, t_m, required by the leading vehicle,

$$t_m = \frac{l_n + h_{n+1} + d_n}{v_n}$$

where n is the index of the leading vehicle, l is the length, h is the stop distance, d is the distance travelled in one second and v is the speed. If the actual time headway between vehicles is greater than t_m, the vehicle is generated at $t_r = t_g$. Otherwise, the new vehicle is not allowed to enter the system at t_g and its generation time is delayed to t_r, the real generation time, that caters for the minimum headway consideration. This requirement does not significantly affect the generation of the remaining vehicles in the lane, since:

a. as the poposed generation times for all vehicles were determined before starting the actual run of the model, an increase in the proposed time of generation of a vehicle decreases only the time headway between this vehicle and the next being generated in this lane.

b. under normal volume conditions the need for delaying the proposed time of generation is little used.

Once the real generation time, has been obtained by WVEHRE, the vehicle will be inserted when,

$$t_s - 1 \leq t_r < t_s$$

A driver will try to enter the roadway while travelling at his desired speed. However, short headways and previously developed queues of vehicles sometimes make entry at the desired speed impossible.

Only the first vehicle to be generated in each major lane may enter at the desired speed without having to evaluate a limiting maximum speed to avoid collisions. If the desired speed of the vehicle to be inserted is smaller than the actual speed of its leader, the vehicle is inserted at its desired speed. For all other situations, an entry speed is computed by RELVEH so that the entering vehicle can reduce its speed, without exceeding its desired deceleration level, to the current speed of the leader. When a vehicle enters the system shortly after another has arrived, its speed is determined as the minimum value among the driver's own desired speed, the speed of the leading unit and the speed determined by the relative distance between vehicles, v_i,

$$v_i = c \ln \left(\frac{x_t}{x_j} \right)$$

where the parameters are defined as in section 9.5.

The adoption of a settling down distance (see chapter 12) enables vehicles to further adjust their dynamic characteristics before measures of effectiveness are obtained.

Module POOLTR is called just before the vehicle is inserted in the system. Its function has been previously discussed in section 9.10.1.

9.10.7 Inserting minor lane vehicle

The traffic simulated network is formed by major and minor roads as shown by figure 8.2. Within the particular situation being studied, i.e. Brazilian high flow two way urban avenues, two different types of control are used at the junctions:

a. stop signs - every driver is required to stop before entering the intersection. This condition is legally enforced by the presence of stop signs. Parked vehicles, pedestrian crossing movements and sight distance restrictions (buildings) also act as physical reinforcements to the stop requirement.

b. traffic signals- the vehicles react not only to the signal indication but also to intersection conflicts whenever the signal aspect is displaying the initial seconds of green for the approaching minor road traffic. As no left turn (right in UK) is usually allowed to vehicles travelling along these avenues traffic signal controlled minor roads provide the only possible way of crossing the major road traffic stream.

While the main interest of the model is to study the behaviour of vehicles travelling along the major road, minor lane vehicles are inserted for the sake of realism. Therefore more simplifying assumptions were used in updating minor road traffic before entering the major roadway system.

9.10.7.1 Stop sign controlled approaches

After the time has been increased and the major lane vehicles have been updated, subroutine UPDELA checks the first vehicle placed in each of the minor lane arrival queues. A vehicle is placed in the queue once its proposed generation time is within the last time increment interval.

If the arriving vehicle is the only vehicle in the queue by the time the above condition is fulfilled, module EVALAG evaluates the existing lag in the kerb lane of the major lane. The vehicle enters the major lane once the existing lag is bigger than its fixed lag value previously determined by the pre-simulation processor. If this condition is not met, the vehicle remains stopped by the intersection and the queue counting index is increased. Another search for an available time gap will be conducted again, for the first vehicle on the queue, once the time is incremented and the major road vehicles are updated.

Where the gap or lag is accepted, the initial dynamic characteristics (speed, acceleration and distance) are evaluated according to the free-flow acceleration rules. The vehicle is inserted in the kerb lane of the main road by module INSERT provided that a safe distance is available. A vehicle index is selected for the driver and his files are brought to the active pool by module POOLTR. The second vehicle in the waiting queue is then brought to the head of the queue but an entry opportunity will only be evaluated again by EVAGAP once another incremental time interval is elapsed. The flowcharts of the modules used for gap and lag acceptance evaluation, as well as for updating minor lane units, are represented in figure 9.18.

9.10.7.2 Traffic signal approaches

The leader of a minor lane queue will only be able to start moving from its still position once the traffic light is green for its approach and the junction is free of conflicts. Module UPDSIL (figure 9.19) ensures that the leader of a minor approach queue remains stopped until the last major lane vehicle, positioned ahead of any of the vehicles required to stop by the traffic signal, has cleared the intersection. At each time increment minor lane vehicles arrive at the back of the queue according to generation times previously obtained by the pre-simulation processor from shifted (1 second) negative exponential distributions.

Module UPDSIG, also shown in figure 9.19, determines the entering speed of an arriving vehicle as a function of the dynamic characteristics of the last vehicle in the queue. When the signal indication is displaying a red light for the approach under consideration, the entering speed is set equal to zero. The reaction model included in UPDSIG, for updating and discharging each individual queued vehicle, incorporates both the car following and the free flowing features already described in previous sections of this chapter. The desired speed on the approach is, however, limited by the radius of the turning movement and is calculated as in section 9.4.3.

A minor lane vehicle is inserted in one of the major traffic lanes once its updated position is greater than a fixed distance value. The insertion process ceases at the first second of the amber indication while all the vehicles still to be inserted return to the original stopped queue with speeds reset to zero. The model caters only for the generation of minor lane vehicles whose destination is the major, simulated, traffic stream.

1965 ten

Table 9.1 Values of the constants a and b in terms of the mean number of passengers boarding, M, for a maximum number of 30 passengers boarding

a	b	M
0.10	0.01	0.04
0.20	0.04	0.13
0.30	0.08	0.27
0.40	0.14	0.43
0.50	0.20	0.60
0.60	0.28	0.78
0.70	0.36	0.96
0.80	0.44	1.14
0.90	0.53	1.32
1.00	0.62	1.50
1.10	0.71	1.67
1.20	0.81	1.83
1.30	0.91	1.99
1.40	1.01	2.15
1.50	1.11	2.30
1.60	1.21	2.44
1.70	1.31	2.58
1.80	1.42	2.72
1.90	1.52	2.85
2.00	1.63	2.98
2.10	1.74	3.10
2.20	1.84	3.23
2.30	1.95	3.34
2.40	2.06	3.46
2.50	2.17	3.57
2.60	2.29	3.68
2.70	2.40	3.79
2.80	2.51	3.89
2.90	2.62	3.99
3.00	2.74	4.09
3.10	2.85	4.19
3.20	2.97	4.28
3.30	3.09	4.37
3.40	3.20	4.46
3.50	3.32	4.55
3.60	3.44	4.64
3.70	3.56	4.72
3.80	3.68	4.81
3.90	3.80	4.89
4.00	3.92	4.97
4.10	4.05	5.04
4.20	4.17	5.12
4.30	4.29	5.20
4.40	4.42	5.27
4.50	4.54	5.34
4.60	4.67	5.41
4.70	4.79	5.48
4.80	4.92	5.55
4.90	5.05	5.62
5.00	5.18	5.68
5.10	5.31	5.75
5.20	5.44	5.81
5.30	5.57	5.87
5.40	5.70	5.94
5.50	5.83	6.00
5.60	5.96	6.06
5.70	6.09	6.12
5.80	6.23	6.17
5.90	6.36	6.23
6.00	6.50	6.29
6.10	6.63	6.34
6.20	6.77	6.40
6.30	6.91	6.45
6.40	7.04	6.50
6.50	7.18	6.56
6.60	7.32	6.61
6.70	7.46	6.66
6.80	7.60	6.71
6.90	7.74	6.76
7.00	7.88	6.81

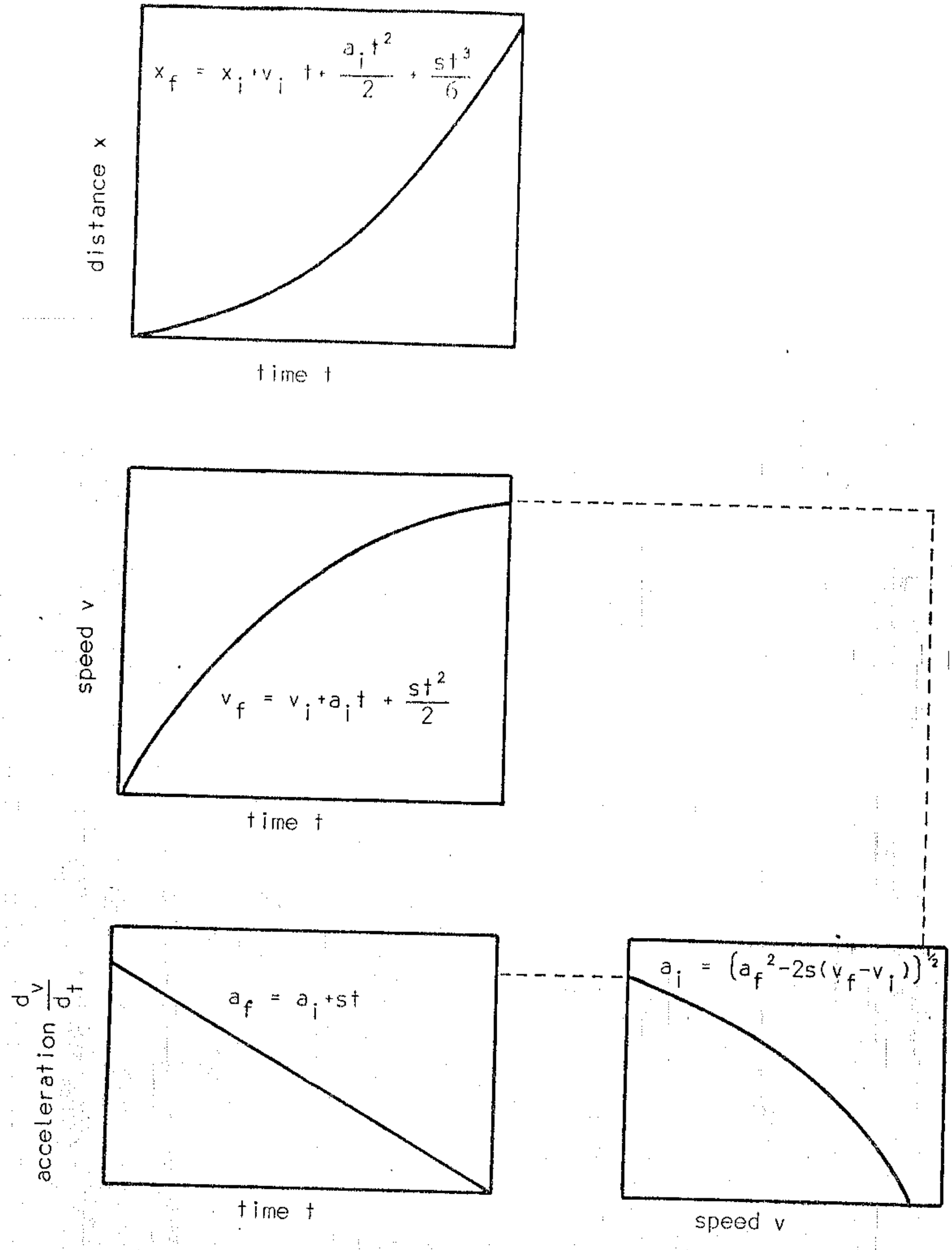


Figure 9.1 Linear acceleration model

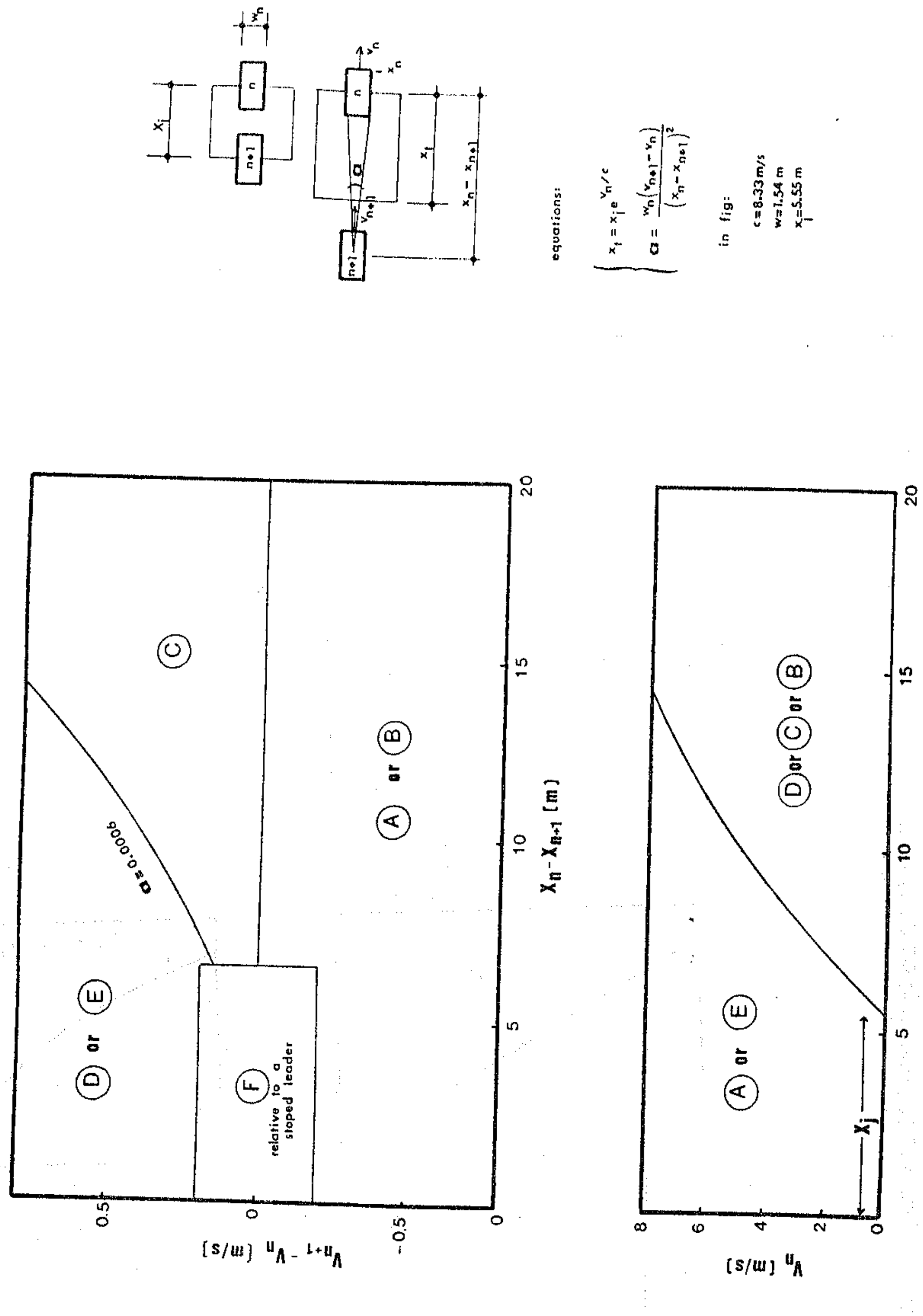


Figure 9.2 Vehicle reaction model

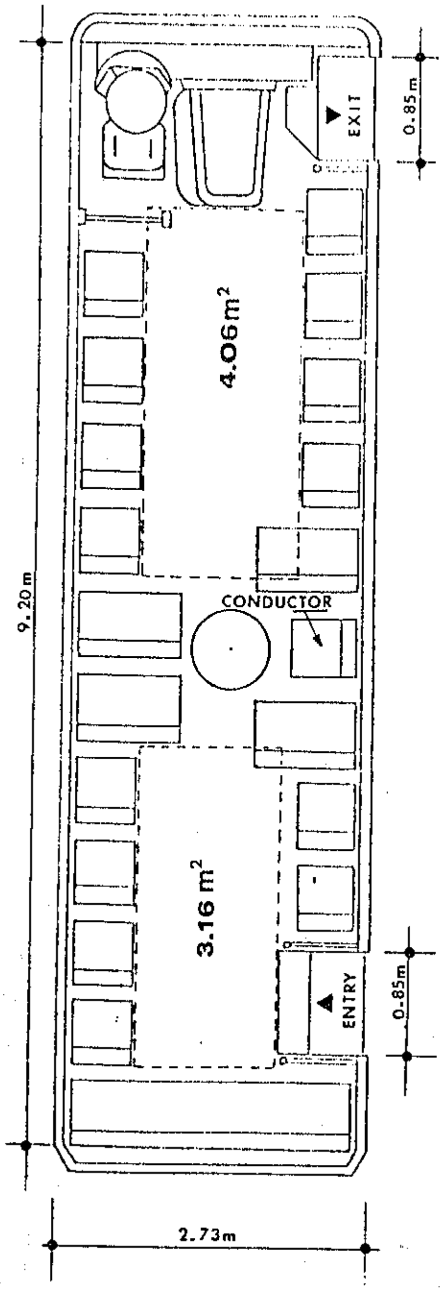


Figure 9.3 Layout of a typical bus

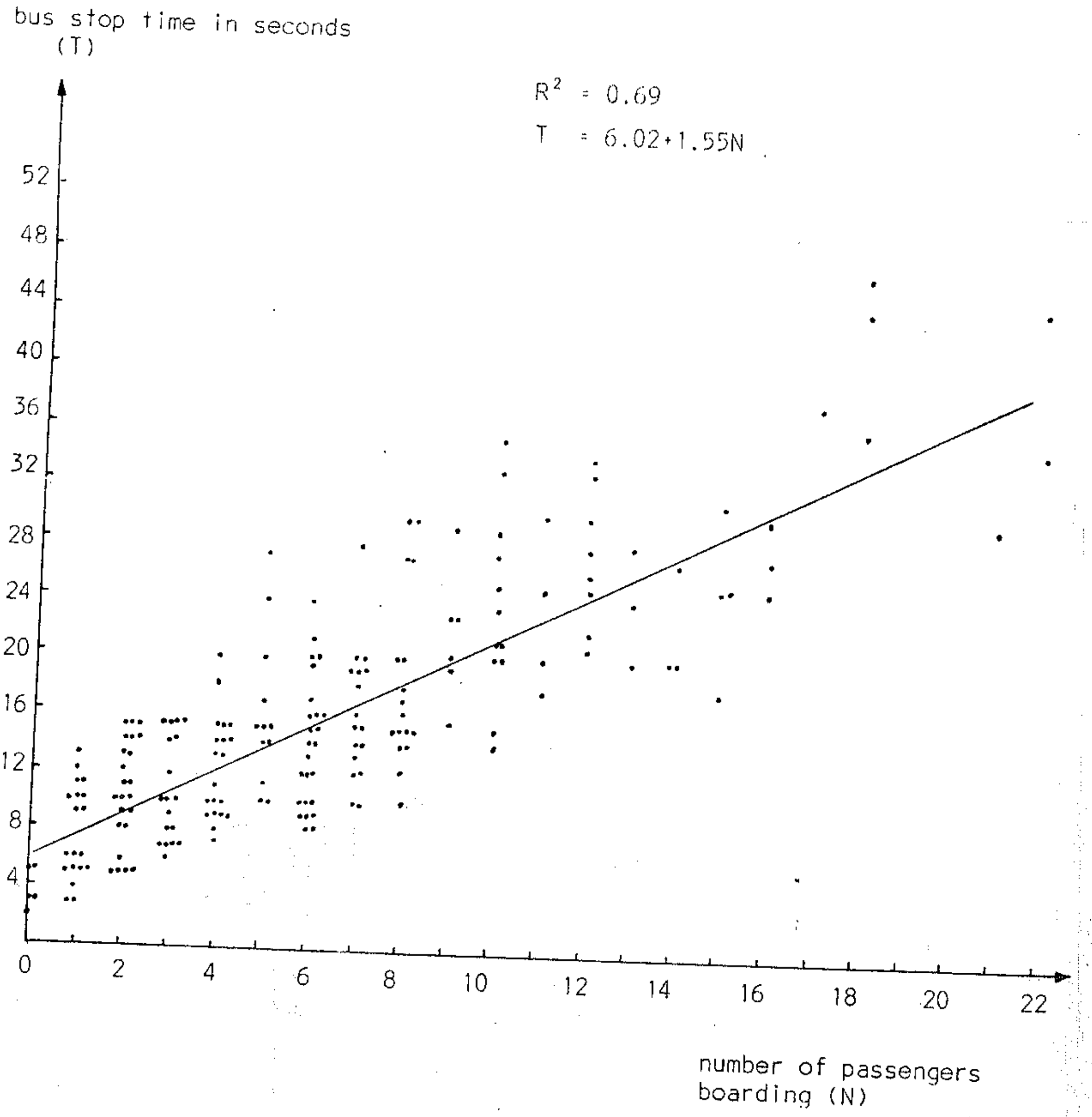


Figure 9.4 Relation between bus stop time and number of passengers boarding

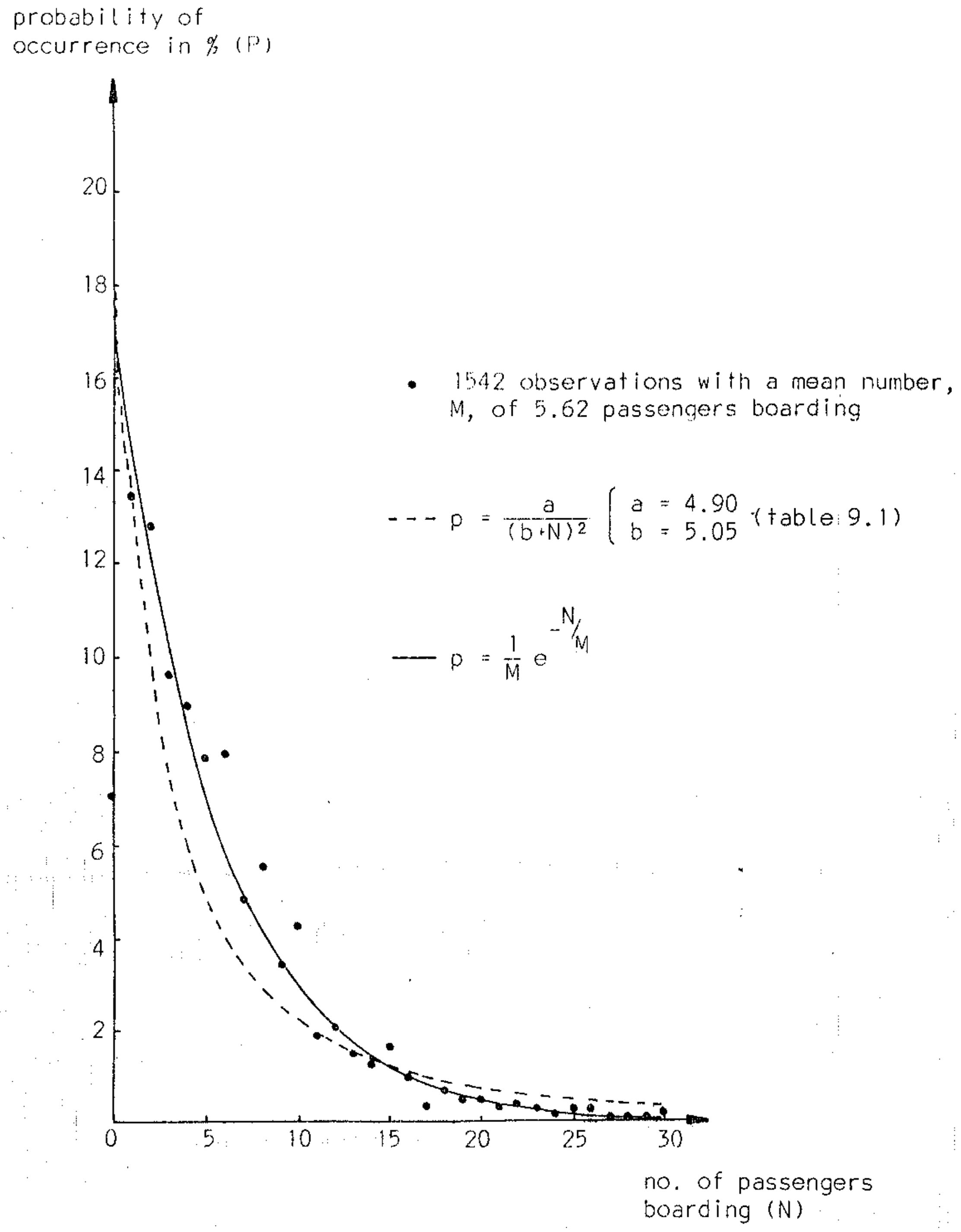


Figure 9.5 Number of passengers boarding

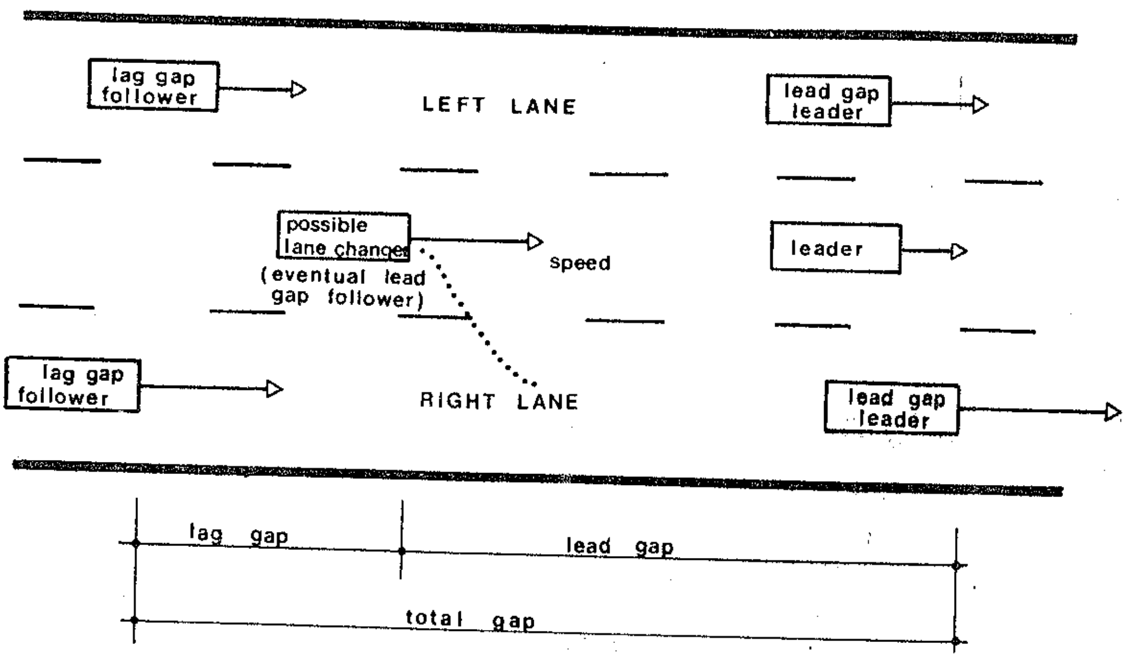
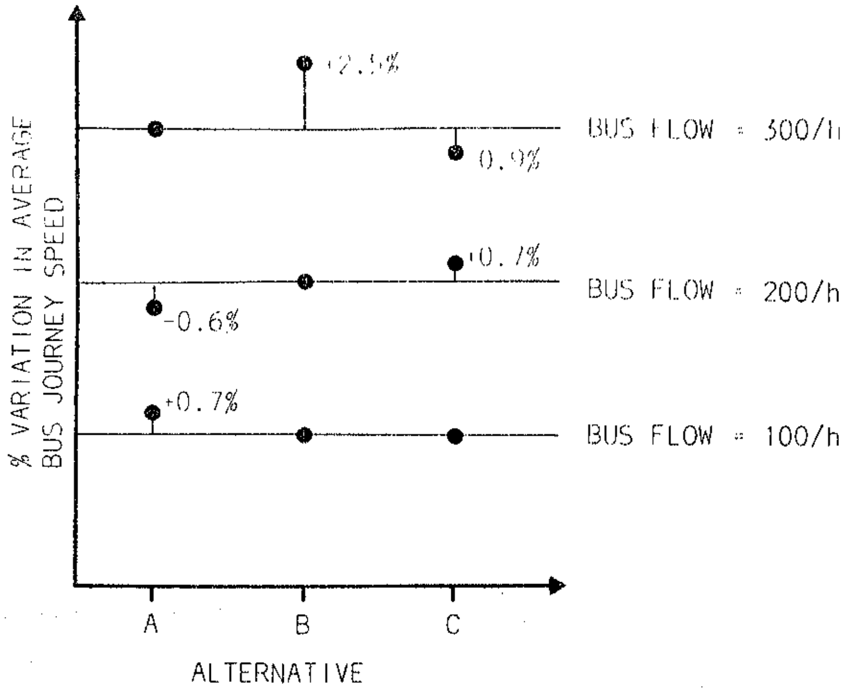


Figure 9.6 Elements of the lane changing manoeuvre



I	cumulative probability of stopping F(I) (see figure 7.2)		
0	0.00	0.00	0.00
1	0.20	0.30	0.10
2	0.40	0.55	0.30
3	0.60	0.75	0.60
4	0.80	0.90	0.90
5	1.00	1.00	1.00
alternative ⟶	A	B	C

I = relative position of kerb lane vehicle that will allow a stopped bus to change lanes

testing conditions equal to 'study' section, see chapter 12

3 bus stop berths

alternative A was adopted

Figure 9.7 Sensitivity of forced lane changing assumptions

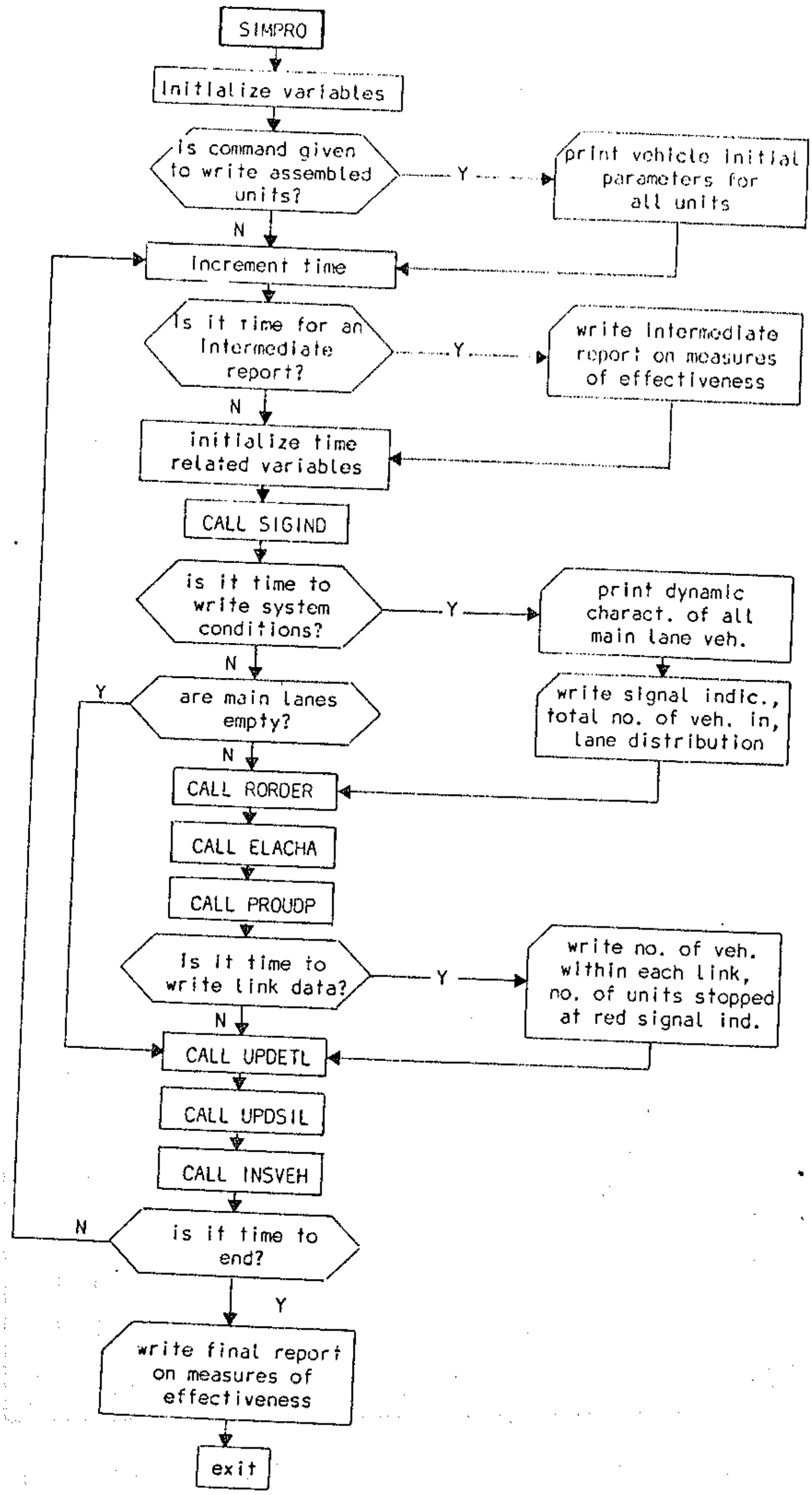


Figure 9.8 Flowchart of SIMPRO

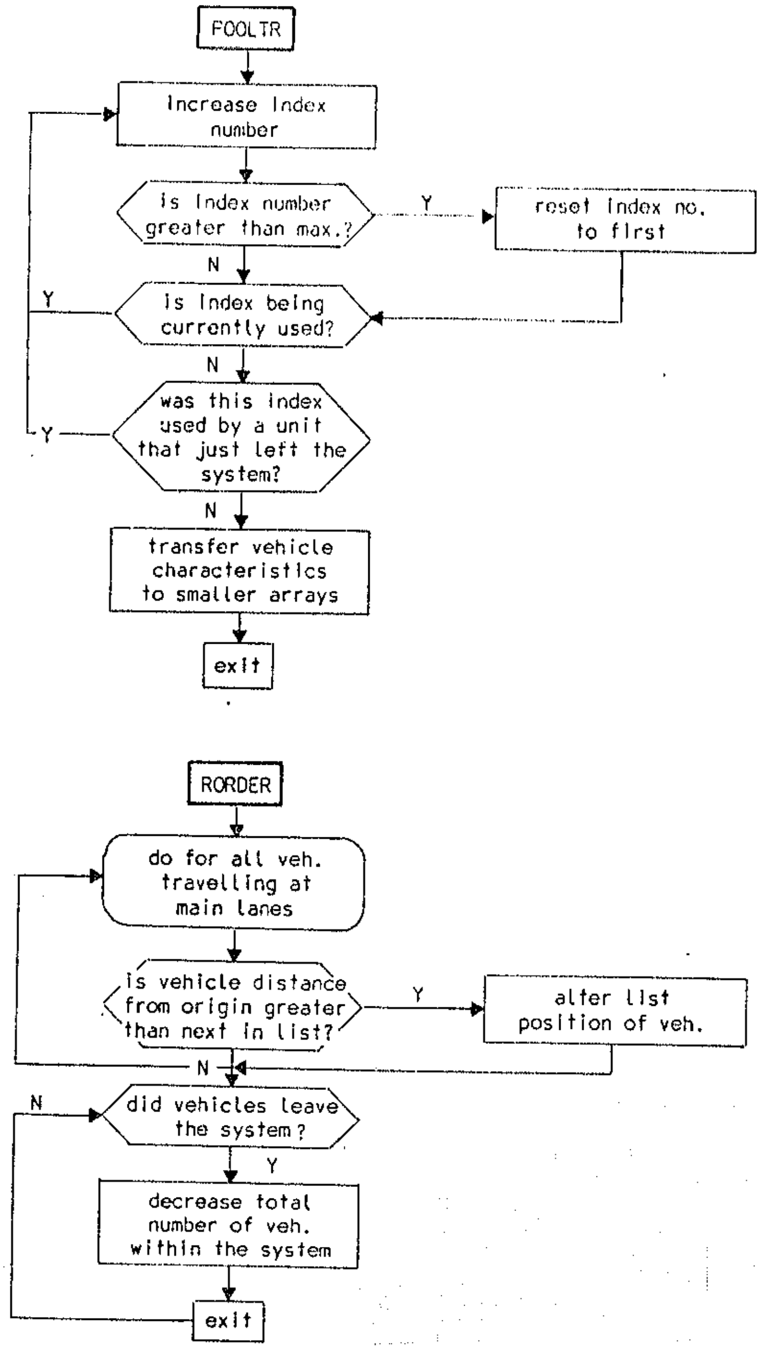


Figure 9.9 Flowcharts of POOLTR and RORDER

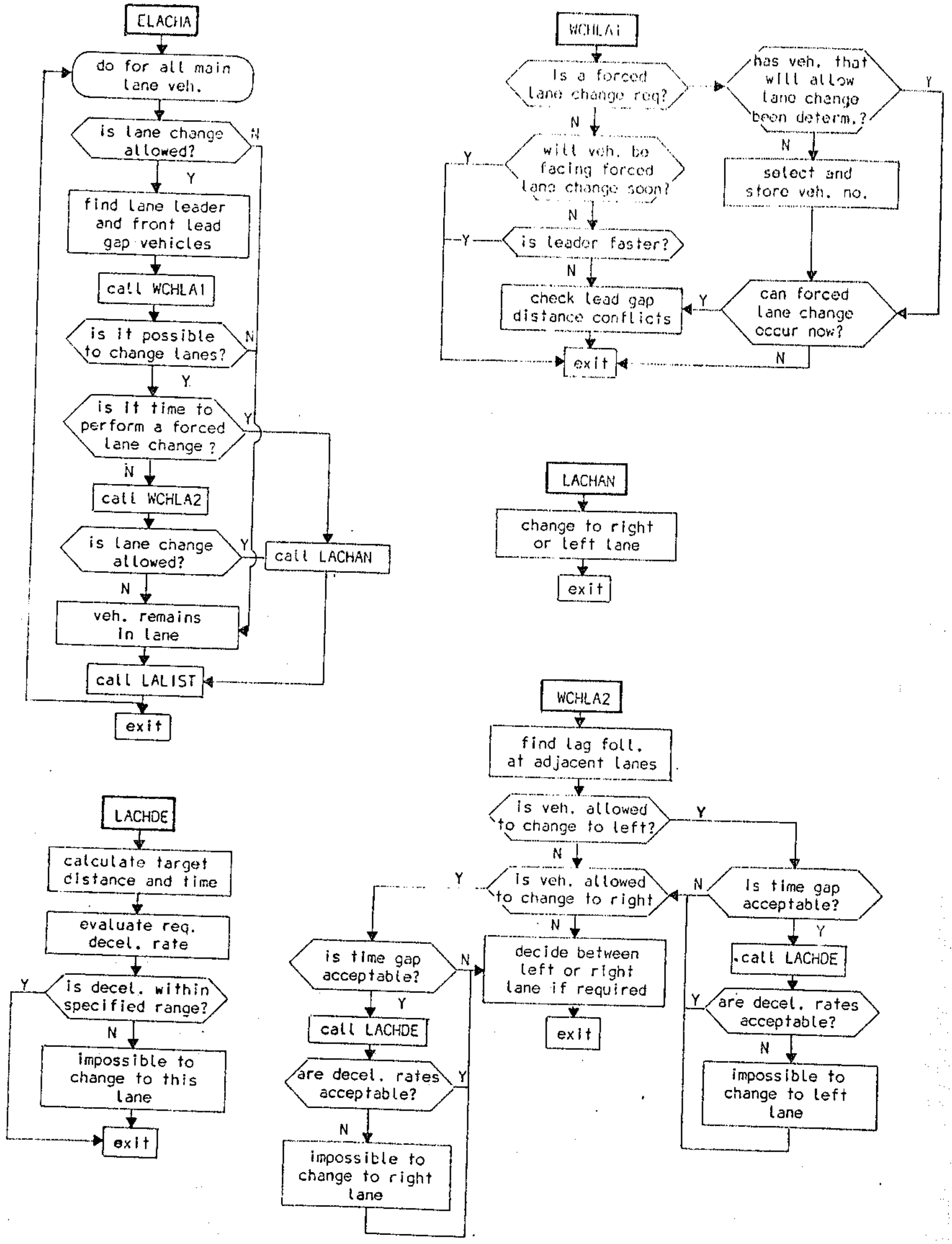
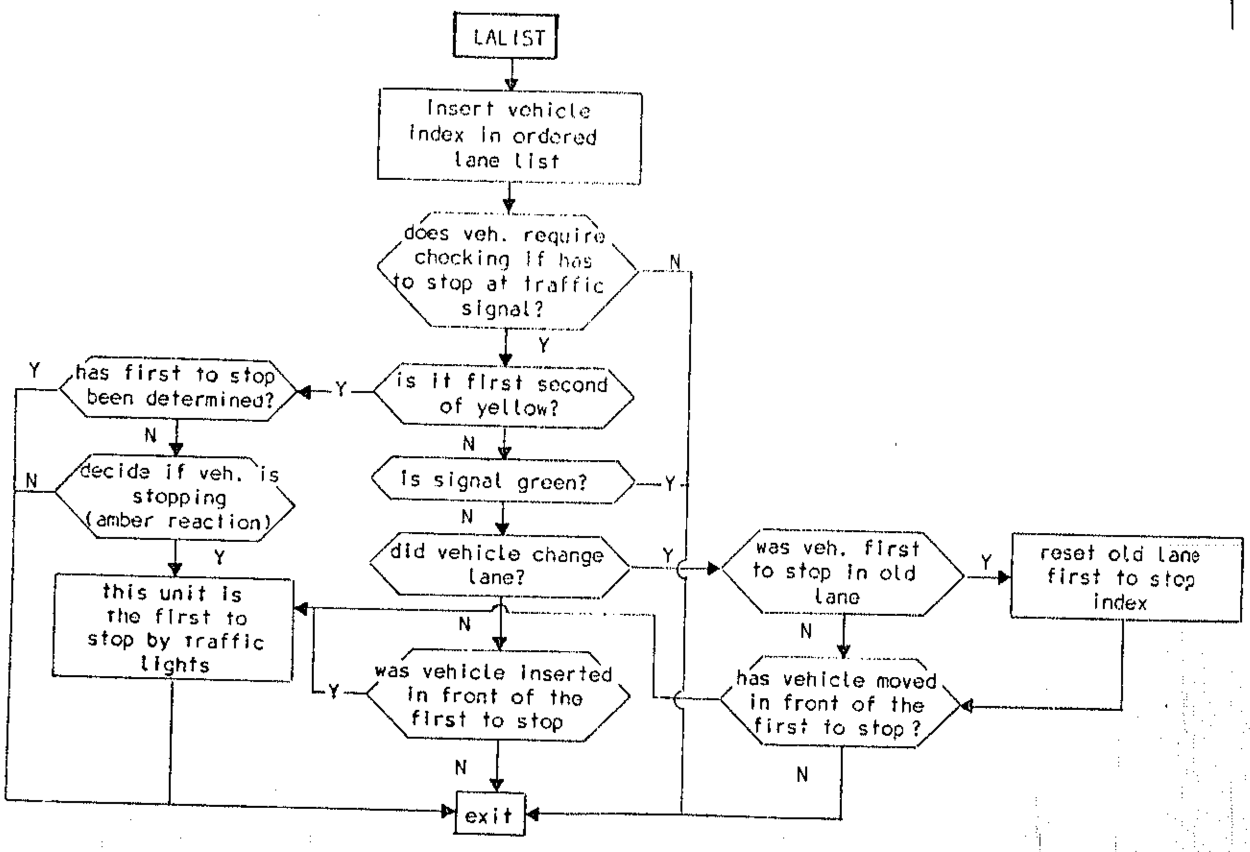


Figure 9.10 Flowcharts of lane changing modules



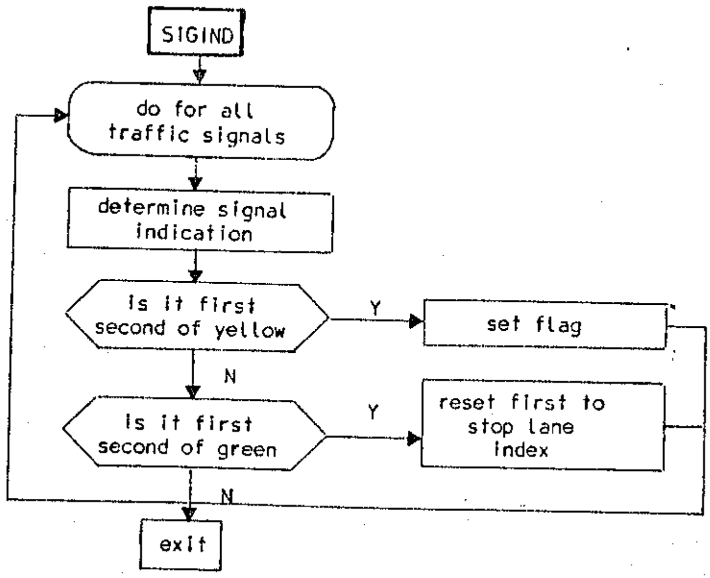


Figure 9.11 Flowcharts of LALIST and SIGIND

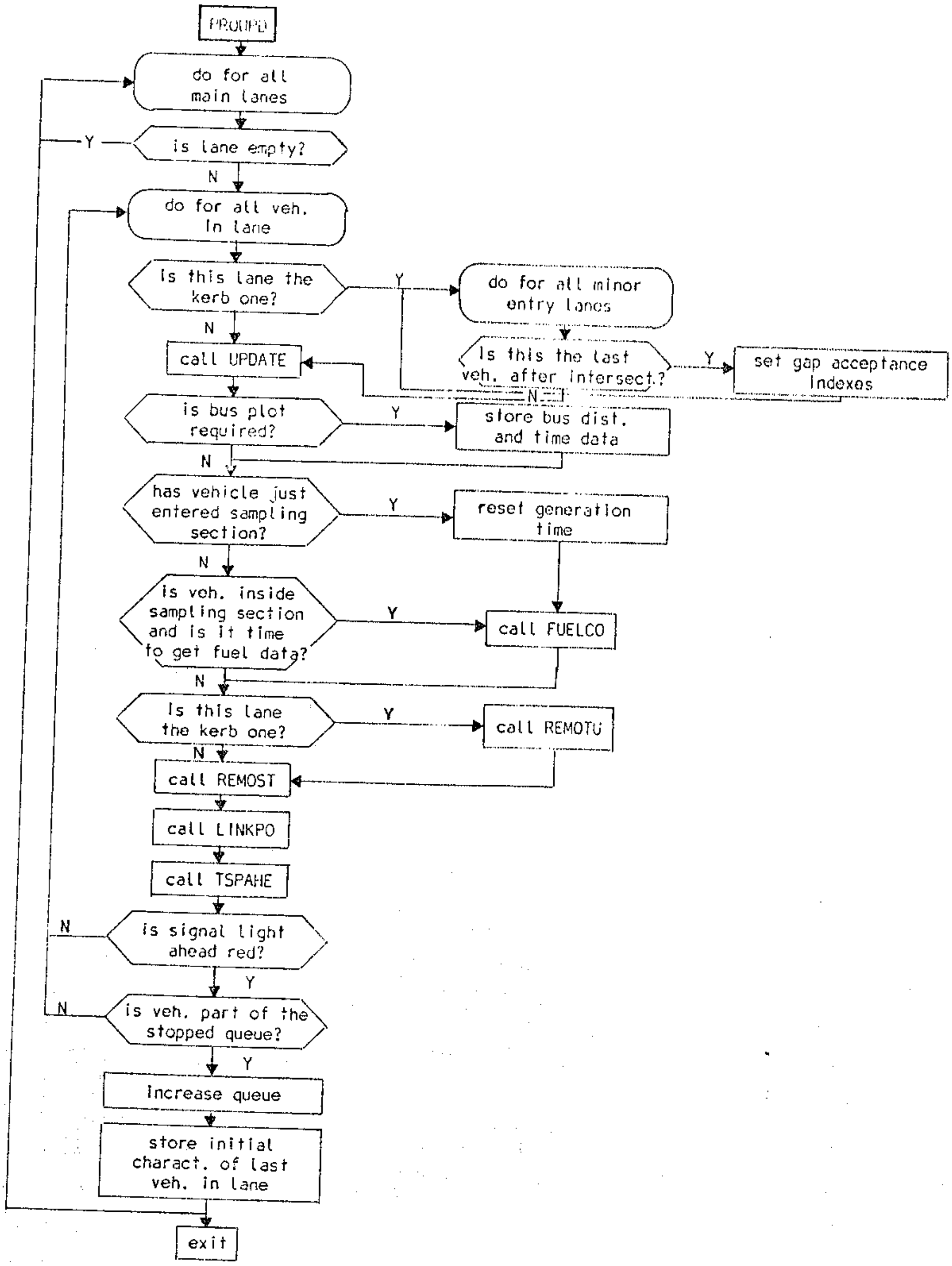


Figure 9.12 Flowchart of PROUPD

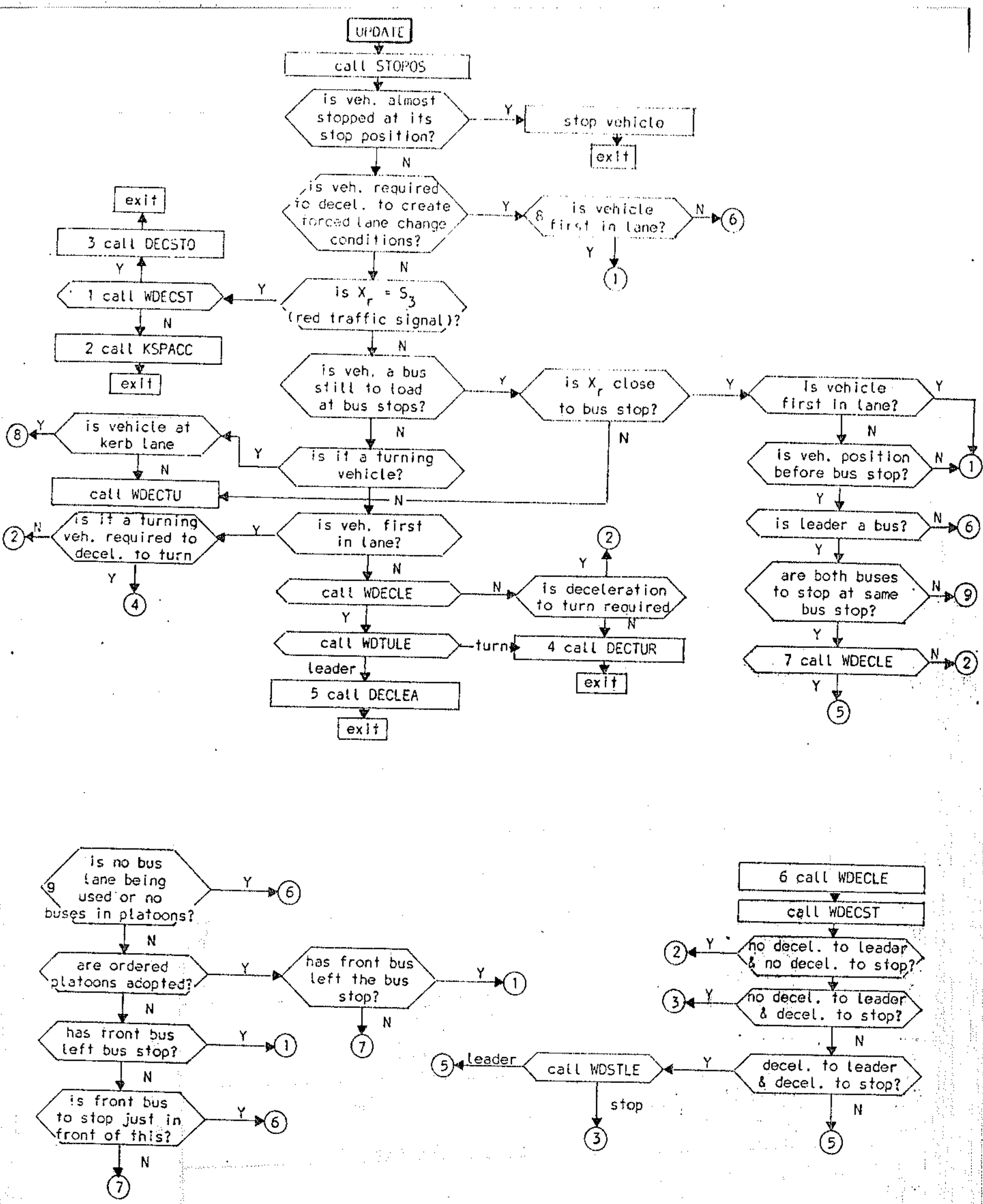


Figure 9.13 Flowchart of UPDATE

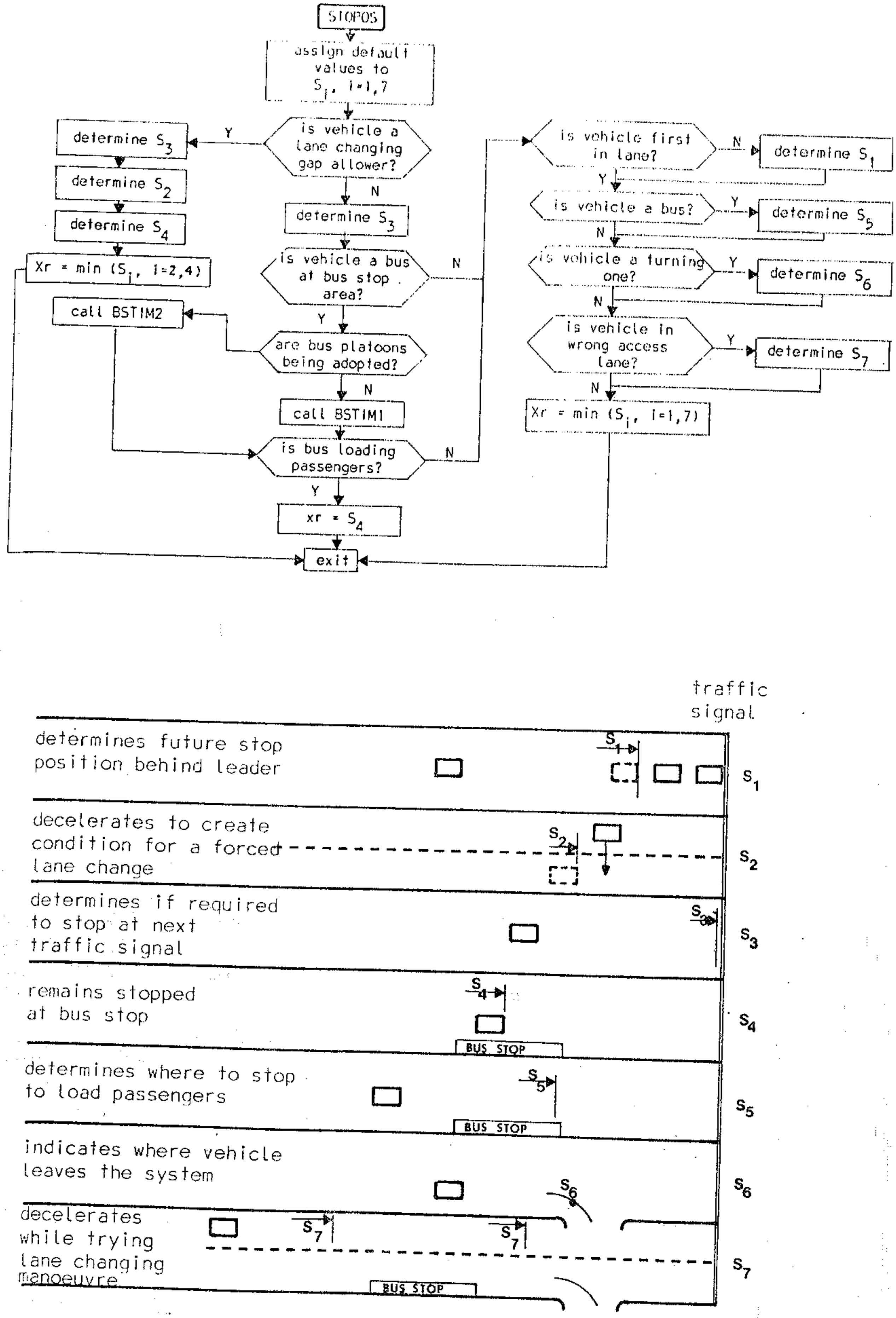


Figure 9.14 Flowchart of STOPOS

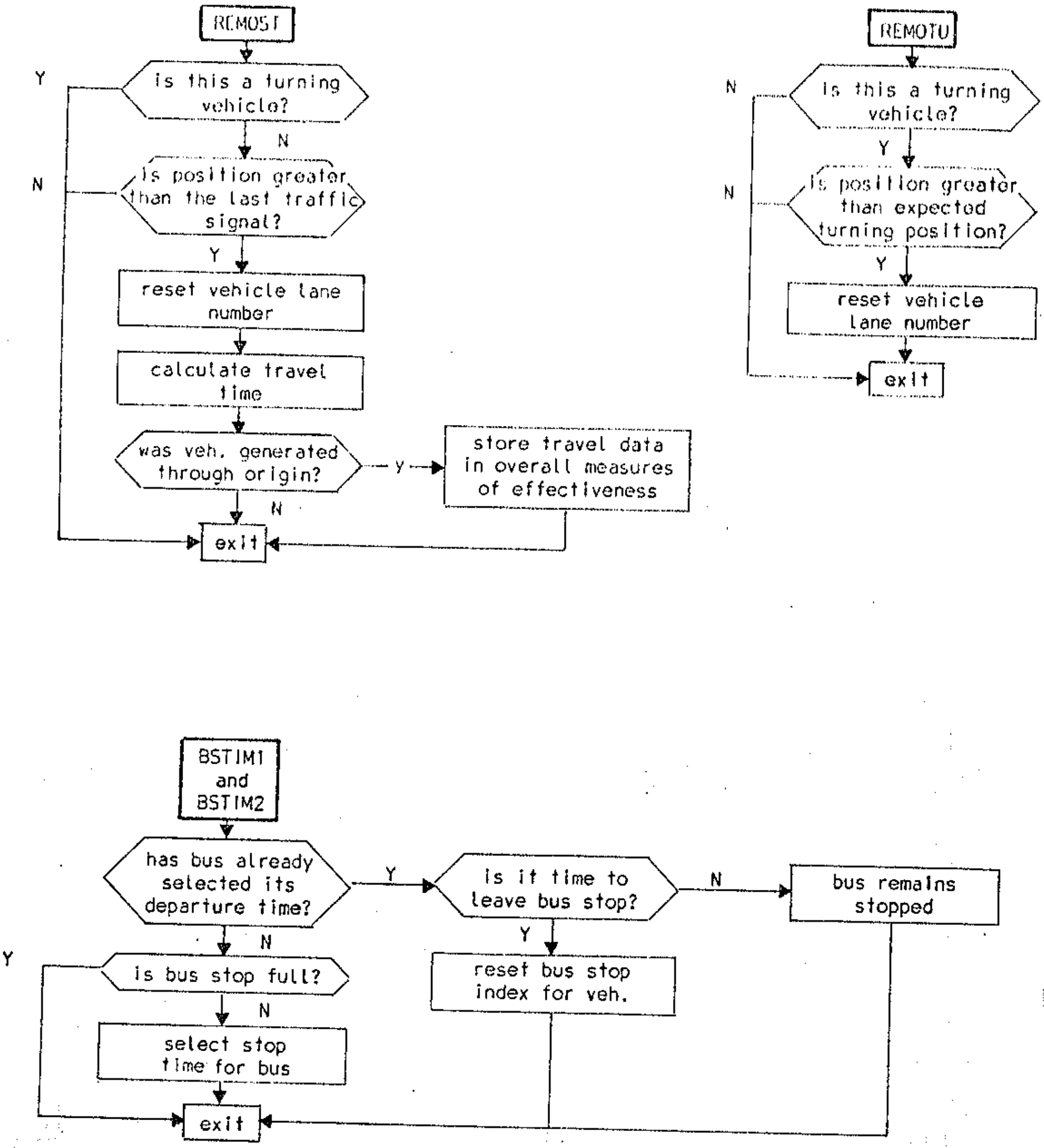


Figure 9.15 Flowcharts of REMOST, REMOTU and BSTIM (1 & 2)

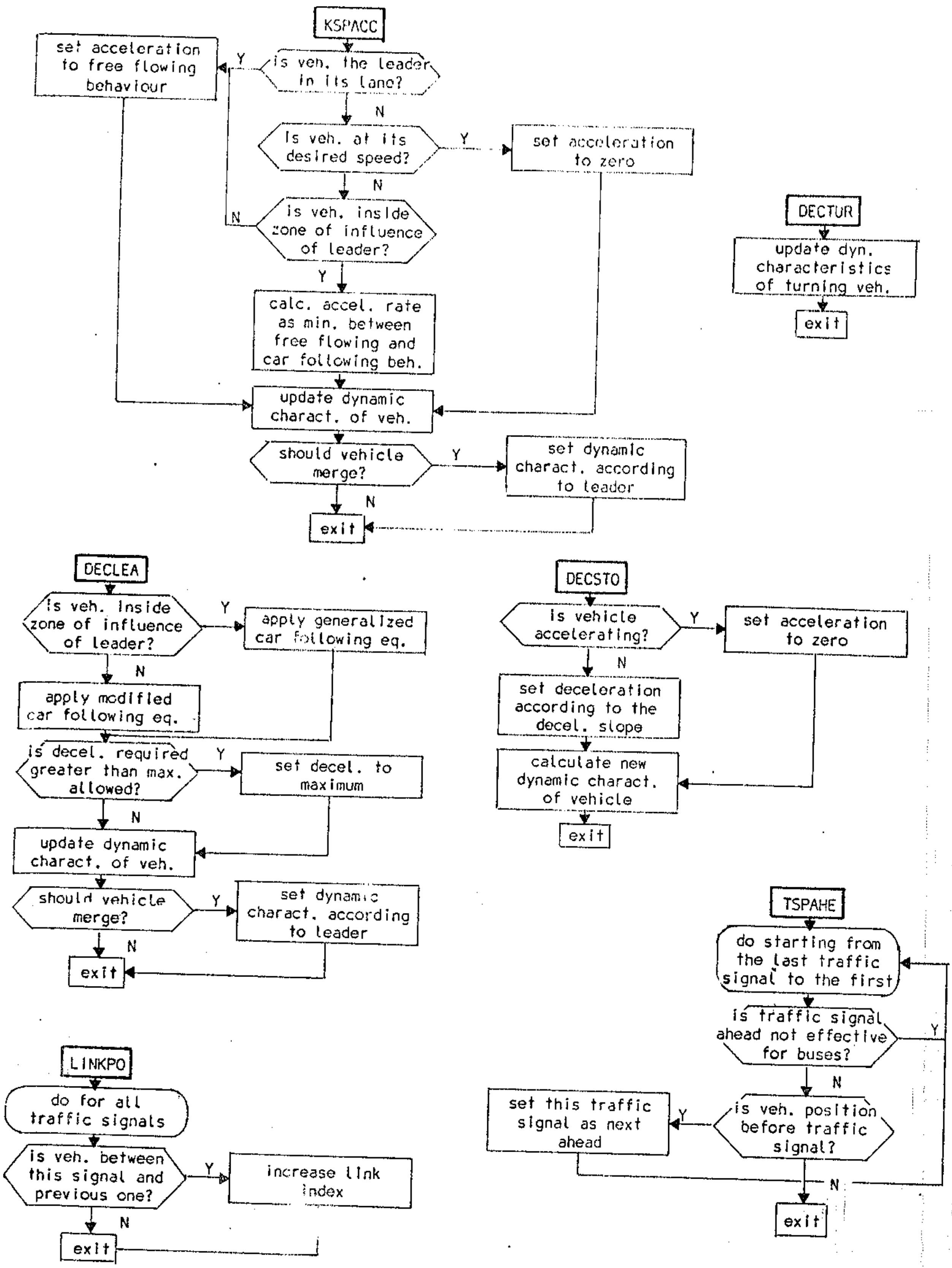


Figure 9.16 Flowcharts of traffic reaction modules

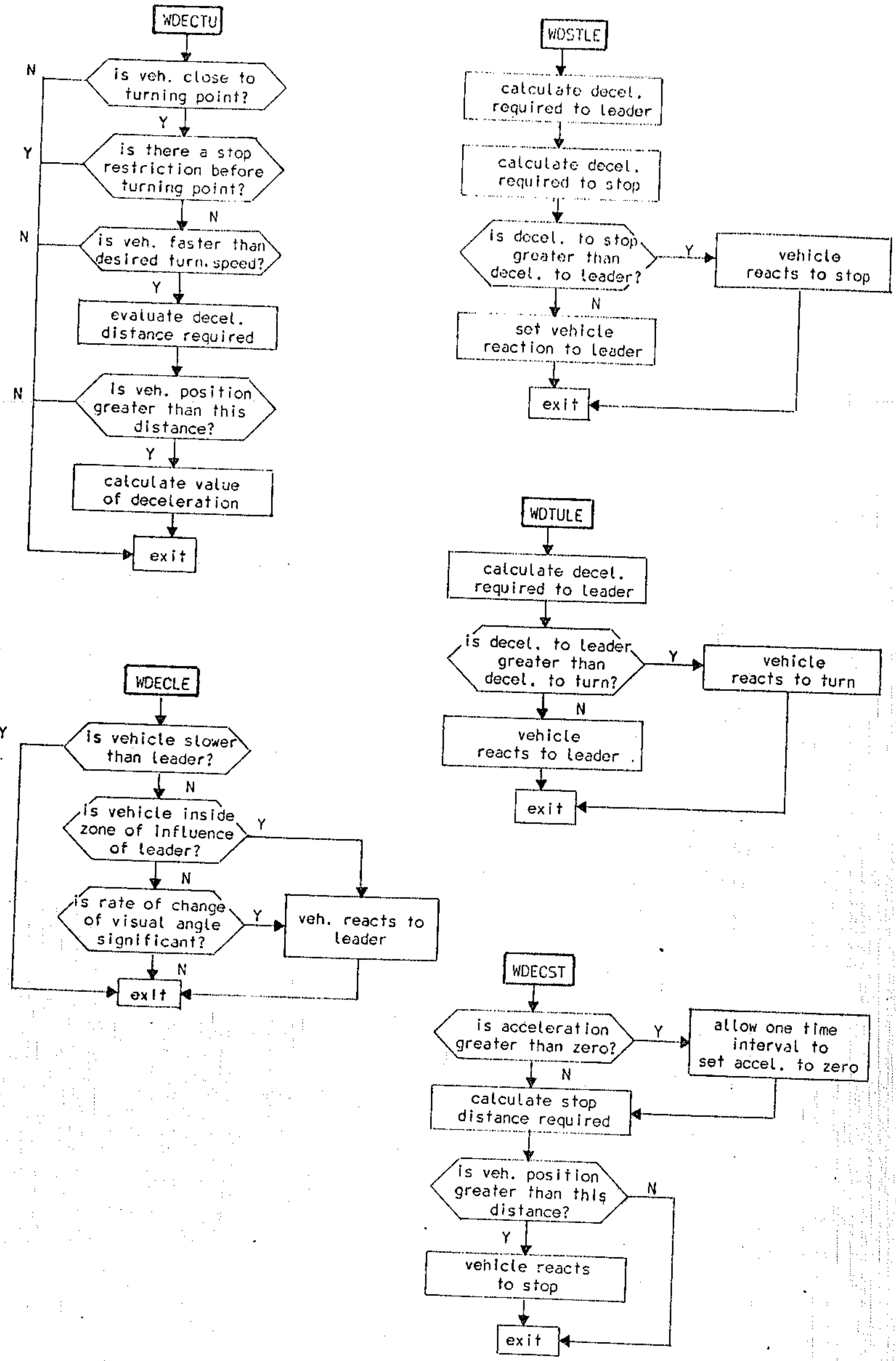


Figure 9.16 continued

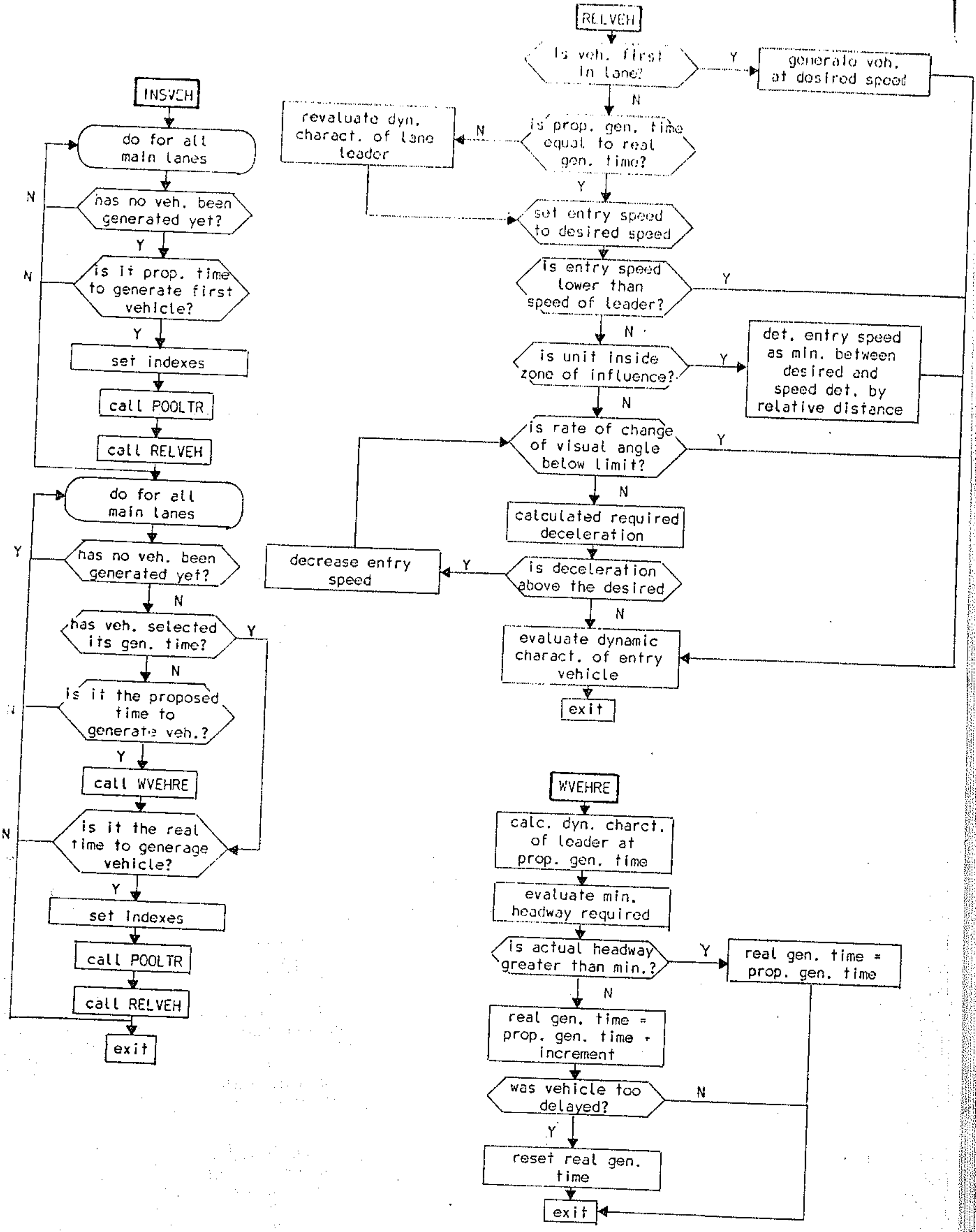


Figure 9.17 Flowcharts of major lane vehicle insertion modules

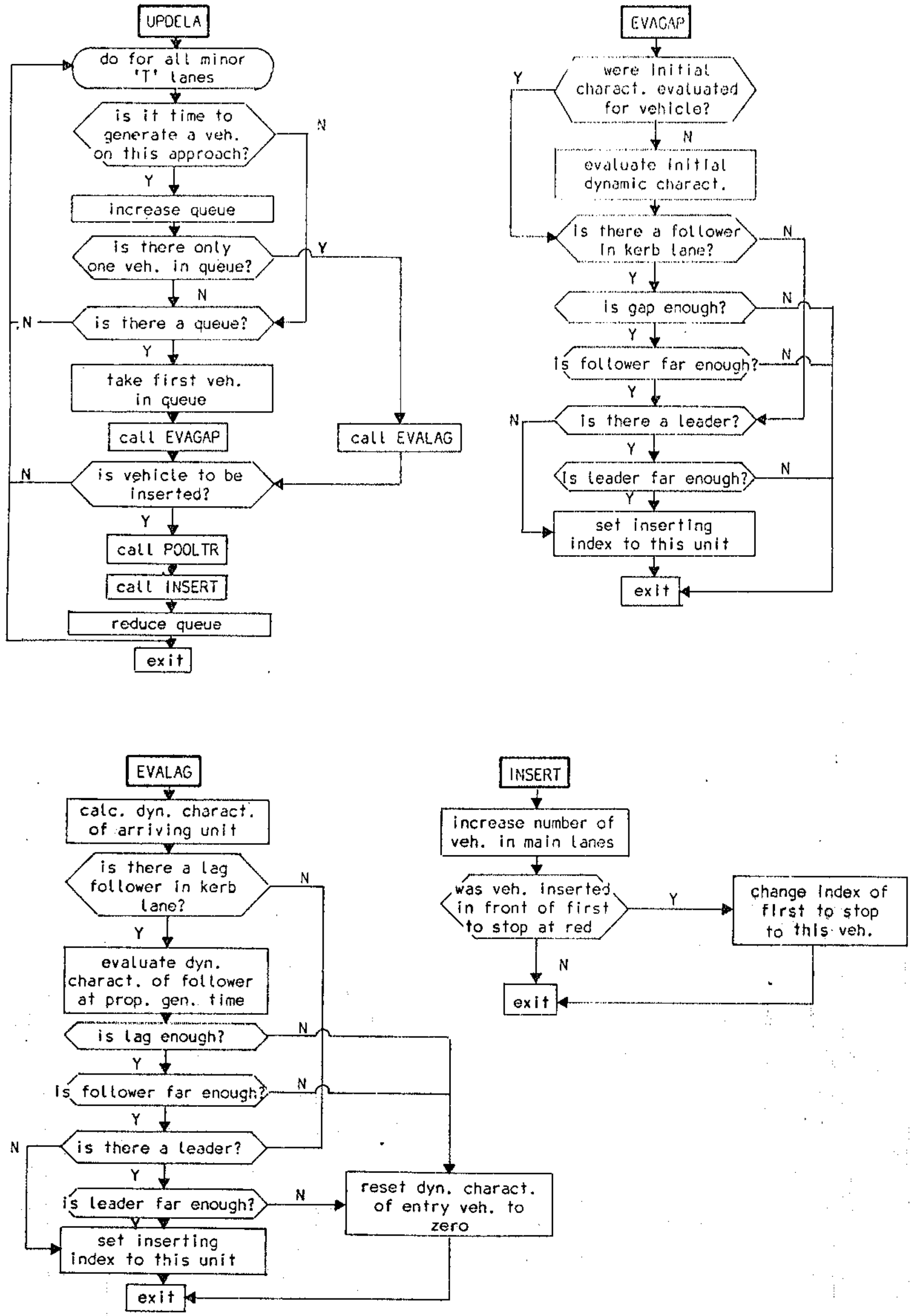


Figure 9.18 Flowcharts of minor 'T' lane vehicle insertion modules

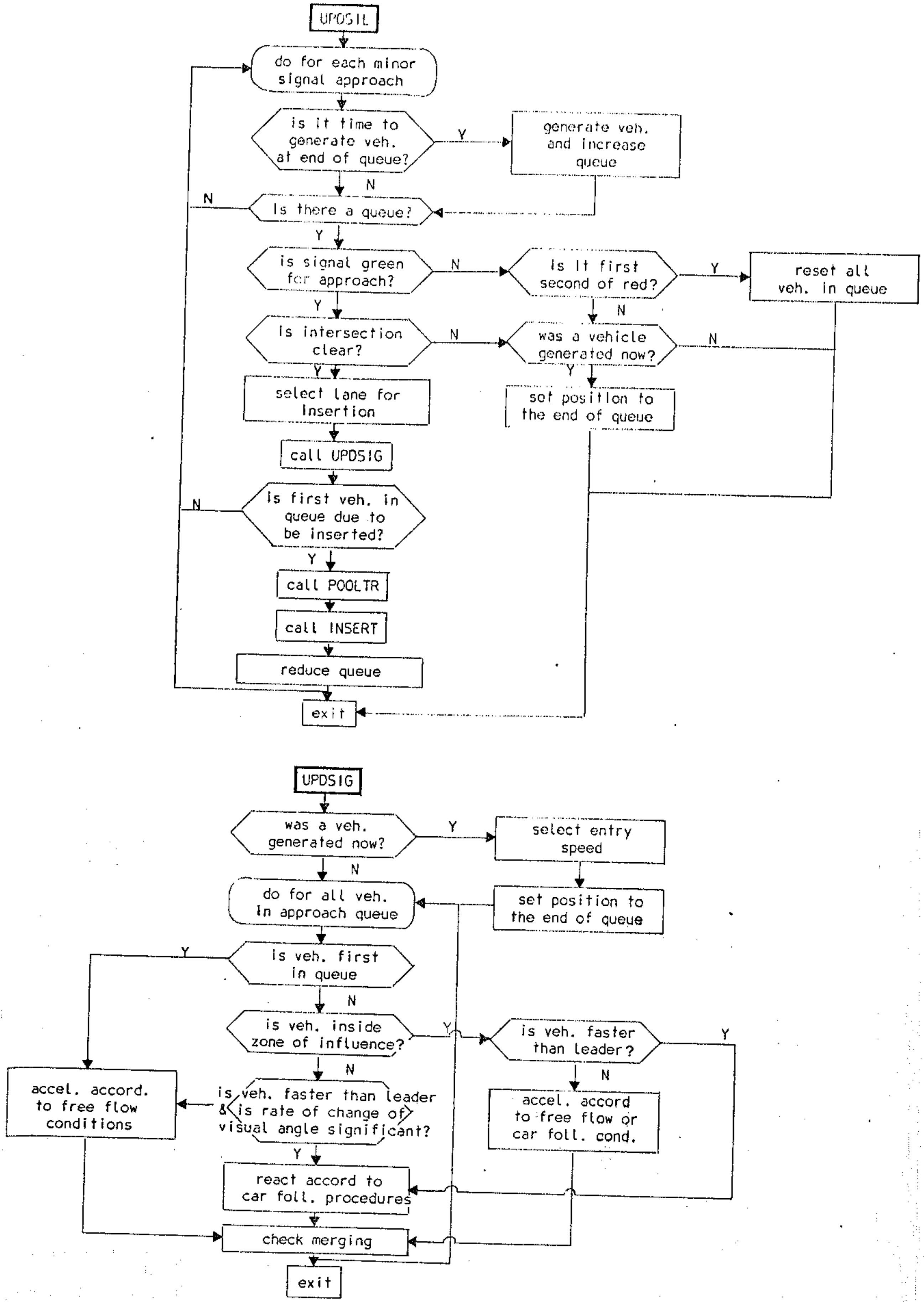


Figure 9.19 Flowchart of minor lane (signal) vehicle insertion modules

10. FUEL CONSUMPTION PROCESSOR

10.1 Introduction

The need to use available petroleum to the best possible advantage has became a major concern in recent years throughout the world. Car manufacturers have improved engine performance, reduced both overall vehicle mass and aerodynamic resistances. The progress over the last five years, in vehicle design, has led to a saving of between 10 and 30 percent in fuel consumption over the wide range of vehicles built in different countries {177}.

The evaluation of vehicular fuel consumption under real traffic and operating conditions is an essential element when developing programs to save energy. Estimates of fuel consumption have been used for the justification of new facilities or the implementation of different transportation system management strategies.

The fuel consumption of a road vehicle is determined largely by the driver, the type of vehicle he drives and the traffic conditions {178}. A complex interaction of these factors gives the overall fuel consumption of vehicles operating in urban traffic. Variations in design between vehicles produce different on-the-road performances. Vehicles operating in urban traffic undergo frequent changes in speed due to traffic flows, regulatory restrictions and traffic lights. Consequently, a detailed mathematical description of such a system is not a simple task.

10.2 Average journey speed models

It has been previously shown {179} that, for urban trips with an average speed less than 60 km/h, fuel consumption per unit distance, ϕ, could be expressed approximately as a linear function of the reciprocal of the average trip speed, $\overline{v}$. That is,

$$\phi = k_1 + \frac{k_2}{\overline{v}} \quad (\overline{v} < \sim 60 \text{ km/h})$$

The parameters k_1 and k_2 are vehicle dependent and are approximately proportional to vehicle mass, m, and idle fuel flow rate, I, respectively {180},

$$k_1 = c_1 \cdot m$$
$$k_2 = c_2 \cdot I$$

where c_1 and c_2 are constants of proportionality that can be estimated from figure 10.1.

Evans and Herman {181} stated that such a simple relationship explained over 70% of the variance in fuel consumed per unit distance. They noted that the unexplained variance was probably due to variations in such factors as roadway systems and driver behaviour. The OECD study {177} stated that 83% of the variance could be explained by the inclusion of the acceleration, a, and the journey distance, d,

$$\phi = k_1 + \frac{k_2}{\bar{v}} + k_3\bar{v}^2 + k_4 \frac{1}{d} \int_0^T a\,v\,dt$$

where T is the journey distance and k_3 and k_4 are parameters.

In the United Kingdom, Everall {182} studied the fuel consumption of several types of vehicles as a function of their average journey speed under a variety of conditions including travel in urban areas. His relationship is of the form,

$$C = 6.11 + \frac{209}{V} + 0.0004V^2$$

where C is the consumption in litres per 100 km and V is the average journey speed in km/h.

The majority of the mathematical models were developed to compute the fuel consumption of private vehicles. While estimating the effects of fuel savings to be expected from changes in bus operation strategies, Muzyka et al {183} adopted the fuel rate parameters shown in table 10.1. Balassiano {184} studied fuel consumption of Brazilian buses operating in urban areas. His relationship, which explained 78% of the variance, is given by,

$$C = 0.44 + \frac{1.38}{V} - 0.007V + 0.00008V^2 + 0.001P$$

where C is the diesel consumption in l/km, V is the average speed in km/h and P is the average number of passengers inside the bus.

10.3 Delay and stop model

Robertson et al {185} incorporated delays and stops to the quantification of fuel consumption. They expressed the total fuel consumption in an urban area as,

$$F = aL + bS + cD$$

where, in a specified period of time, F is the total fuel consumed in litres, L is the total distance travelled in vehicle-kilometres, D is the total delay in vehicle hours, and S is the total number of stop/starts. The coefficients a, b c depend upon such characteristics as traffic composition, cruising speed and road gradients. The values of these coefficients were determined from measurements of fuel consumption made on the test track at TRRL. This fuel model was inserted in TRANSYT version 8 and good agreement was obtained between the predicted and the observed fuel consumptions of survey cars in Glasgow.

10.4 Fuel consumption model

In order to evaluate the effects of different road layout designs along the study section, it was necessary to develop a model capable of predicting additional fuel consumption due to traffic interaction.

The fuel consumption model, used in this study, takes in detailed consideration the various forces that act on a vehicle that is being driven on the road. The vehicle propulsion must provide the force necessary to overcome resistance. The forces resisting the movement of a road vehicle are:

a. rolling resistance - produced by the contact of the tyres with the road surface. It is caused by such factors as deformations on the surfaces of the tyres and the road, friction at the tyre contact patches and underpressure effects at the separation of the tyre and the surface. For passenger cars travelling on paved roads it is expressed as,

$$R_r = \left[f_o + 3.24\ f_s(V/160)^{2.5}\right] W$$

where R_r is the total rolling resistance for the car in kg, f_o is the basic coefficient of resistance at zero speed, f_s is the coefficient to account for the speed effect, V is the vehicle speed in km/h and W is the weight of the car in kg {186}. Both f_o and f_s are related to the tyre inflation. For a pressure of 24 psi, the suggested coefficients, are f_o = 0.0112 and f_s = 0.0068. The expression for a transit bus has the form,

$$R_r = \left[c_o + c_1 V\right] W/1000$$

where the constants recommended by the Society of Automotive Engineers {187} assume the values, $c_o = 7.6$ and $c_1 = 0.056$.

b. air resistance - related to the frontal area of the vehicle, the length, shape and smoothness of the surface, the density of the air and the relative velocity of the vehicle. The equation that takes in consideration all these effects is,

$$R_a = 0.005\ C_a\ A\ V_r^{\ 2}$$

where R_a is the air resistance in kg, C_a is the coefficient of air resistance for a particular vehicle, A is the projected frontal area of the vehicle in m^2 and V_r represents the speed of the vehicle relative to the air in km/h {188}. The constant C_a is selected according to average values reported by Taborek {188}, i.e., 0.45 and 0.65 for cars and buses respectively.

c. gradient resistance - derived from the analysis of forces acting on a vehicle placed on a road incline. It is equal to the component of the vehicle's weight acting down the grade and is expressed as,

$$R_g = Wi/100$$

where R_g is the grade resistance in kg and i is the slope in % {186}.

d. curvature resistance - ignored in this study due to fact that it is difficult to measure it for highway vehicles since curvature resistance varies with such factors as type of vehicle, actual vehicle path and road surface {23}.

e. inertia resistance - caused by accelerating the vehicle to achieve a speed increase. It is very difficult to measure acceleration effect on fuel consumption since it is never constant and occurs for short periods only. It is normal procedure in fuel consumption models to express the force necessary to accelerate a vehicle as,

$$R_s = (W/g)a$$

where R_s is the accelerating force in kg, g is the acceleration of the gravity and a is the acceleration of the vehicle, both in m/s^2 {186}.

f. power transmission resistance - produced by the transmission system which transforms the engine speed into road speed. The total power loss, caused by several components of the transmission chain, is of the order of 7 to 13 percent and the average figure of 10 percent {186} for passenger cars with manual transmission is adopted.

The power required by the vehicle to overcome the effect of all these resistances is expressed by,

$$P_t = \left[1 + R_t/100\right]\left[R\ V/273.69 + R_s\ d/76.04\right]$$

where P_t is the power for traction in HP (metric), R is given by $R_r + R_a + R_g$, R_t represents the power transmission resistance in percentage and d is the distance travelled during one second, expressed in metres {186}.

The conventional braking procedure adopted by drivers is reported to have no influence on energy consumption {23}. Within the model it is assumed that for decelerations less than $-0.3\ m/s^2$ the engine operates at a no-load condition which results in the instantaneous idling-consumption rate {189 and 183}.

The internal combustion engines use the potential energy stored in the fuel. The total power produced can be expressed as function of the density and calorific power of the fuel being used,

$$P_p = F\ C$$

where P_p is the total power produced by the fuel in HP (metric), C is the energy consumption of the vehicle in l/h and F is a coefficient that incorporates the conversion factors and the product of the calorific power and density of each fuel {190}. The values of F are assumed equal to 12.65, 16.59, 7.45 and 10.35 for diesel, petrol, alcohol and a mixture of petrol (80%) and alcohol (20%), respectively.

By defining the efficiency, η, of the internal combustion engine as,

$$\eta = P_t/P_p$$

energy consumption is expressed by,

$$C = P_t/(\eta F)$$

De Menezes {190} determined the efficiency curves for both a passenger vehicle and a typical Brazilian bus. The results obtained by him and adopted in the fuel consumption processor are shown in figure 10.2.

Fuel consumption for stopped vehicles is computed by using idling fuel consumption rates, C_i in l/h, also based on measurements undertaken in Brazil {190 and 184}. These values as well as other fuel consumption parameters used in the model are given in table 10.2.

There is considerable room for improvement in the fuel consumption model developed for SIBULA, since a crude macroscopic relationship was adopted in order to express energy efficiency as function of speed. While interpreting an engine efficiency map, Watson {205} observed that engine efficiency is a complex function of the speed, torque and gear of the engine. The insertion of such relationships in fuel consumption models of manual transmission vehicles is only possible after the estimation of probabilities of upshifts or downshifts, at particular regions of engine torque or speed, consistent with observed driver behaviour.

In a recent study, Akçelik {203} described a simple instantaneous fuel consumption model,

$$f = \frac{dF}{dt} = k_1 + k_2 v + k_3 v^3 + \left| k_4 av + k_5 a^2 v \right|_{a>0}$$

where F is the fuel consumption in ml, t is the time and hence $f = dF/dt$ is the instantaneous fuel consumption per unit time in ml/s, v is the instantaneous speed in km/h, $a = dv/dt$ is the instantaneous acceleration rate in km/h/s, k_1 is the constant idling fuel consumption rate in ml/s, k_2 and k_3 are constants representing fuel consumption related to rolling and air resistance and k_4 and k_5 are constants related to fuel consumption due to positive acceleration.

Akçelik's model was used in order to provide the basic relationships from which more macroscopic fuel consumption models such as the elemental {204} and the PKE model {205} could be derived. The parameters k_1 to k_5 were found by separate analyses of constant-speed cruise and acceleration fuel consumption data. Although a high correlation was observed between predicted and measured fuel consumption data, the information was only available for a single 6 cylinder, 4100 cm^3 Australian test car operating under a limited range of constant acceleration rates.

The utilization of this equation would lead to a more adequate approach to the evaluation of fuel consumption at a microscopic level. However its application would only be possible after extensive fuel consumption measurements with a wide range of vehicles and test conditions. For this simulation appropriate data on typical Brazilian cars and buses would be required.

10.5 Simulation module

Fuel consumption is determinated by the program unit FUELCO. Fuel consumption is evaluated, in the present version of the program, only for major lane vehicles generated at the main generation point that exit the system through one of the major lanes. As each of these vehicles is updated (module PROUPD), its instant fuel consumption, in litres, is calculated and added to a total based on the vehicle type. FUELCO determines the average acceleration and speed values for the vehicle under consideration over the last time interval. It also evaluates the forces resisting the movement, calculates the power required to overcome the resistances, and based on the efficiency index of the engine, that varies according to the average speed, obtains an incremental fuel consumption that is added to the previous total.

The procedure is repeated once the time is incremented. At the end of the simulation run, average values are obtained for each class of vehicle under consideration. The flow chart of the module is presented in figure 10.3.

Table 10.1 Fuel rate parameters for diesel buses (adapted from ref. 183)

vehicle acceleration (m/s^2)	vehicle speed (km/h)	fuel rate (l/h)
0.91	0 - 22	16.3 - 28
0.61	22 - 40	21.6 - 34.8
0	40	12.1
-0.30	40 - 20	1.6
-2.13	20 - 0	1.6
0	0	1.6

Table 10.2 Fuel consumption parameters for simulated vehicles

	car	bus
parameter	VW 1600	Mercedes
C_a	0.45	0.65
A	2.309	6.6
W	1000	11700
F	10.35	12.65
C_i	0.72	1.59

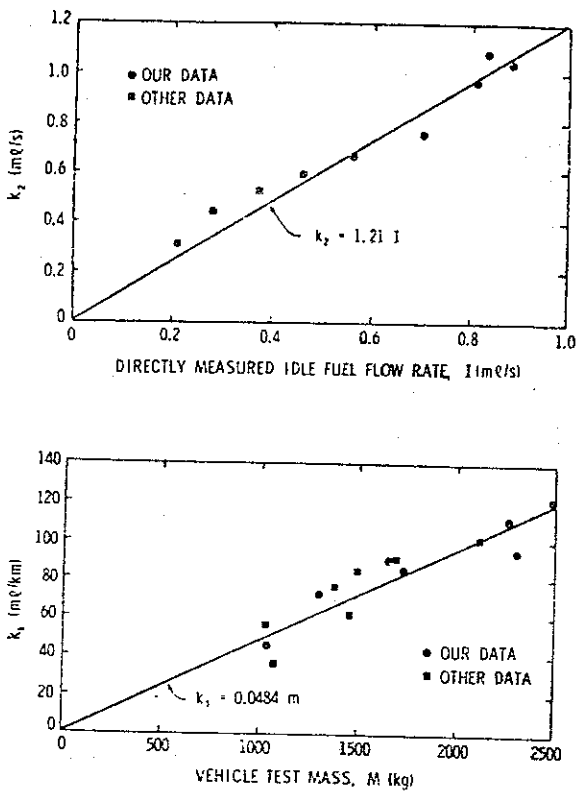


Figure 10.1 Constants of proportionality for fuel consumption models (source: ref. 180)

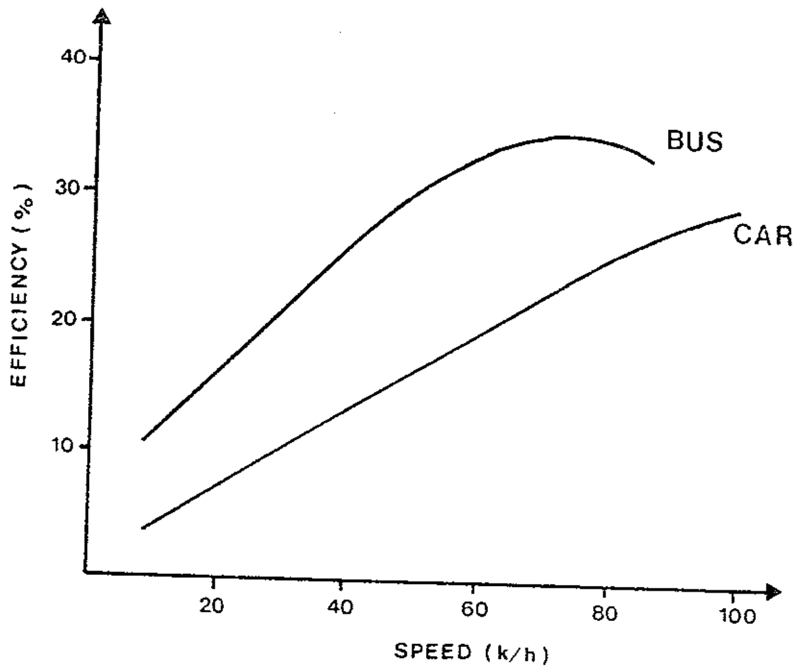


Figure 10.2 Engine efficiency curves (adapted from ref. 190)

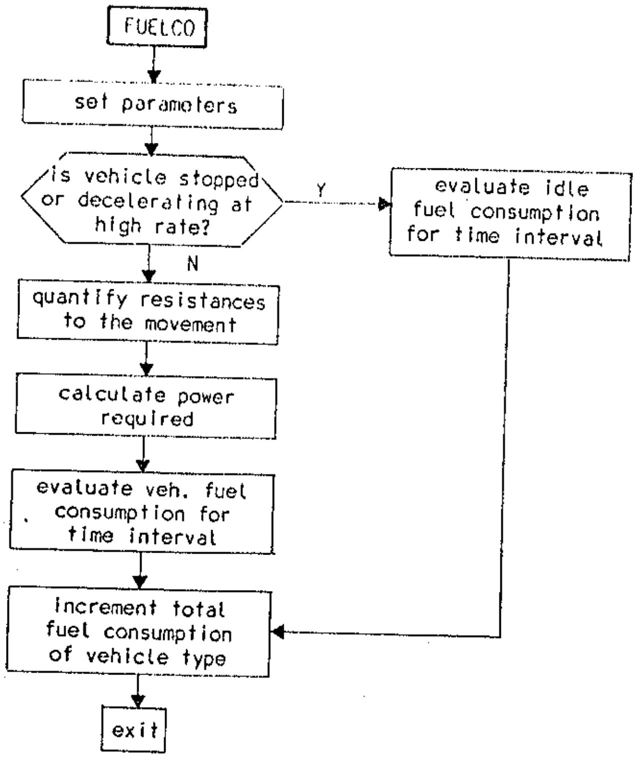


Figure 10.3 Flowchart of the fuel consumption processor

11. VALIDATION

11.1 Introduction

The main objective of this study is to develop a simulation model that enables the determination of the efficency of alternative designs of median bus lanes before field implementation. Such a model can only be considered operational when it has been subject to tests designed to analyze and verify its performance according to the rules of knowledge and logic, and to assess its results by comparing them with those from real situations.

Most of the traffic parameters input to the model have been calibrated with data collected from urban sites along arterial roads. Statistical distributions and the values of the traffic parameters were obtained from the data analysis procedure described in previous chapters. Refinements and improvements in the modelling of the process were achieved by using ploting routines and introducing writing statements to the program. These procedures allowed the possibility of tracing individual vehicles as they travelled through the system. This was of particular importance in the development of an adequate combination of car following and free flowing reaction models.

The model performance has been assessed by comparing predicted results with measured traffic data and other available and comparable information. As will be seen, the model adequately represents the traffic behaviour at urban roads. The methods which have been used for validating the model are described in the following sections of this chapter.

11.2 Discharge headways at stop lines

The capacity of a given approach of a signal-controlled intersection is given by the amount of traffic that can pass through it during the period of one hour. It depends on the green time available to the traffic and on the maximum flow of vehicles passing the stop line during the green period, i.e. the saturation flow {39}.

One of the several procedures employed in the estimation of the saturation flow is the 'average headway method' {191} . This method is based on the collection of the average discharge headway of a traffic lane. The saturation flow is obtained by the inverse of this average value.

There are indications that the delay in accelerating away at the onset of the green indication can be a critical factor in the accuracy of urban network models {192}. Furthermore, Briggs {193} recognized that no micro-simulation of traffic could be regarded as satisfactory if the discharge headway at stop lines was not correctly modelled.

While procedures for determining saturation flows vary between different countries, most of the variability in the observed capacity is attributable to the characteristics of the passenger cars {194}. Therefore, in order to obtain local field values as a mean of comparing simulated and real queue discharge conditions, observations were conducted in signal intersections of RU60 and RU61 (appendix 1).

The selection of the sites to undertake investigation on saturation flow was based on the following ideal features {195}:

a. perfectly flat
b. exit arms exactly aligned with entry arms
c. no blocking back from other intersections
d. complete parking restrictions
e. absence of pedestrian crossings and bus stops
f. restrictions on turning movements, i.e. straight ahead movements only
g. fully saturated cycles for at least thirty minutes in peak periods
h. good site characteristics such as visibility and road surface condition

The stop line was chosen as the location to record headways. For each lane of the approaches, the following information was collected, for every headway, during saturated cycles:

a. position in queue
b. type of vehicle
c. headway to previous vehicle, measured from rear axle to rear axle

The car following model was evaluated by a simulation of 35 queues, each consisting of passenger cars only. The comparison between simulated and observed headways, by position in queue, is shown in figure 11.1. The t-test applied to paired observations showed that at the 5% level of significance there is no difference between simulated and observed average values.

11.3 Travel time

The validation of travel time, i.e. the verification of the accuracy with which the model can predict the characteristics of traffic flow on a real section of road, was undertaken by comparing the outputs of the model with surveyed information from a section of RU60.

Measurements were made on a section of road operating under bus priority conditions. Figure 11.2 shows a representation of the study section. The surveys included the determination of the signal settings of the three sets of signals. Traffic flows and compositions were recorded during the afternoon peak hours in fifteen minute time intervals at position X in figure 11.2. The amount of traffic entering and exiting the system through minor lanes was estimated from previous hourly counts. The geometry of the site, including length of main lanes, position of bus stops, location of traffic signals, was extracted from 1:500 scale plans.

The northbound journey speeds of non-priority vehicles between points Y and Z of figure 11.2 were calculated from journey times collected by a number plate technique. A comparison between the results obtained during each observation period showed a small variation in traffic flows and average journey speeds. The overall result was compared with samples obtained by running the simulation model under different initial conditions. This was achieved by changing the random seeds for each of the runs. A close agreement was found between the observed and simulated average journey speeds as shown by figure 11.3.

An alternative approach was adopted to investigate the agreement between real and simulated conditions for buses running on the exclusive lane. It would be a very complex task to collect bus travel time along section XY of figure 11.2 since it would involve recording, apart from entry and exit times, the exact stop location of each bus within the bus stop area and the time each bus remained stopped while boarding and alighting events were occurring. This requirement is due to the fact that, for example, bus 2 in figure 11.2 causes an extra delay to buses 3 and 4 as they will only be able to reach their respective berths once 2 clears the bus stop. Also, a difference in input headways and relative speeds of buses 4 and 5 may or may not reflect on the total travel times of buses 6, 7 and so on.

Even if such a detailed data collection procedure were to be undertaken, it would be extremely difficult to reproduce exactly the same average observed journey time since a small variation between simulated and real reactions would have a compounded effect on subsequent vehicles, specially under high bus flow conditions. Therefore it was decided to investigate the validity of the vehicle reaction (section 9.6) assumptions applied for buses starting from bus stops. The time taken by each bus of three-bus platoons to reach pre-determined roadway positions was obtained from time-lapse analysis. This headway data was then compared with time-distance plots produced by running the simulation model for a bus platoon composed by three identical buses, where all buses had equal characteristics taken as the average parameters of the previously calibrated distributions of the model. A comparative representation of the results of this investigation is shown in figure 11.4.

11.4 Fuel consumption

It is not the objective of this section to compare, in absolute terms, the output of the fuel consumption model with predictions resulting from the application of simple average journey speed models of the type described in section 10.2. Such attempts would be impossible, in practice, due to a series of reasons:

a. average journey speed models do not explain the total variance of fuel consumed

b. these studies have been undertaken over routes designed to include a wide variety of traffic conditions

c. stop/start manoeuvres, one amongst the major factors affecting vehicle fuel consumption in urban areas, are not expressed in the equations

d. other factors, such as the size of vehicle, type of fuel, bus boarding times, and vehicle loading apart from different driving instructions, are also reported to influence the total amount of fuel being consumed.

Therefore, a comparative analysis between simulated results and previously developed expressions, as shown in figure 11.5, is only valid in terms of general trends.

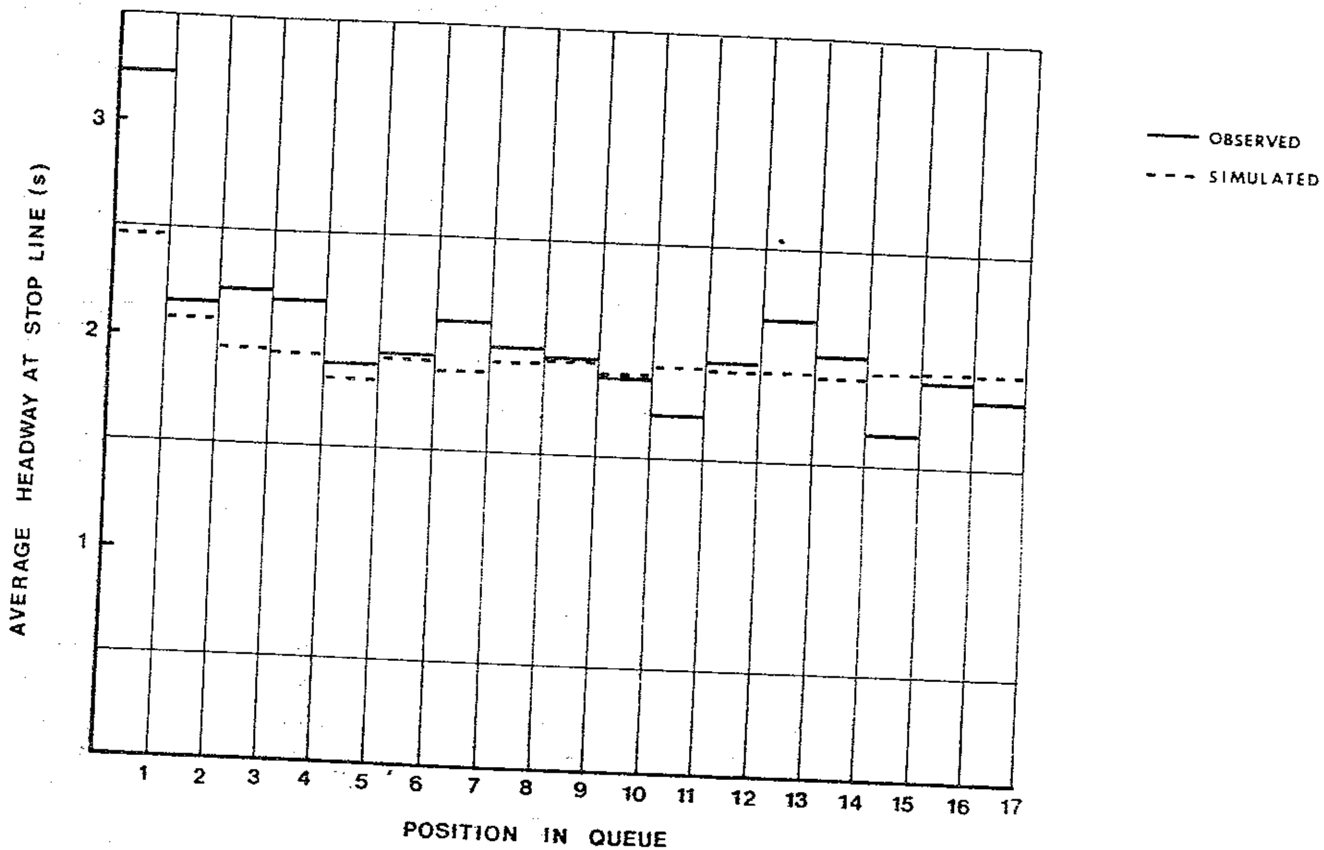


Figure 11.1 Headways of discharging queues of vehicles

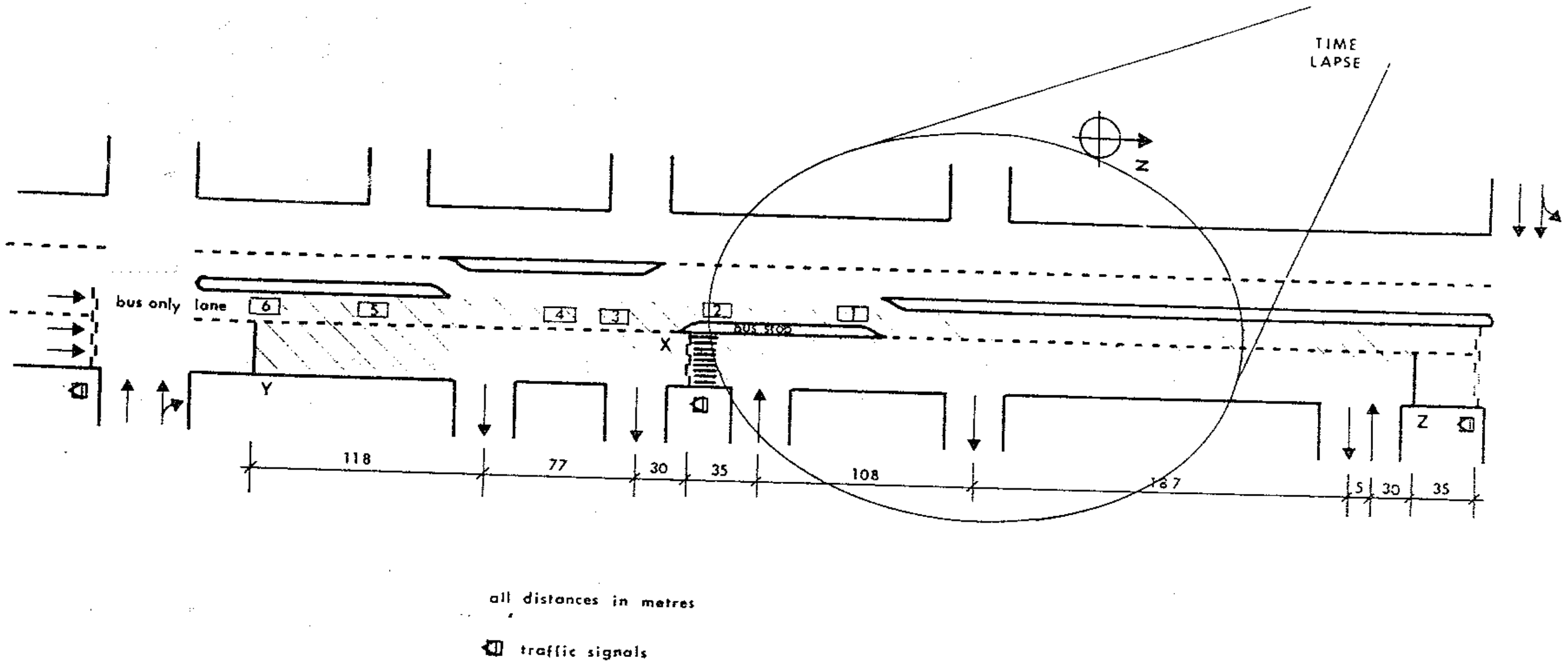


Figure 11.2 Section of RU60 used for travel time validation

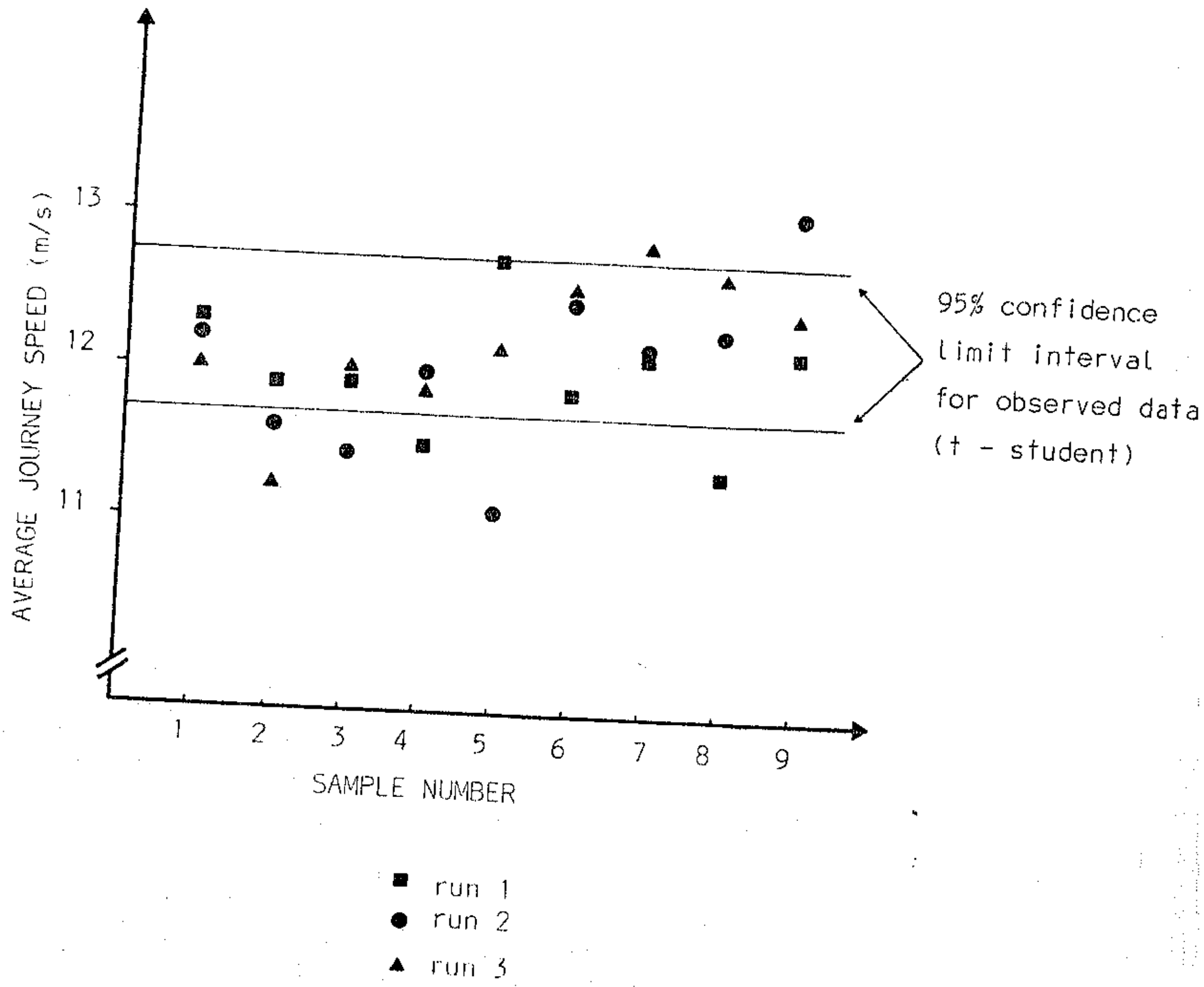


Figure 11.3 Comparison of observed and simulated average journey speeds (non-priority vehicles)

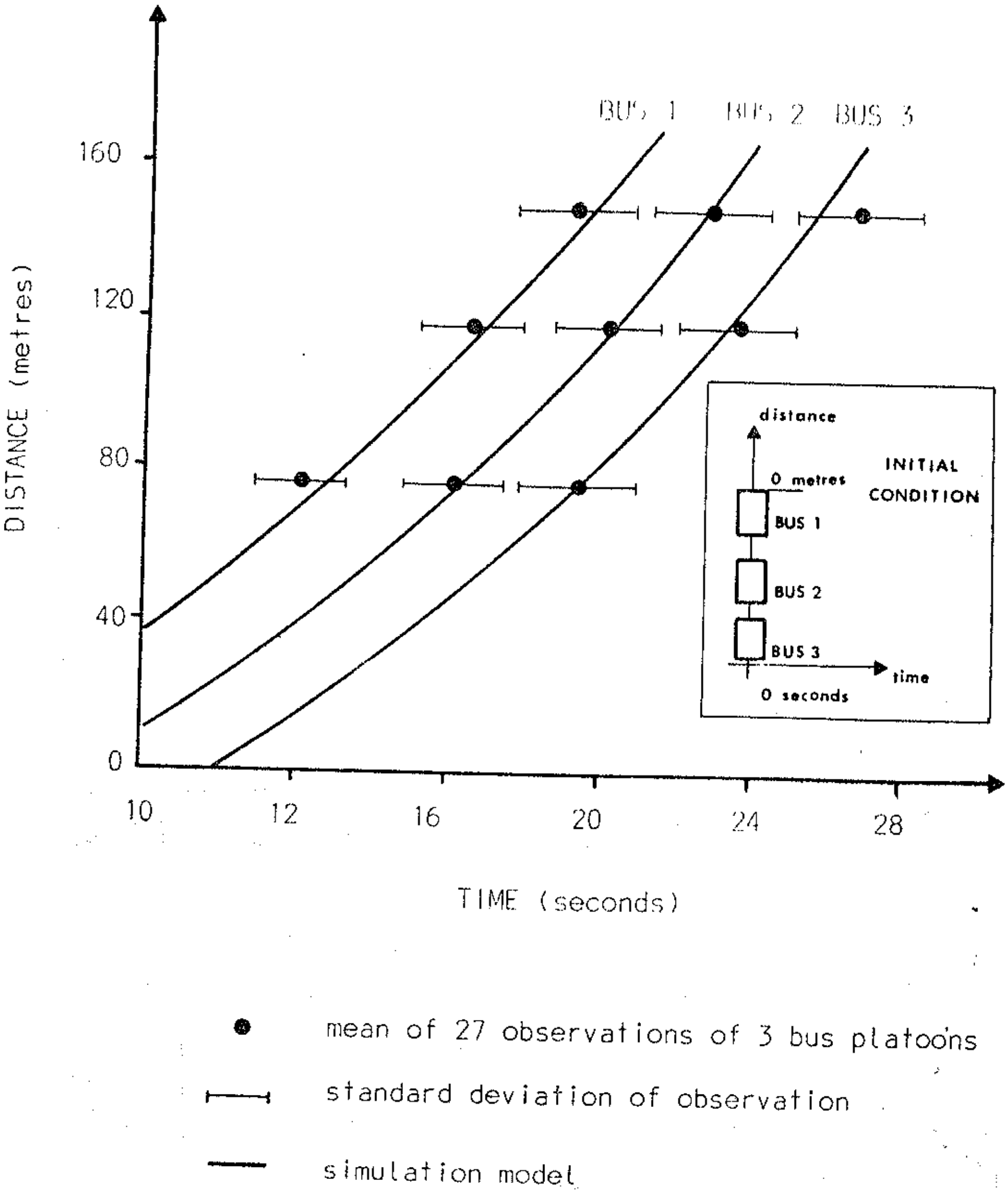


Figure 11.4 Comparison of observed and simulated data for 3 bus platoons

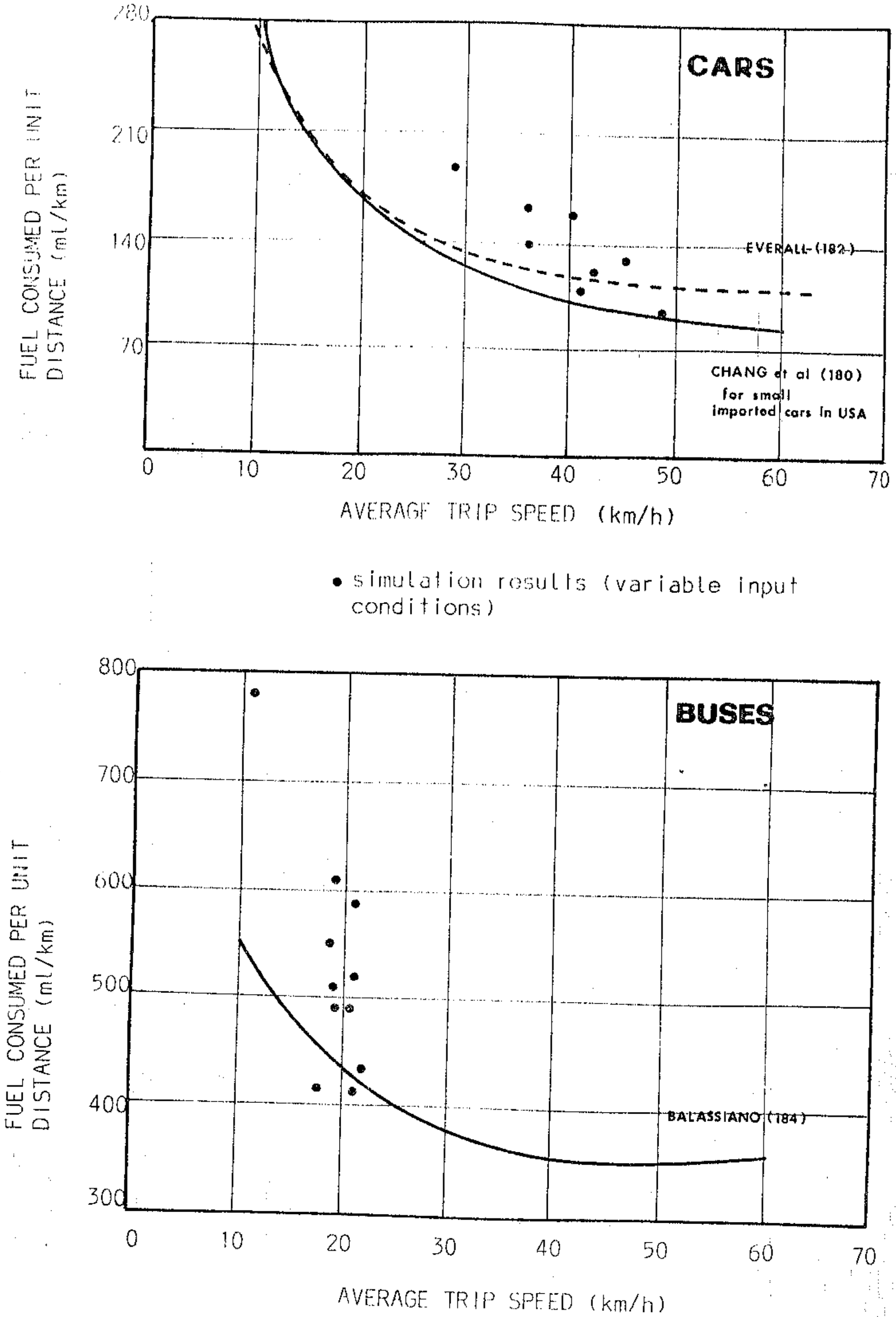


Figure 11.5 Observed and predicted fuel consumption

12. APPLICATION

12.1 Introduction

A microscopic model of traffic flow at urban arterials has been formulated, calibrated and validated. The considerable degree of flexibility included in the formulation of this 'tool' enables the investigation a wide range of geometric designs, traffic management and bus operation schemes. Particular areas of application include the evaluation of:

a. bus lane priority conditions

b. bus operation schemes by
   - i. altering the bus stop configuration
   - ii. introducing ordered and non-ordered bus platoons
   - iii. changing the location of bus stops
   - iv. reducing or increasing average bus dwell time

c. flow changes by modifying
   - i. volumes
   - ii. lane composition
   - iii. turning percentage

d. different signal control options by altering
   - i. cycle lengths and splits
   - ii. traffic signal linking

e. roadway geometry changes by
   - i. adding or deleting input and exit lanes
   - ii. altering the location of traffic signals

It was concluded from the literature review (section I) that many elements involved in the design of median bus lanes at urban areas were still to be evaluated. In an experiment to assess the full effects of potential variation, all the combinations should be taken into consideration. Such an approach in which n values are designed to every element k, a total number of n^k design points would be required. However, due to time and, computer budget constraints, as well as common sense, it was neither possible nor desirable to simulate such a number of alternatives. In this study the concentration has only been on the investigation of single and joint effects on measures of effectiveness caused by changing the elements marked in table 12.1.

12.2 Output capabilities

As the model updates all vehicle dynamic characteristics at each time increment, it is possible to produce a comprehensive listing of the microscopic vehicular behaviour during a specified time interval. Such information was particularly useful in identifying the source of errors during the development stages of the program. However, under normal running conditions, three types of outputs are produced by the present version of SIBULA: display of input data, measures of effectiveness and time-distance plots.

12.2.1 Display of input data

The standard output for the model includes a printed summary of the main geometric and flow parameters specified for the entire simulation run. The display of such data, an example of which is shown in figure 13.1, enables a quick identification of the alternative being simulated. It also permits the identification of any possible input error not detected during the running of the program. A special printout, including the initial characteristics of all simulated vehicles, can also be produced on request.

12.2.2 Measures of effectiveness

Measures of effectiveness or figures of merit are the parameters used in the evaluation of the performance of a specific traffic situation. Average travel time and average fuel consumption, for both light vehicles and buses travelling on the main lanes, were selected. They can express the effectiveness of the entire system being tested, whereas such measures as intersection delays can only indicate the effects on parts of the system {64}. Alternatively, more detailed information such as lane distribution, headways at a specified point, link density and queue lengths during red periods can also be obtained.

12.2.3 Time-distance plots

A special ploting routine using the CALCOMP plotter software {201} was developed to enable the production of time-distance plots for buses travelling under bus lane priority conditions, as shown in figure 12.2. The graphical display of trajectories enables an immediate observation of the performance of alternative bus strategies.

12.3 Time and space sampling intervals

Where a simulation run starts, the system is empty and measurements made on measures of effectiveness are not representative. This problem is most simply tackled by excluding an initial start-up period from the system evaluation (202) . A minimum equilibrium time of 10 minutes (figure 12.3) was adopted for all alternatives tested. This selction was based on simulation runs conducted under two different geometric and traffic conditions as shown in figure 12.3.

It is normal procedure, in computer simulations of traffic systems, to permit vehicles to travel an initial distance before reaching the test section. Where traffic flow is controlled by sets of traffic signals the introduction of such an initial settling down link that includes a signal controlled intersection will enable vehicles to adjust their initial input conditions to car following behaviour without affecting the figures of merit.

12.4 Cases studied

Each of the cases studied was specified by a combination of the conditions described next (refer to figure 12.4 for illustration):

a. The 'do nothing' situation in which buses and other types of vehicles share the use of the main lanes.

b. The 'priority' sutuation in which vehicles travelling along the kerb and middle lanes are physically separated from the bus traffic which is confined to the median lane.

c. Bus stops are varied by location (mid-block and near-side) and length (number of bays). The length of a bus stop refers to the number of buses allowed to load and unload passengers simultaneously. When buses operate under mixed traffic conditions, the number of loading bays in the bus stop is limited to three, as passengers have to search for their respective buses within the boarding area.

d. Bus platoons within which buses are restricted to a single exclusive lane, no overtaking manoeuvres are allowed, and therefore no alteration occurs in their initial order. The ordered platoon technique allows bus passengers to assemble at the proper bus stop bay (A, B or C in figure 12.4) prior to the arrival of the platoon. Apart from a possible reduction of boarding times, the designation of a specific bay for each bus enables more than three buses to be serviced at the same time.

e. Signalization in which signal offsets are calculated to give progression for two-directional traffic flows (section 8.5) within the context of a common cycle time.

f. The roadway geometry which represents the section of an urban artery that conforms to the existing conditions of RU60. This test section, schematically reproduced in figure 12.5, provides three lanes in one direction for the vehicles travelling along the major road.

The alternative systems selected for testing are described in the text below and displayed in figure 12.6

Alternative 1. All vehicles were simulated in mixed traffic conditions. Although buses were not allowed to use the median traffic lane, bus overtaking manoeuvres occurred via the middle lane. The bus stops were located at the middle of the blocks and signal offsets calculated in order to provide a two-directional progressive system for light vehicles. A common cycle time of 60 seconds was adopted with 50% of green time allocated to main lane traffic.

Alternative 2. Bus traffic was confined to the exclusive use of the median lane. Bus stop operation was not altered in relation to alternative 1, i.e., a total number of 3 bus bays were provided at each bus stop. As bus passengers had to cross two traffic lanes to assemble at the bus stops, mid-block pedestrian traffic signals, effective only to non-priority lane vehicles, were introduced. Signal progression was calculated as in alternative 1 but different offsets resulted from the adoption of these extra traffic signals, where green indications for vehicles were displayed for 36 seconds.

Alternative 3. Differs from alternative 1 since buses were not allowed to leave the kerb lane.

Alternative 4. Similar to alternative 2. The only alteration was in the location of the bus stops. Near-side bus stops were introduced to enable pedestrian crossings at the signal controlled intersections with the consequent removal of the mid-block traffic signals.

Alternative 5. This was derived from alternative 1, the difference being in the shifting of bus stops to 50 metres (near-side) of the major intersections.

Alternative 6. The geometric characteristics were identical to alternative 1. The common cycle time was increased to 90 seconds but a 50% green light indication was still guaranteed to the main lane traffic.

Alternative 7. The change with respect to alternative 2 was only expressed by the introduction of a common cycle time of 90 seconds since the new signal settings were proportionally increased.

In the remaining combination of cases tested, alternatives 8 to 12, the geometric configuration was kept as that in alternative 2. The bus platoon concept, i.e. introducing one ordered group of m buses during each cycle, was tested against the alternative of having buses inserted in a non-ordered (first come first service) basis. In both ordered and non-ordered cases a total of m bays was provided at each bus stop. The operational differences of these two alternatives is exemplified in figure 12.7.

Alternative 8. Non-ordered platoons were adopted.

Alternative 9. Buses were inserted in ordered platoons.

Alternative 10. Boarding time was reduced to 85% of the previous alternatives. Only ordered platoons were simulated.

Alternative 11. Buses operated in ordered platoons as in alternative 9 but signal offsets were calculated to provide a two-directional progressive system for buses.

Alternative 12. Similar to alternative 11 but in this case a fixed stop time, equal to the mean boarding time, was assigned to each bus.

The simulation of all these different cases was performed with minor alteration of the input data as alternative logic mechanisms were already incorporated into the main framework of the model. In order to reduce the bias in comparing alternatives, the length of the study section was kept constant and similar traffic conditions were input. The total number of vehicles entering the system was always calculated as a function of the specified bus flow (section 8.4) which itself varied from 60 to 420 buses per hour.

Figures 12.8 to 12.10 present results of the model runs in which the procedure adopted was to increase the bus flow until system saturation was achieved, i.e. until the traffic queues reached the main generation point (origin). Each point represents the average travel time of all vehicles leaving the system during 15 minute time intervals and a maximum of two points were obtained from each computer run. Because of restraints on computer time, it was only feasible to obtain a relatively small number of points for each alternative tested and therefore an 'eye-fitting' procedure was adopted in drawing curves. These curves represent the general form of the relationship between travel time and traffic flow and were interrupted, in the figures; at regions where the maximum output flow condition inherent to the system was achieved. The thin dashed lines and arrows in figures 12.8 to 12.10 and 12.13 only indicate travel time trends at oversaturated conditions as, under such regime, traffic behaviour may not be fully described by SIBULA (refer to Appendix 3 for discussion). Apart from discussing some limitations of the model, Appendix 3 describes further studies that were undertaken to investigate the travel time-flow relationship and the extent to which different random streams of vehicles affect the output of the model.

Although in all alternatives tested light vehicle flows have never reached capacity, it is still possible to observe relative trends. Low flow light vehicle points were not included in these curves as only small relative differences in travel times were observed at such input flow levels.

12.4.1 Effect of introducing a median bus lane

The travel time-flow points produced by alternatives 1 and 2 were similarly spread around a single fitted curve (figure 12.8). It is therefore apparent that the adoption of a bus priority measure that only allocates the median traffic lane for the exclusive use of buses does not exhibit a good potential for improving the performance of urban arterial buses.

The introduction of mid-block pedestrian signals (alternative 2) interferred with the average travel time of vehicles on the remaining non-priority lanes. It seems that only at high flow conditions the gains derived from the physical separation of buses outweight the effects caused by these extra signals.

12.4.2 Effect of restricting bus traffic to the kerb lane

The policy of banning bus overtaking in the 'do nothing' situation, as simulated in alternative 3, produced an overall increase of the order of 15 seconds in the average bus travel time when compared to the results of alternatives 1 and 2 (figure 12.8). On the other hand, the results also show that light vehicles benefited, in terms of travel time, from the adoption of such a policy. These benefits probably arose as, under alternative 3, light vehicle trajectories were generally free from the interference caused by bus lane-changing manoeuvres.

The relative (alternative 3 vs. alternative 2) reduction in average travel time, resulting from alternative 3, was most probably related to the minimization of the overall effects caused by turning vehicles. In both alternatives the non-priority traffic had the exclusive use of two main lanes. However, in alternative 3, further benefits arose to straight ahead traffic as turning vehicles were enabled to perform the deceleration stages of their exiting manoeuvres along a third lane.

12.4.3 Effect of introducing near-side bus stops

Figure 12.9 shows that the introduction of near-side bus stops, located just before the traffic signals (alternative 4), produced disastrous results in terms of both capacity and bus travel time along the exclusive median lane. These results are related to the inexistance of a bus storage length between the bus stop and the next traffic signal. Oncoming buses were delayed as clearance of loading positions could only occur during green periods.

The results obtained from alternative 5 in which bus stops were located 50 metres before outbound intersections in a 'do nothing' situation are also shown in figure 12.9. It was assumed that the adoption of such a configuration would reduce the turning conflicts that would otherwise arise if bus stops were positioned nearer to the intersections. The curves superimposed on the results of alternative 5 are the same ones fitted in figure 12.8.

The observed points lie close to those superimposed curves. Therefore, it is reasonable to conclude that no significant alteration occurred, in terms of average travel times and overall capacity, between alternatives 5 and 1 & 2.

The geometric configuration of alternative 2 differs from alternative 4 as no mid-block pedestrian signals were introduced in the latter. In the bottom graph of figure 12.9 the curve superimposed on the results of alternative 5 was obtained from alternative 1. Therefore, the displacement between this curve and the one fitted to the results of alternative 4 reveals the single effect, on the average travel time of light vehicles, of confining all bus traffic to the median lane.

12.4.4 Effect of increasing the cycle time

The results obtained by simulating alternatives 6 and 7, in which cycle times were increased to 90 seconds are shown in figure 12.10. A comparison between these results and the superimposed curves of figure 12.8 (cycle times of 60 seconds) demonstrates that shorter cycle times decreased the overall average bus travel time by about 35 seconds for flows well below system capacity.

The changes observed were as expected since it has been previously suggested {10} that long cycle times at successive intersections may produce variable journey times causing buses to bunch so that services become irregular. These results also reinforced what has been previously concluded from section 12.4.1, i.e. that no apparent advantage for buses seemed to result from the single introduction of an exclusive median bus lane.

The trends observed for the light vehicles were also similar to the ones observed while simulating alternatives 1 and 2. Above a certain flow input, the average travel speeds produced by the 'priority' situation (alternative 7) were higher than the ones attained under the 'do nothing' configuration (alternative 6). In general, the results indicated that the average travel time of light vehicles also increases with cycle time.

12.4.5 Effect of introducing buses in platoons

Buses were introduced in the system in ordered platoons of different sizes (alternative 9), and travel times were compared to situations in which non-ordered platoons were simulated (alternative 8). A computer program was written to evaluate the average relative delays involved in forming ordered platoons of different sizes. The following assumptions were used in the formulation of the model:

a. bus arrival times were sampled from negative exponential functions.

b. an identical rate of arrival was adopted for each different bus (A,B,C,...) of the platoon.

c. only delays arising from the ordering process were taken in consideration. All buses in a platoon were delayed until the arrival of the last bus to complete the platoon or, if the last bus arrived during a red period, until the onset of the following green period. However, when a bus arrived during a red period, the remaining red time was decreased from the delay evaluation. This procedure is exemplified in figure 12.11.

d. implicit to the previous condition is the assumption that during the non-ordered alternative all buses arriving during a red signal indication would be inserted into the system immediately after the onset of the following green period.

e. a maximum total of one ordered platoon was allowed to be released during each green period.

f. if the arrival of the last bus to form a platoon occurred during a green indication where no previous platoon was due to be inserted, checks were made to ensure that the whole platoon could be released during the remaining green period.

The delays in forming ordered platoons of different sizes vary with traffic flow as illustrated in figure 12.12 for a typical case, i.e. cycle time of 60 seconds and effective green time of 30 seconds. Each point represents the average of results obtained from a total of 10 simulation runs with different random seeds.

Figure 12.13 demonstrates that the adoption of ordered platoons (alternative 9) enabled the achievement of much higher system capacities than under the non-ordered situation (alternative 8). These results showed the influence of bus stop operational configurations in the overall travel time. It should also be noted that the application of alternative 8 to non-ordered platoons of 3 buses (left upper curve in figure 12.13) caused a considerable reduction in capacity in relation to the results obtained from alternatives 1 & 2 (upper graph in figure 12.8). This change in system capacity is solely due to the alteration in the boarding operation at the bus stops. In alternative 8 each bus was assigned to one of the available loading bays while in one specif the previous alternatives the same bus would be serviced at any vacant bay.

In deciding the flow levels at which buses would benefit from being inserted in ordered platoons, it is important to consider the following:-

a. a priority scheme may consist of several sections as the one simulated in this study.
b. the initial delays related to the ordering process should be divided by this number of sections.
c. very high bus flows can only be achieved when a bus ordering process is adopted.
d. increases in system capacity are directly related to increases in the size of the ordered platoons. This was consistently observed until platoons of 7 buses were adopted. Further increments in the platoon size were limited by capacity constraints

as the specified system was unable to cope with longer platoons at input frequencies of the order of 1 platoon per cycle time.

12.4.6 Effect of reducing boarding time

Once buses are assigned to specific bays at the bus stops it is reasonable to expect a reduction in average loading times mainly due to a decrease in dead times as passengers may assemble at their respective bays prior to the arrival of the buses. In alternative 10 the effects of reducing bus boarding times by 85% in relation to alternative 9 were investigated for a range of bus platoon sizes. The result in table 12.2 show that such a reduction causes significant increases in mean bus speeds and that these percentual changes tend to increase with platoon size.

12.4.7 Effect of introducing signal progression for buses

A signal progression system calculated to give priority to buses travelling along the median lane (alternative 11) caused increases in average travel times for other vehicles. In figure 12.14, the travel time-flow results are compared to the superimposed curve obtained from alternative 2. The increment in average journey times was of the order of 12 seconds for the observed range of flows.

An examination of the results obtained for buses (table 12.2) shows that alternative 11 produced no benefits in terms of average speeds, when compared to alternative 9. This is probably due to the fact that the variability in individual bus dwell times masked any effect produced by the bus progression system. Therefore, in alternative 12, all dwell times were fixed to a mean value based on the average number of boarding passengers (section 9.8). The bus signal timing plan then succeeded in reducing average bus speed. The percentual increase in average speeds obtained by comparing alternatives 12 and 11 is statistically significant for all input flow conditions tested. Furthermore, this evidence suggests that the joint adoption of a bus signal progression and a reduction in the variability of dwell times is capable of significantly enhancing the performance of high-flow arterial bus lanes.

12.4.8 Effect of the different alternatives on fuel consumption

The percentual variation of fuel consumption in relation to alternative 1, in which a 'do-nothing' configuration was adopted, is represented in figure 12.15 for both buses and light vehicles at different input flows. The changes in fuel consumption should be accounted for in alterations in average journey speeds as well as to variations in the number of stops and speed change cycles resulting from the different cases studied. It can be observed in figure 12.15 that the effects of the different alternatives on fuel consumption vary with the input flow of vehicles.

When analysing the relative fuel consumption results for buses it is possible to note that:

a. the reduction in the number of stops arising from the adoption of near side bus stops (alternatives 4 & 5) at low flow conditions has led to substantial decreases in fuel consumption. However, as flow built up, the extra fuel consumed by queuing buses waiting for the clearance of the bus stops overcame the aforementioned benefits causing a steep rise in the volume of fuel consumed.

b. longer cycle times always resulted in positive percentual variations in fuel consumption. These increments were found to be more pronounced during the 'priority' situation (alternative 7) than under the 'do-nothing' configuration (alternative 6).

c. operational measures in which buses were introduced in ordered platoons (alternatives 9 - 12) consistently reduced the total fuel consumed. This is not surprising giving the significant increases in average speeds achieved under such configurations (figure 12.13).

With regard to straight ahead moving light vehicles:

a. the adoption of a signal progression system that favoured the movement of buses produced the worst relative fuel consumption results. However, these effects tended to be minimized at high input flow conditions. A possible explanation is that the efficiency of progressive systems is likely to decrease with increases in input flows (section 8.5).

b. the effects arising from the removal of a traffic lane from the general traffic and the insertion of extra pedestrian signals (alternative 2) were similar to the previously discussed travel time results. The disbenefits of such a geometric configuration only disappeared at high flow conditions where fuel consumption reached the level of alternative 1.

c. cycle length effects were found to be less pronounced at high input flows. However, increases in fuel consumption were consistently produced within the flow range tested.

d. the only situation in which general traffic achieved lower fuel consumption levels than in alternative 1 occurred when buses travelling on the kerb lane were not allowed to perform lane changing manoeuvres. These results were expected since this configuration was also the one that produced the lowest average travel time for light vehicles leaving the study section (figure 12.8). Relative advantages would probably also have arisen from alternative 4 had the geometric configuration allowed the insertion of flows of the order of 300 buses per hour.

Table 12.1 Elements investigated

element	'DO NOTH.'	EXCLUSIVE BUS LANE
BUS STOP POSITION	✓	✓
CYCLE TIME LENGTH	✓	✓
SIGNAL PROGRESSION		✓
SIZE OF BUS PLATOON		✓
ORDERED PLATOONS		✓
BUS DWELL TIME		✓

Table 12.2 Results of alternatives 9 - 12

average bus speed (m/s), and standard deviation (m/s), for an input frequency of 1 platoon per cycle time

size of ordered bus platoon: alternative	3	4	5	6	7
9	5.70, 0.48	5.65, 0.48	5.21, 0.56	4.66, 0.37	4.04, 0.36
10	5.88, 0.24	5.76, 0.41	5.55, 0.48	5.16, 0.49	4.61, 0.32
11	5.72, 0.45	5.68, 0.44	5.20, 0.55	4.73, 0.39	3.97, 0.34
12	5.86, 0.19	5.87, 0.24	5.70, 0.33	5.63, 0.36	4.78, 0.37
range of sample sizes	140-141	184-187	233-236	278-280	318-325

percentual change in bus speeds of alternative X in relation to alternative Y

size of ordered bus platoon:		3	4	5	6	7
X	Y					
10	9	+3.2*	+1.9*	+6.5*	+10.7*	+14.1*
11	9	+0.4	+0.5	-0.2	+1.5*	-1.7*
12	11	+2.4*	+3.3*	+9.6*	+19.0*	+20.4*

*the change is statistically significant at the 5% level

PRIORITY SITUATION
SIZE OF BUS PLATOONS AT BUS STOP= 6
ORDERED BUS PLATOONS USED
HEADWAYS TAKEN FROM PLATOONS IN LANES WHERE CSI.=1
1 1 1 0 0 0 0

GEOMETRIC CHARACTERISTICS

POSITION OF INTERSECTIONS (M)

0 >	~	~	~	~	@	@	@	@	@
0 >	*	*							
0 >	205.	805.	600.	900.	300.	700.	806.	1150.	1255.

~ - MINOR INBOUND LANES
@ - MINOR OUTBOUND LANES
* - INSERT DURING RIGHT SIGNAL PHASE

POSITION OF TRAFFIC SIGNALS
200. 420. 800. 1020. 0. 1250.

SIGNAL INT FOR MINOR INBOUND TRAF
1 3

TRAFFIC SIG NOT EFFECTIVE FOR BUSES
2 4

POSITION OF BUS STOPS (M)

486.75	474.50	462.25	450.00	437.75
425.50	1086.75	1074.50	1062.25	1050.00
1037.75	1025.50	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00

FLOW CHARACTERISTICS

OFFSETS CALCULATED BY BANDWIDTH FOR CARS
15.0 10.0 45.0 10.0 0.0 15.0

NO.SIGNAL= 1	CYCLE= 60.	GREEN= 26.	AMBER= 4.	RED= 30.
NO.SIGNAL= 2	CYCLE= 60.	GREEN= 36.	AMBER= 4.	RED= 20.
NO.SIGNAL= 3	CYCLE= 60.	GREEN= 26.	AMBER= 4.	RED= 30.
NO.SIGNAL= 4	CYCLE= 60.	GREEN= 36.	AMBER= 4.	RED= 20.
NO.SIGNAL= 6	CYCLE= 60.	GREEN= 26.	AMBER= 4.	RED= 30.

INPUT FLOW OF BUSES= 360

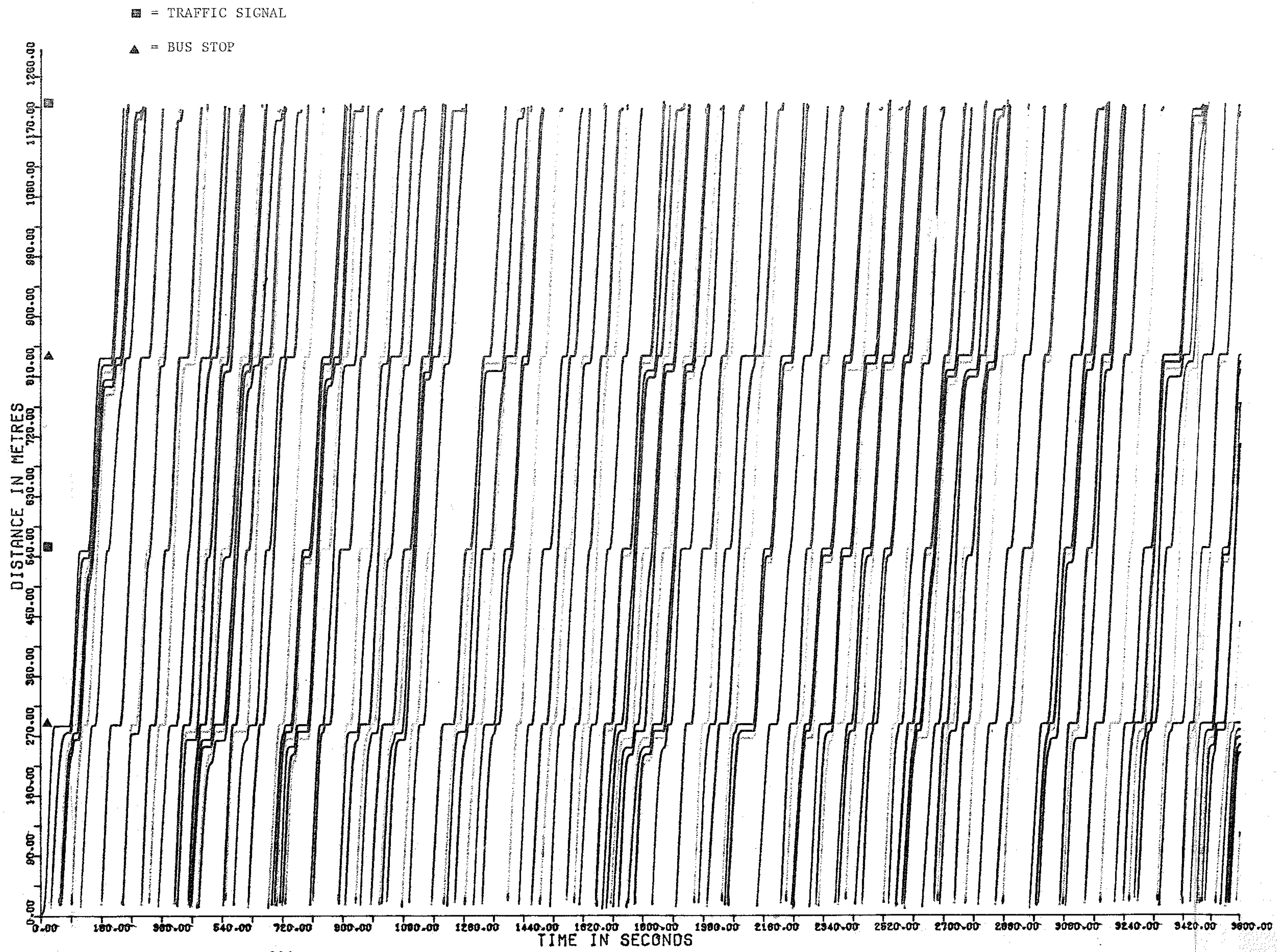
CUM. FLOWS AT INPUT LANES IN VEH/H
704 1352 1712 1917 2122 2207 2292

COMPOSITION OF INPUT LANES IN %

TYPE1	0.65	0.74	0.00	0.83	0.83	0.83	0.83
TYPE2	0.32	0.23	0.00	0.12	0.12	0.12	0.12
TYPE3	0.00	0.00	1.00	0.00	0.00	0.00	0.00
TYPE4	0.02	0.03	0.00	0.05	0.05	0.05	0.05

Figure 12.1 Display of input data (an example)

Figure 12.2 Bus trajectories (an example)



1965(4)

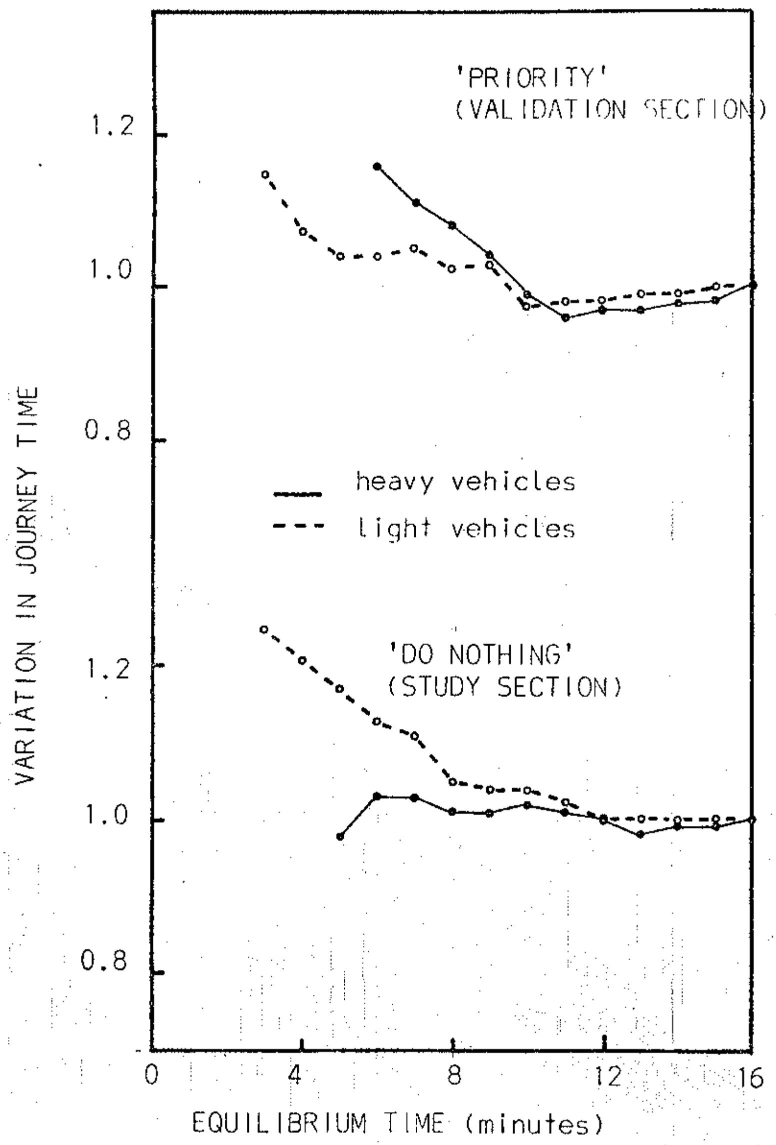


Figure 12.3 Sensitivity to equilibrium time at undersaturated conditions

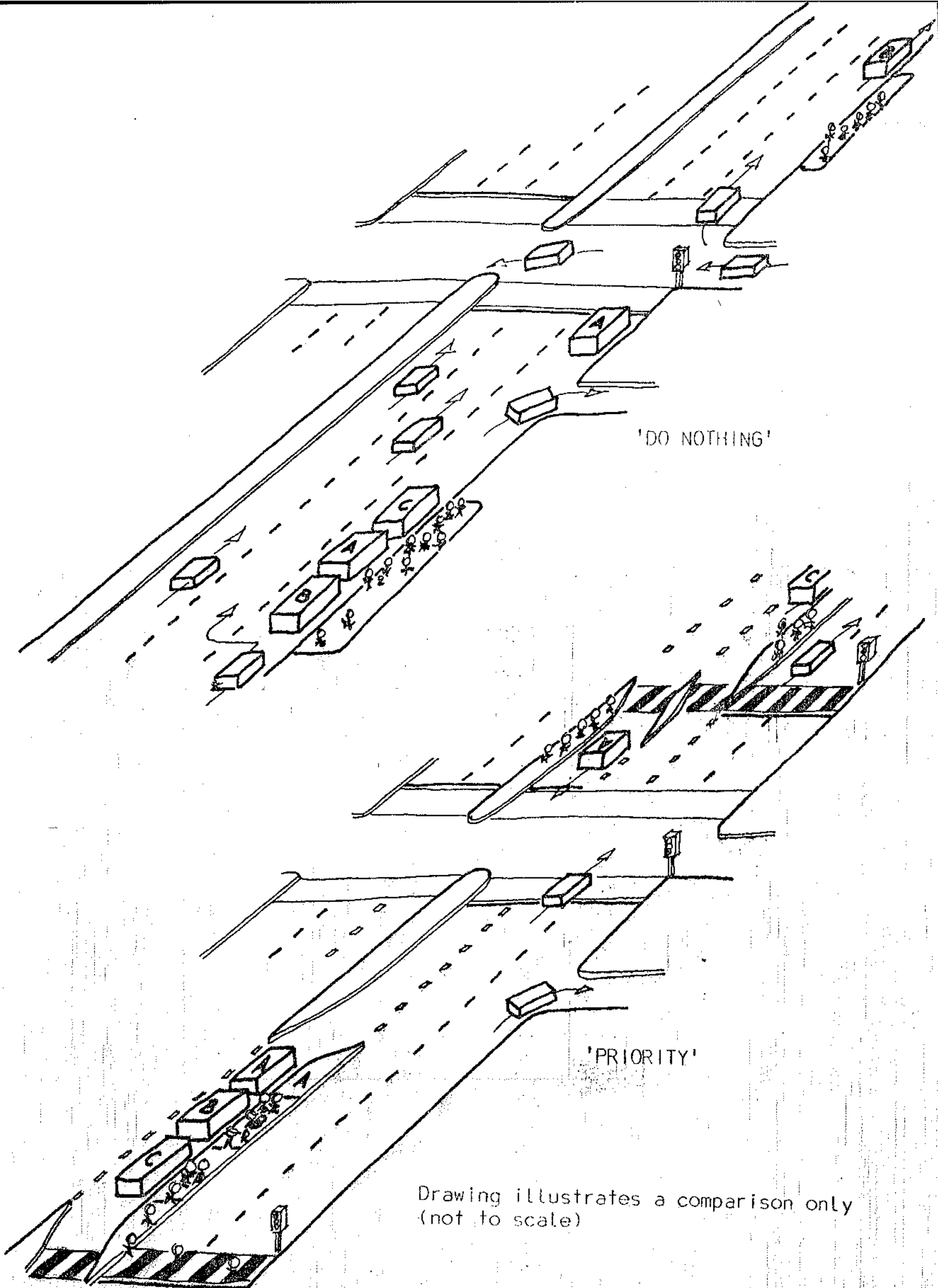
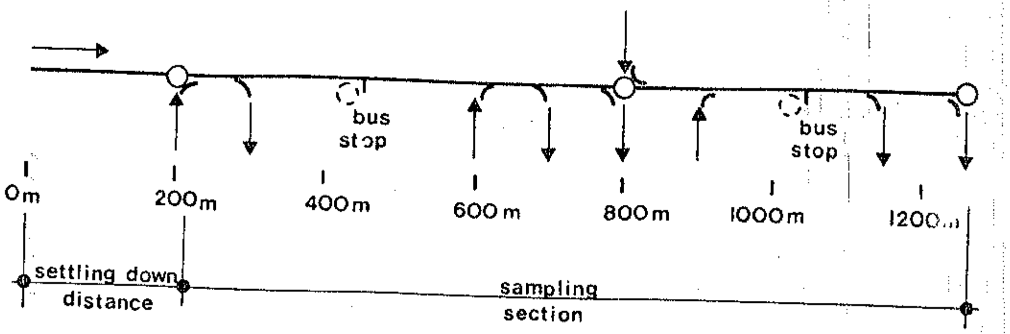


Figure 12.4 Traffic operation under non-priority and priority conditions



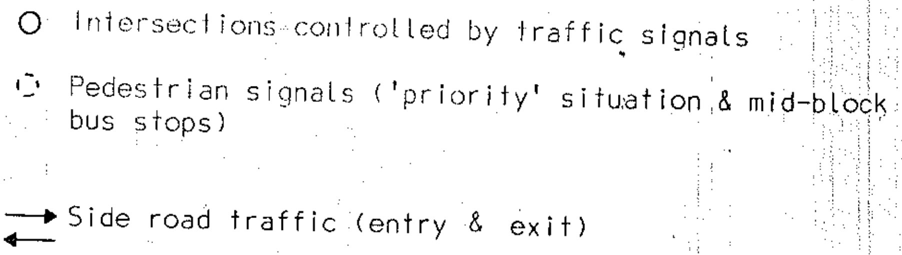


Figure 12.5 Geometry of the simulated study section

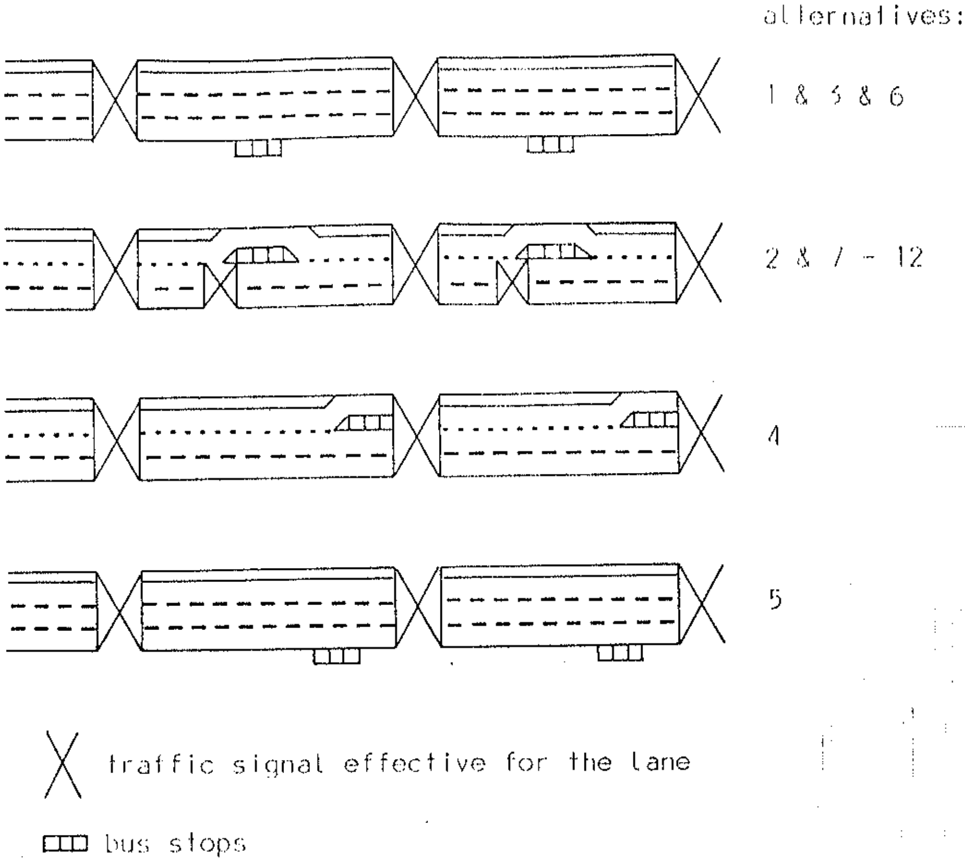


Figure 12.6 Geometric display of the cases studied

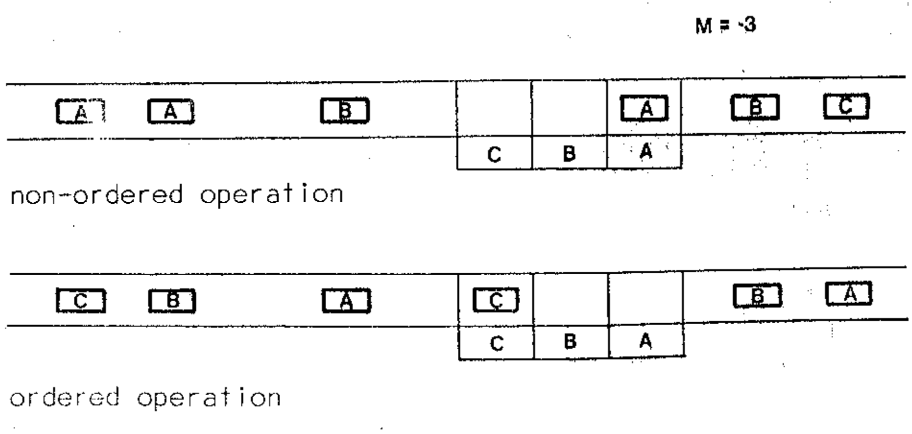


Figure 12.7 Differences in platoon operation

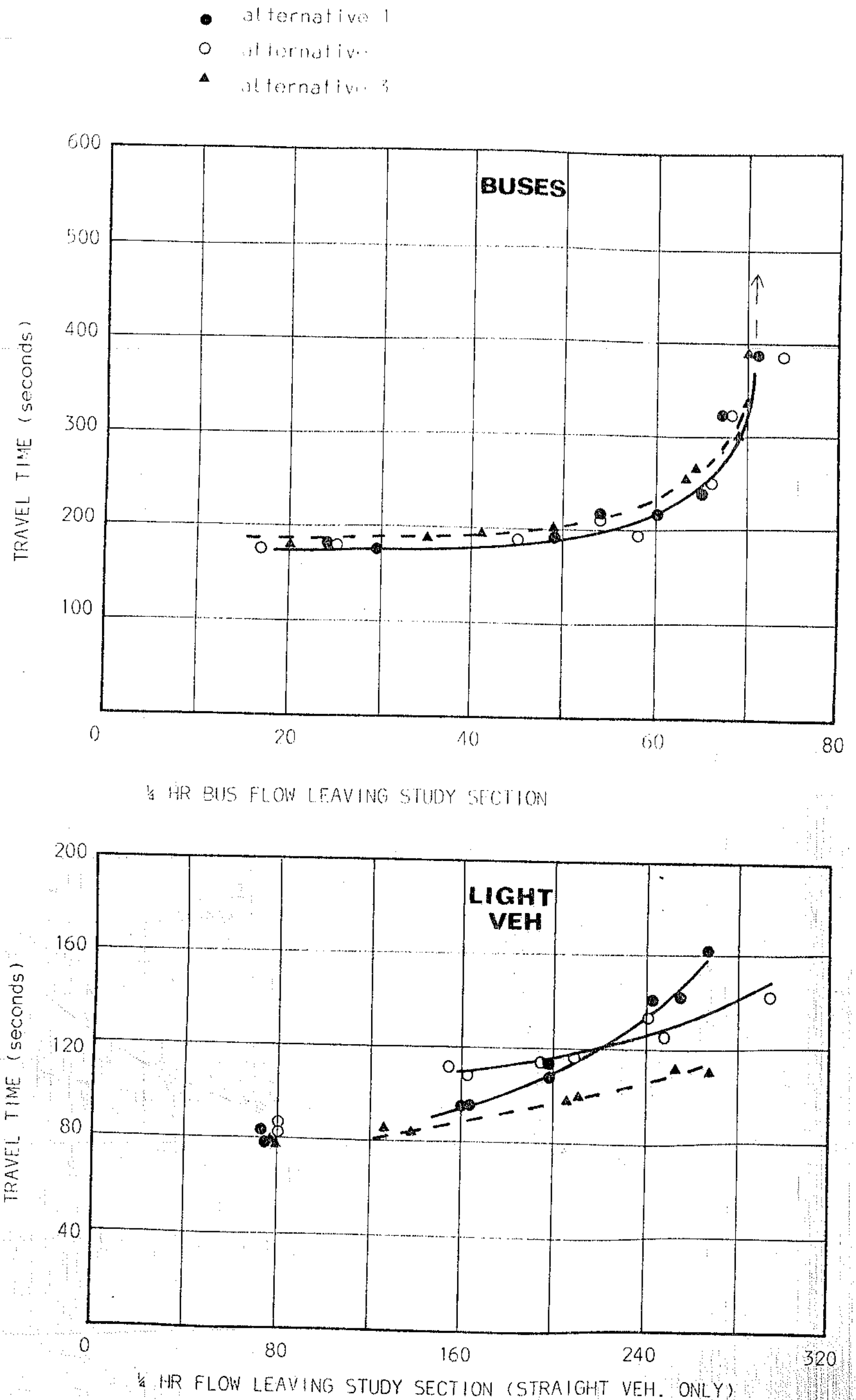


Figure 12.8 Results of a natives 1, 2 & 3

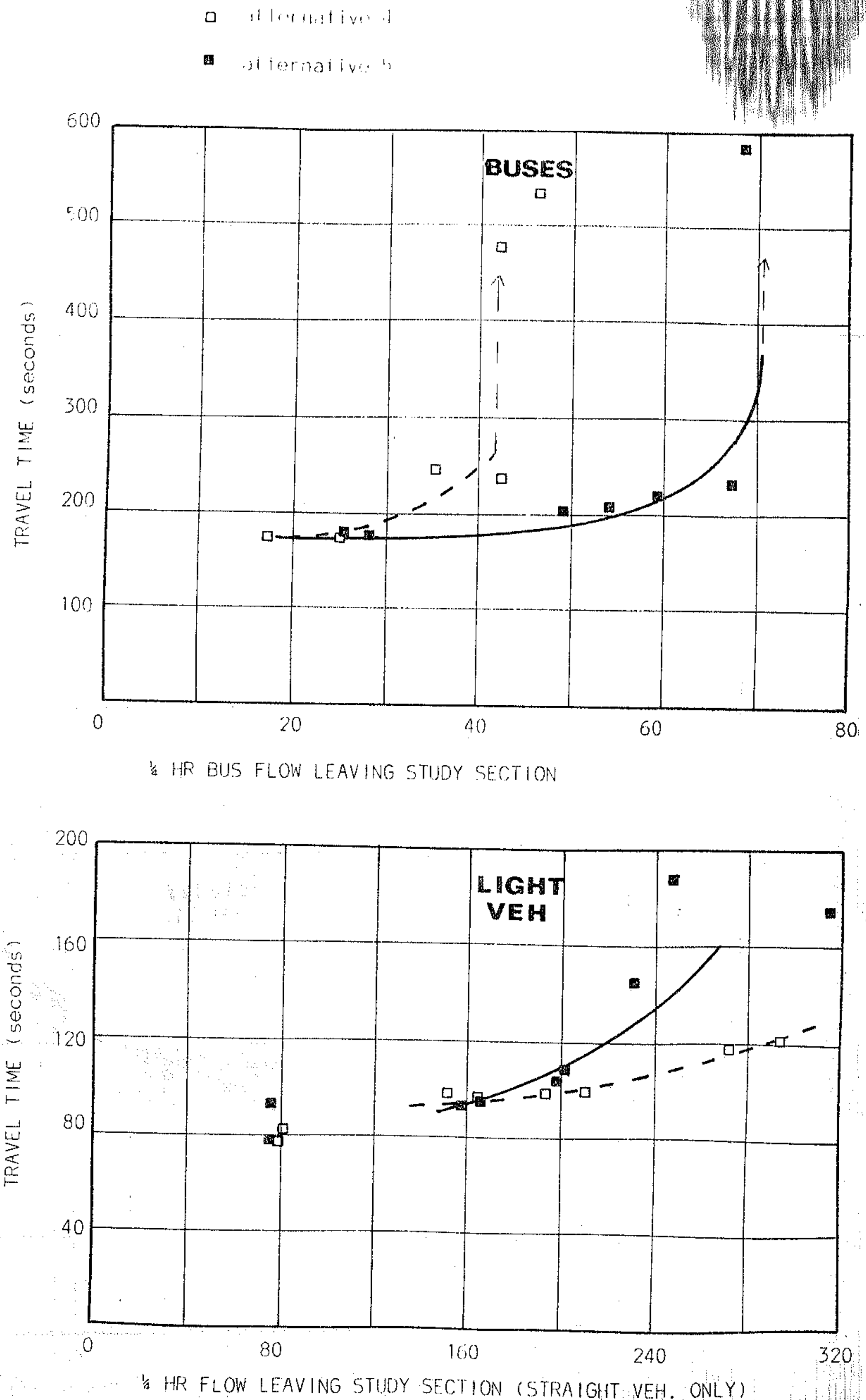


Figure 12.9 Results of alternatives 4 and 5

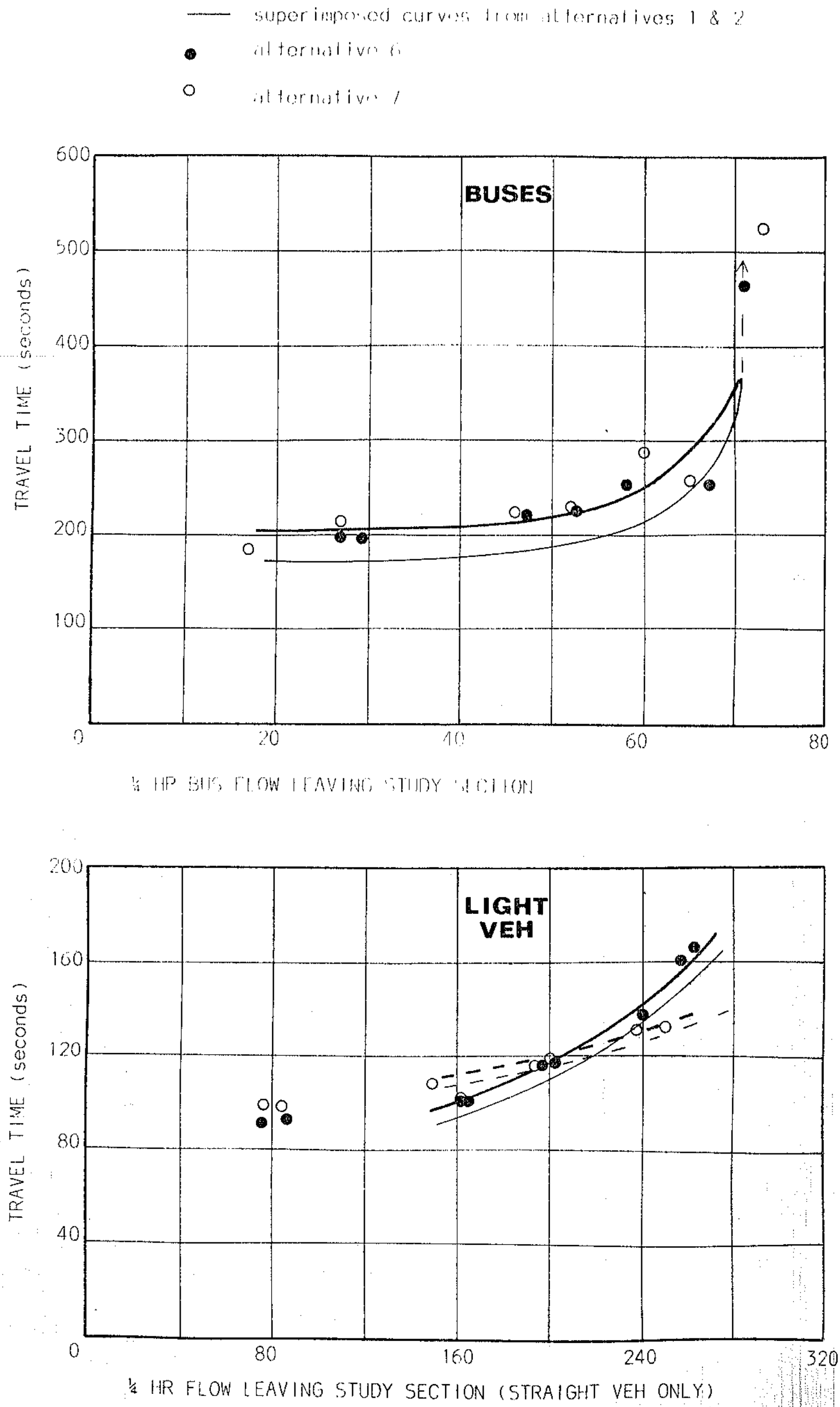
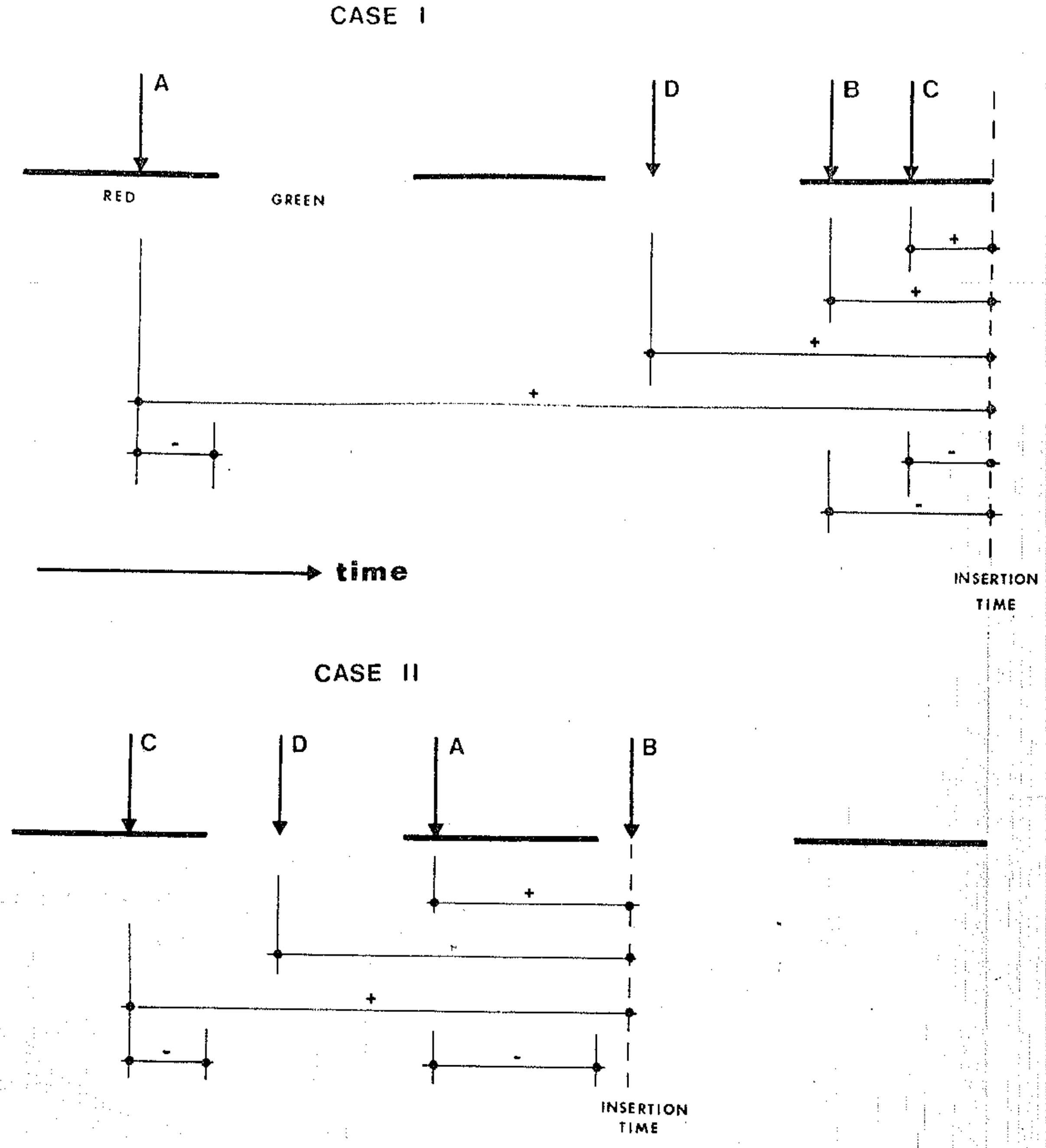


Figure 12.10 Results of a. ernatives 6 and 7



PLATOON OF 4 BUSES

Where the arrows represent bus arrivals

+ indicates a positive increment in the overall delay

- indicates a negative increment in the overall delay

Figure 12.11 Delays arising from the platoon ordering process

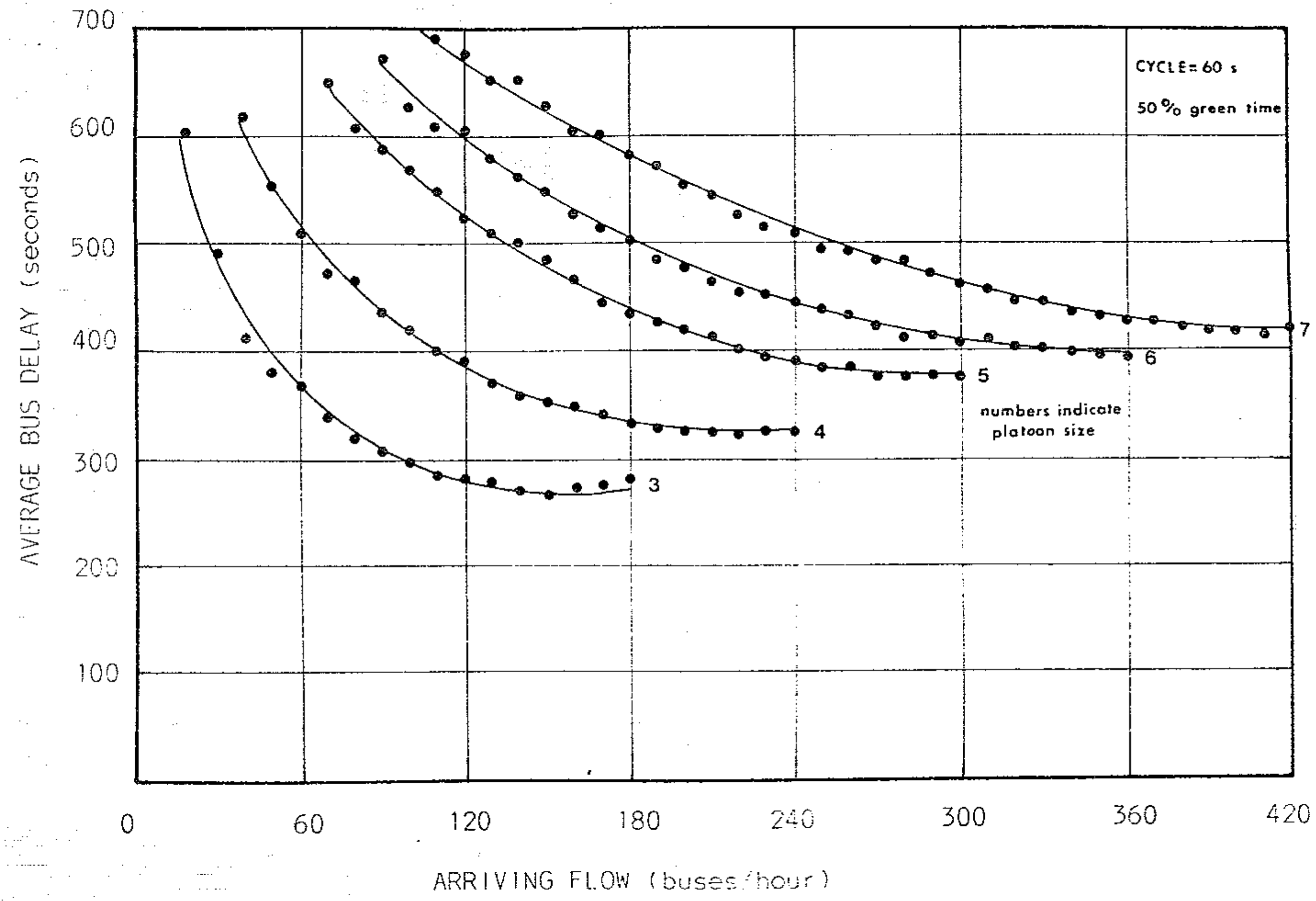


Figure 12.12 Delays in forming ordered platoons

where the numbers indicate the platoon size
O represents ordered platoons

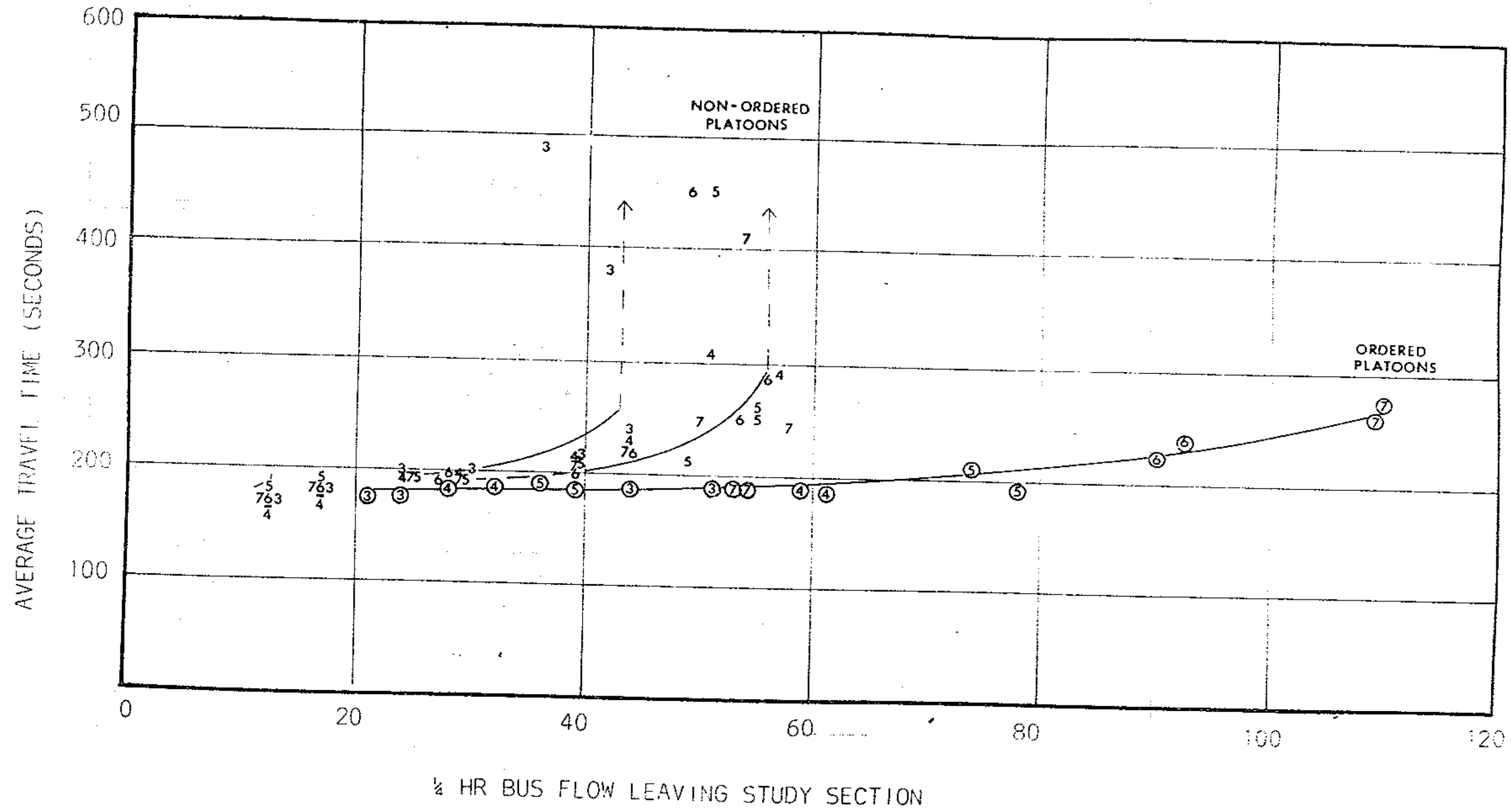


Figure 12.13 Bus travel times under ordered and non-ordered platoon configurations

— superimposed curve from alternative 2

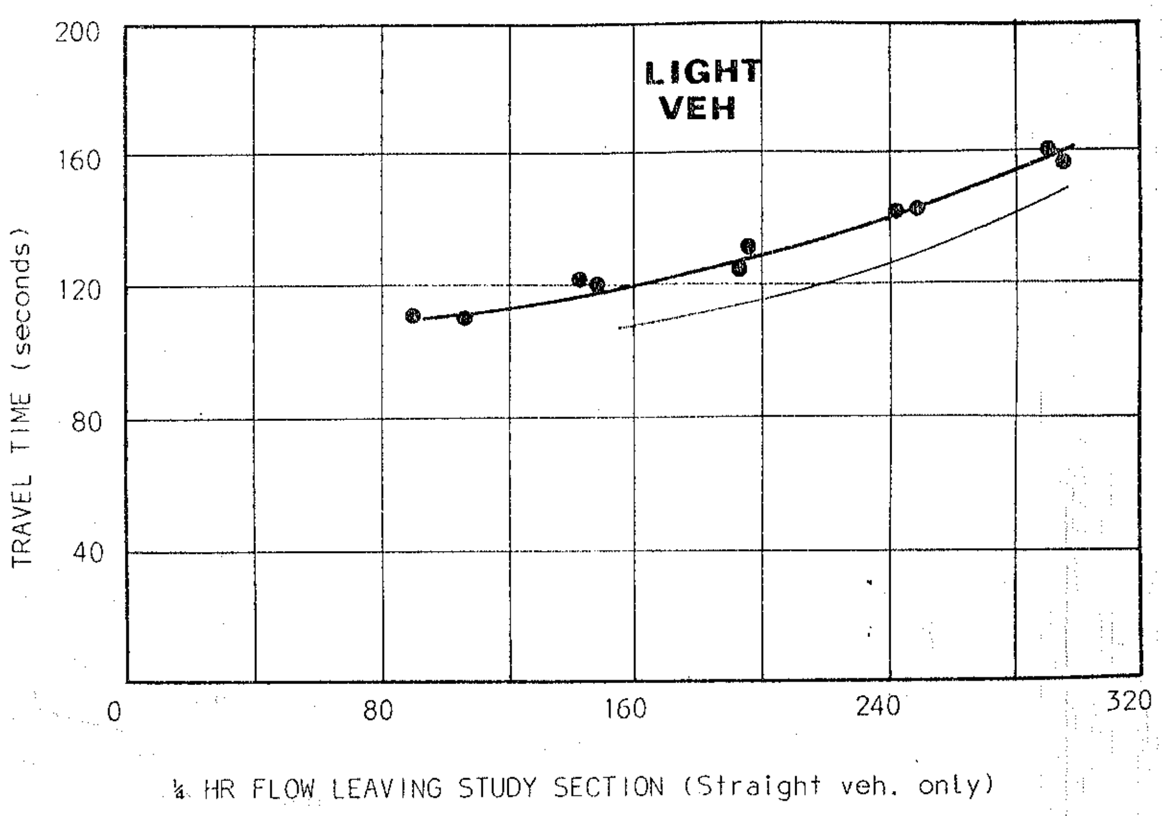


Figure 12.14 Light vehicle results of alternative 11

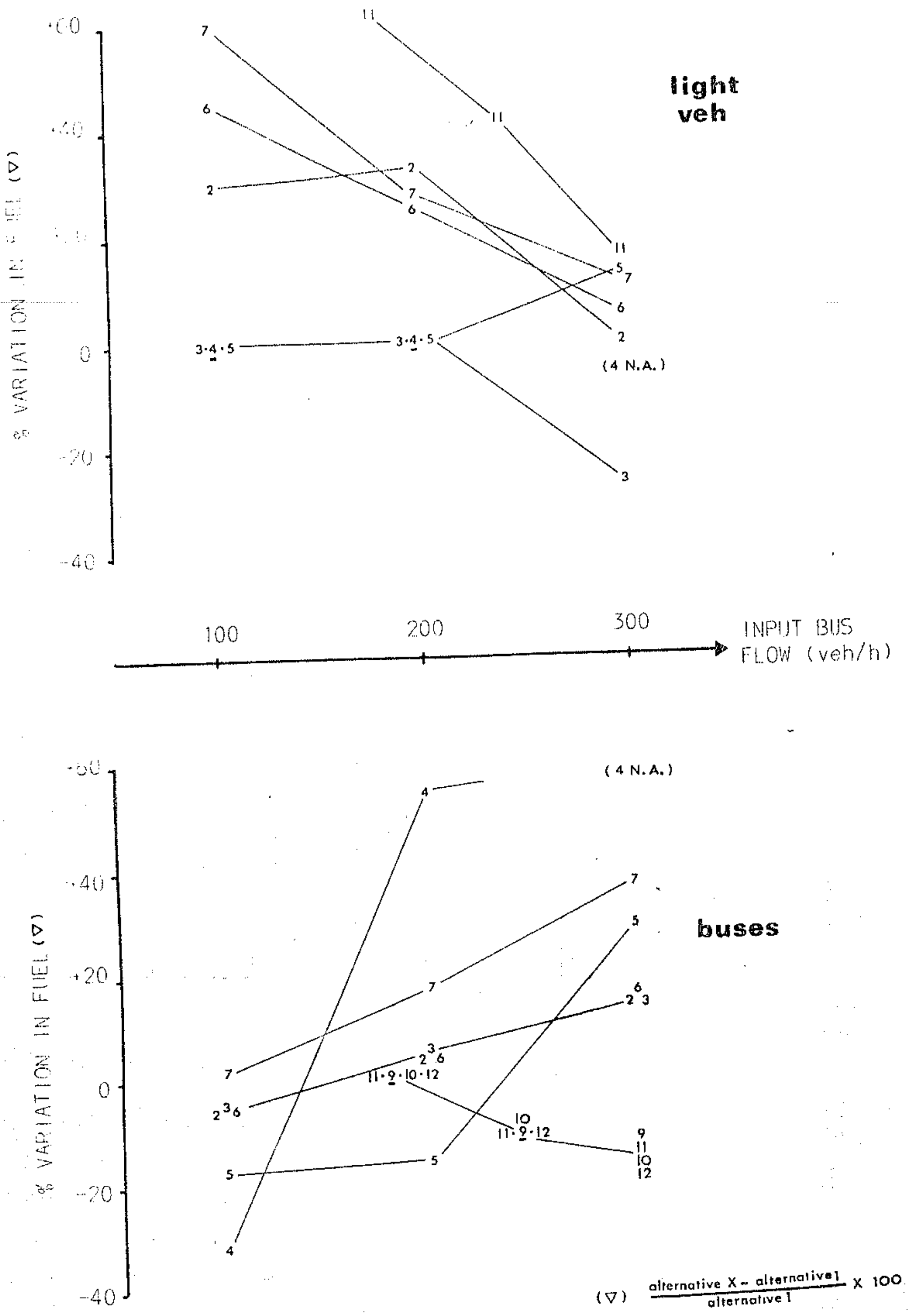


Figure 12.15 Percentual variation in fuel consumption in relation to alternative 1

13. SUMMARY AND CONCLUSIONS

The research described in this thesis has been concerned with the investigation of priority measures to improve high-flow bus operation in urban areas with particular application to Brazilian conditions. As part of the national urban transport policy, the introduction of median bus lanes on radial arterial routes has been recommended by the Brazilian Government to several metropolitan regions. Therefore, it was decided to concentrate the work on the investigation of geometric design and operational aspects related to such bus priority measures.

The study consisted of three distinct parts, the first being a comprehensive literature review of bus priority schemes. The second part involved the formulation, calibration and validation of a model of a section of an arterial road suitable for the evaluation of a range of bus priority alternatives. In the third part of the work the model was applied to test the effectiveness of alternative configurations.

The literature review described in section I (chapters 2-4) provided a broad view of bus priority measures. It was also useful in the identification of the extent to which elements/concepts common to different schemes, such as signal preemption or bus stop location have been previously investigated. Based on this review, it was observed that, although existing criteria tended to indicate the value of exclusive median bus lanes, the potential for the introduction of such lanes in urban areas had not been properly established.

The adoption of a computer model was justified since the complexity of the system would make an accurate analytical approach an almost impossible task. Simulation also has distinctive advantages over field experiments which lack flexibility as they are limited in the extent to which operational aspects and geometric designs can be altered. A periodic microscopic model was developed as only this type of tool could represent the traffic stream with the degree of detail required for the intended investigations. Further discussion of the different methods of approach is found in chapter 5.

The model simulates in detail the traffic flow on a three lane section of an urban artery with up to 6 traffic signals with associated input (4) and output (5) links. It may alternatively represent both bus priority and non-priority situations. During 'priority' conditions the median lane can be reserved for the exclusive use of buses. The 'do-nothing' situation is characterized by buses interacting with other vehicles on the main lanes. Alternative signal progression techniques are incorporated to the main framework of the model. Car-following and free-flowing routines are employed in the vehicle updation process. Drivers react to traffic signal indications, perform lane changing manoeuvres and/or decelerate to perform exit turns. Different bus stop configurations and bus platoon operations may be represented. The main freatures of the model are described in chapter 6.

The model is set in a modular computer program formed by four processors:

a. a random number processor that generates random variates from probability distribution functions (chapter 7).
b. a pre-simulation processor that defines the geometric configuration, traffic signal progression and traffic stream vehicles (chapter 8).
c. a simulation processor that simulates the movement of each vehicle in the system (chapter 9).
d. a fuel consumption processor that evaluates the total fuel consumed during each simulation run (chapter 10).

An extensive program checkout was adopted to ensure that the program correctly represented the model.

Particular emphasis has been given to the calibration and validation of the proposed model. Most of the parameters used in the program have been estimated from statistical analysis of traffic field data. The data collection procedure was mainly based in the use of time-lapse filming techniques. Sites were selected among radial urban avenues of the city of Porto Alegre, Brazil. The photographic technique, the study area and the method of film analysis are described in Appendix 1. The data base allowed the determination of both macroscopic elements such as flows and vehicle composition, and microscopic elements such as headways, speeds, accelerations/decelerations, amber reaction, stopping error, vehicle lengths and bus stop times. These elements are described in chapters 8 and 9.

The model performance has been assessed by the validation tests described in chapter 11. Good accuracy was obtained between average travel times predicted by the model and field measurements undertaken at the corresponding section. Queue discharge at stop lines was also adequately simulated. A comparative analysis between predicted and previously developed expressions relating fuel consumption to average vehicle speeds revealed that, in overall terms, similar trends were obtained. The model was subsequently applied to simulate traffic operation under alternative geometric and operational configurations in order to examine the significance of certain design elements. The effects on the measures of effectiveness are presented and discussed in chapter 12.

Section 2 of this study has led to the following major findings and conclusions:

a. The microscopic simulation model was found to be an appropriate design tool. The success experienced in applying the model to the evaluation of alternative road and operational configurations was mainly related to the possibility of deriving effective results from relatively short time and inexpensive computer runs.

b. The sole introduction of a median bus lane did not improve bus traffic operation. No advantage in terms of system capacity and operational speed of buses was derived from a priority measure based on the single assignment of a lane for the exclusive use of buses at high-flow input conditions. These conclusions applied to both short (60s) and long (90s) cycle times. (Sections 12.4.1 and 12.4.4)

c. Light vehicles did not always benefit from being physically separated from bus flow. When the priority scheme being tested required the introduction of extra mid-block pedestrian signals, improvements in travel times in relation to the mixed traffic configuration were only achieved above input conditions determined by flows of the order of 220 buses per hour. This conclusion was found to be relevant to both short and long cycle times. (Sections 12.4.1 and 12.4.4)

d. The system capacity and the average speeds could be substantially increased by operating buses in ordered platoons. A comparison between non-ordered and ordered bus platoon operation in exclusive median lanes revealed that bus system capacities could be increased from around 200 to 420 buses/hour (platoons of 7 buses). The corresponding average speeds at capacities were 10.7 and 14.5 km/h. (Section 12.4.5)

e. The system capacity could be substantially decreased by operating buses in non-ordered platoons. When buses assigned to specific bus bays were allowed to operate under a non-ordered fashion, the system capacities fell quite significantly in relation to the results achieved by configurations which permitted buses to be serviced at any vacant loading bay. (Sections 12.4.1 and 12.4.5)

f. Increases in bus platoon size consistently improved system capacity. This observation was valid to bus platoons consisting of up to seven ordered buses. The simulated system could not cope with larger platoons. (Section 12.4.5)

g. The provision of signal progression to benefit buses was shown to be a very effective measure when fixed bus boarding times were adopted. When a fixed average loading time was assigned to every bus operating on the bus lane, speed improvements, in comparison to the values observed during usual boarding conditions, ranged from 2.4% (platoon of 3 ordered buses) to 20.4% (platoon of 7 ordered buses). This suggests that variability in bus boarding times is capable of disrupting the benefits that would arise from signal offsets specially adjusted to give progression to buses. (Section 12.4.7)

h. The effectiveness of reducing bus boarding was increased with bus platoon size. Reductions in average travel times ranging from 3.2% to 14.1%, for platoons of 3 and 7 ordered buses respectively, occurred when boarding times were reduced to 85% of previous values. (Section 12.4.6)

i. The length of the priority scheme is important in the determination of bus flows that justify the adoption of ordered platoons. The initial delays involved in the process of forming buses into ordered platoons of different sizes and the travel time advantages achieved over non-ordered configurations should be jointly considered in the determination of the bus flows that would benefit from such operational measure. (Section 12.4.5)

j. Evidence favoured the adoption of short cycle times. Cycle times of 60 and 90 seconds were tested. The latter one caused a relative increase in bus travel times of the order of 35 seconds per kilometre over different input flow levels and operational configurations. Light vehicles also benefited from the shorter cycle time. (Sections 12.4.1 and 12.4.4)

k. Alterations in bus fuel consumption were found to be more related to variations in the number of stop-start cycles than to changes in average travel speeds. The relative fuel economies resulting from large increments in average speeds such as the ones achieved through the adoption of ordered platoons were not as significant as the relative economies arising from the reduction of stop-start manoeuvres such as the ones resulting from the introduction of near-side bus stops at low bus flow conditions. (Section 12.4.8)

Direction for future work

The following areas have been identified for further research:

a. detailed examination of the behaviour of buses making forced lane changing manoeuvres in the vicinity of bus stops in multi-lane mixed traffic operations.

b. investigation of the feasibility of a preemption technique that would ensure the avoidance of bus platoon disruption at traffic signals.

c. improvements in the microscopic fuel consumption model.

d. assessment of the performance of bus priority measures under variable traffic flow compositions.

e. incorporation of parameters in the measures of effectiveness to enable the evaluation of alterations caused to the environment.

Alterations in the main framework of the simulation tool formulated in the course of this study would allow the modelling of traffic systems requiring a detailed microscopic representation of vehicular behaviour.

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14. APPENDIX 1: DATA COLLECTION

The aim of the data collection and analysis procedure, adopted in this study, was to obtain information on the wide range of traffic parameters required for the simulation model. Data varied from simple classified counts of flows at a particular location to more complex studies involving the analysis of time lapse films.

Whilst most of the data was collected using film techniques, electronic stopwatches were also used. Computer programs and techniques were adopted to help in the interpretation of the information collected, as well as in classifying data obtained from the local traffic authorities.

14.1 Study area

Sites were selected along the urban avenues, RU60 and RU61 of the city of Porto Alegre, Brazil, where median bus priority lanes were introduced. A plan of the road network within the central area of the city is shown in figure 14.1 which also indicates the bus lane priority schemes implemented.

14.2 Site geometry

A set of 1:500 scale plans, covering the whole length of RU60, was obtained from the local traffic authority. It enabled the extraction, at the required level of accuracy, of geometric details such as the location of bus stops, intersections and traffic lights.

14.3 Photographic technique

Most of the traffic parameters were obtained using time lapse photography, with a camera pointing at a fixed direction. The camera was activated by a built-in intervalometer to ensure film exposures at regular time intervals. There is a number of reasons for selecting this technique:

a. films are a continuous and permanent record of events.
b. the availability of tall structures, as in densely populated

urban areas, can provide an inconspicuous vantage point {1}.

c. this technique helps in minimizing errors that can result from continuous manual collection {2}.
d. photographic procedures allow the use of a minimum of personnel to collect data.
e. the use of time-lapse photography provides, specially in complex traffic situations, more detailed data than is normally available by conventional means {3}.

Due to the availability of sites, all the films were taken from fixed positions at roofs of different high buildings.

14.4 Method of film analysis

There are two basic methods of obtaining data from the frames.

14.4.1 Perspective grid

An analysis grid is constructed based on roadside marks drawn on the screen. If more than one direction of travel is involved a parallactic grid, such as the one shown in figure 14.2, may be superimposed on the screen. Data is obtained by relating the movements of the vehicles to the grid. However, this method presents a series of disadvantages {4}:

a. the grid is not easy to establish since numerous control points have to be painted and identified on the roadway.
b. a new grid may be needed if the camera or projector is moved.
c. analysis of the film is slow because each frame has to be positioned on the perspective grid.
d. visual interpretation has to be used and scaling is difficult due to the non-linearity of the grid scale.

14.4.2 Rectangular coordinates

The coordinates of the vehicles in the film image are converted into lateral and longitudinal position by making use of a numerical routine {5} and a number of reference points. The planimetric positions of these points are provided by a ground survey. The relation between road and film points is accomplished numerically rather than physically, as required with the perspective grid. This procedure allows movement between frames since the coordinates of only four points are necessary to establish the relationship between the film and the roadway plane. The origin and the rectangular coordinate system are arbitrarily determined.

The relationship between points in the roadway and film plane is diagramatically shown in figure 14.3. The following pair of equations carries out the transformation {6}:

$$X_v = \frac{C_1 + C_2 X_f + C_3 Y_f}{C_4 X_f + C_5 Y_f + 1}$$

$$Y_v = \frac{C_6 + C_7 X_f + C_8 Y_f}{C_4 X_f + C_5 Y_f + 1}$$

where

X_f, Y_f = X and Y film plane coordinates of any point

X_v, Y_v = X and Y transformed ground coordinates of the same point

C = coefficients calculated from a set of eight equations making use of the four reference points.

The quadrilateral formed by the set of four reference points requires interior angles between 70° and 110° and sides of approximately equal length {7}.

The method of the rectangular coordinates was selected for analysing the films. The films were exposed at speeds of 1 and 2 frames per second according to their purposes, i.e. the data to be extracted. In order to simplify the process, all the positions of the relevant vehicles on one frame were recorded before moving to the next. A computer program subroutine {4} was used for making the transformation from the rectangular film coordinate system to a rectangular roadway coordinate system. The reference points were usually painted on existing pavement and centre road reference points at a height approximately equal to the one that separates, on average, car bumpers from the road pavement. The exact angles and distances between the reference points were obtained through planimetric surveys conducted at each site studied.

14.5 Instrumentation

The camera used was the 1240 model by TIMELAPSE. It is a fully-automatic Sankyo super-8 camera with a built-in crystal-controlled intervalometer which provides for filming at exact, repeatable intervals. Specifications of the model 1240 include:

a. time-lapse intervals of .5-99.5 seconds in .5 second intervals providing an accuracy within .01% of a second.

b. f/1.2 Sankyo zoom lens, 9.2mm - 37mm, aperture range - f/1.2 - f/45, automatic or manual exposure control, telephoto converter to 51mm, wide-angle converter to 6.38mm.

The data analyser projector used was the 3420 model also assembled by TIMELAPSE, USA. Some of the features of the projector are:

a. quiet operation in all speeds.
b. pushbutton selection of interval speeds - 1,2,3,6,9,18 frames per second.
c. accurate frame counter with four-digit LED display, zero counter reset button.

Digital electronic stopwatches were utilized for the collection of speeds and headways at the stop lines.

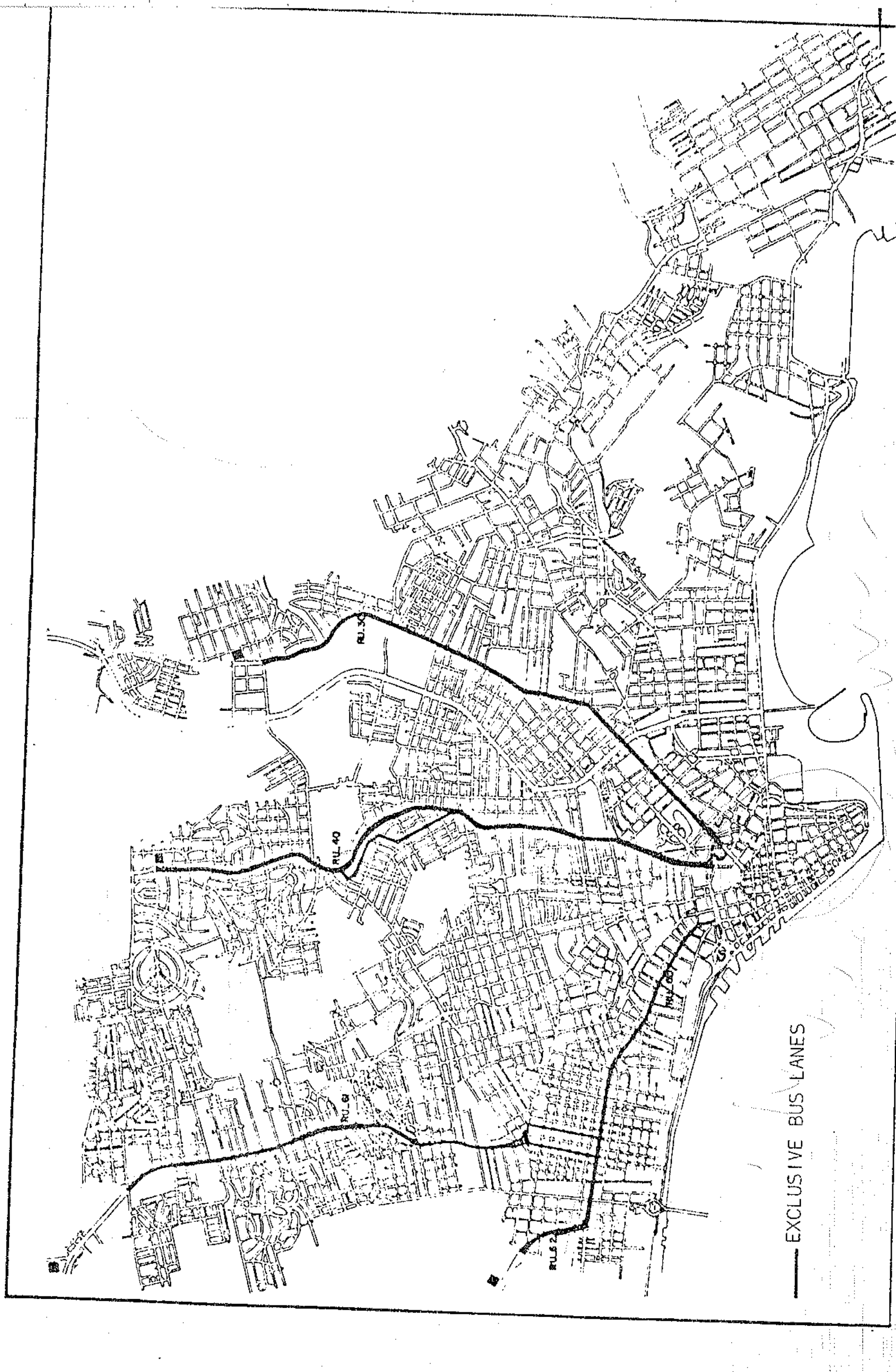

Figure 14.1 Bus priority schemes

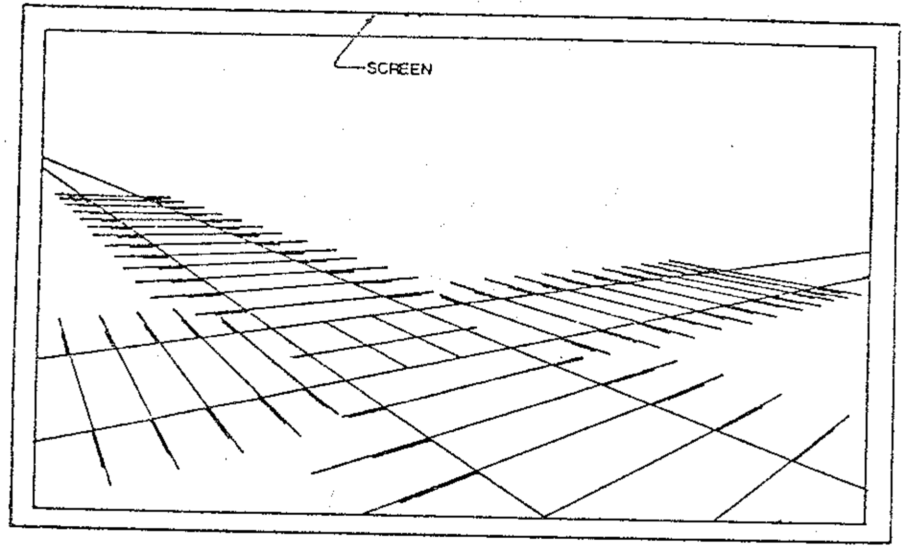

Figure 14.2 Parallactic grid for 4-way intersection

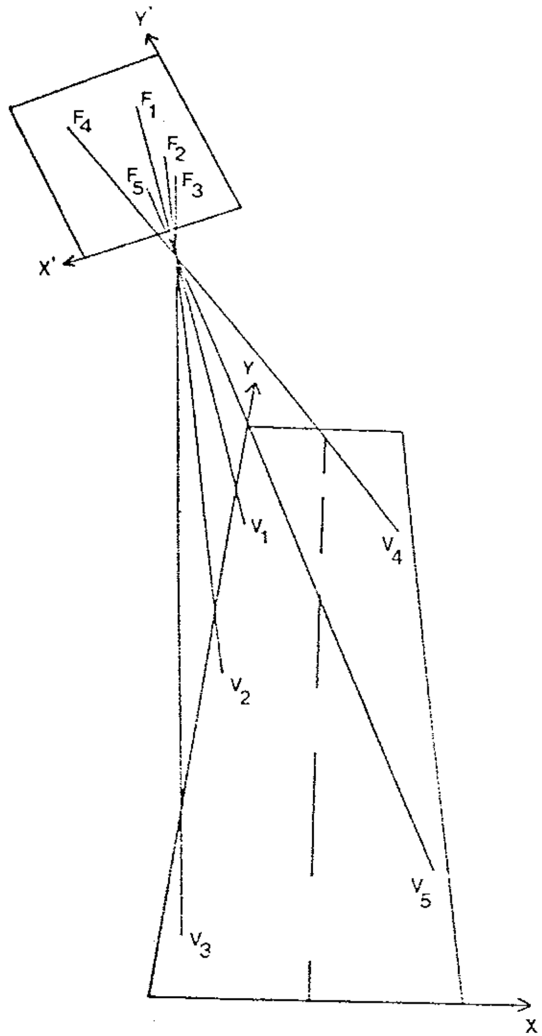

Figure 14.3 Relationship between points in the roadway and film planes (adapted from ref. 4)

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15. APPENDIX 2: LISTING OF PROGRAM

```
C***********************************************************************
C A MICROSCOPIC MODEL TO INVESTIGATE THE TRAFFIC BEHAVIOUR
C ALONG SOME LINKS OF AN URBAN ARTERY
C VERSION - NOVEMBER 1982
C***********************************************************************
      PROGRAM SIMULA
      EXTERNAL IC19HFBLKDTA
      CALL COMPOS
      CALL VEHCHA
      CALL TEMOFF
      CALL SIMPRO
      STOP
      END
C***********************************************************************
      SUBROUTINE COMPOS
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1NUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/CEN1/VELG1(4000),TRGEN1(4000),TPRG1(4000)
      COMMON/CAR1/STDIS1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IBST1(4000)
      COMMON/FLOW/IXO(7)
      COMMON/INIT/KNU,PF(4),PTU,IG(7)
      COMMON/RANS/GA,GE
      COMMON/SEED/GS(10)
      COMMON/BUSP/IBS,ISC
      COMMON/PRIO/IPRI
      COMMON/COMP/XA(7,4),ZD(3,5),ZD2(3,5)
      COMMON/TURN/B(2,5)
      DIMENSION PP(10),IX(3),IX2(2),TOT(3),KS(4)
C CALCULATE FLOWS OF EACH LANE
      IF(IPRI.EQ.1)GO TO 601
  602 CONTINUE
C DET TOTAL NO. OF VEH TYPE N IN TOTAL FLOW OF 5 MAIN LANES
      DO 401 N=1,4
      KS(N)=(PF(N)/PF(3))*KNU
  401 CONTINUE
      KS(3)=KNU
      DO 402 M=1,3
      TOT(M)=0
      DO 402 N=1,4
C DET TOTAL FLOW IN EACH MAIN LANE
      TOT(M)=KS(N)*ZD(M,N)+TOT(M)
  402 CONTINUE
      DO 403 M=1,3
      DO 403 N=1,4
      XA(M,N)=KS(N)*ZD(M,N)/TOT(M)
  403 CONTINUE
      IT=0
      DO 404 M=1,3
      IXO(M)=IT+TOT(M)
      IT=IXO(M)
  404 CONTINUE
      DO 405 M=4,7
      AY=IG(M)
      IXO(M)=IXO(M-1)+(AY/100.)*IXO(3)
  405 CONTINUE
      NOC=0
      IF(IBS.NE.0)GO TO 205
  206 CONTINUE
      DO 100 ILANE=1,7
      IF(ILANE.EQ.1)GO TO 101
      J=IXO(ILANE-1)+1
  102 CONTINUE
      DO 100 I=J,IXO(ILANE)
      IBST1(I)=0
C DET TYPE OF VEH
      CALL RANDNU(1)
      GX=GS(1)/GA
      R=0.
      DO 10 IJ=1,4
      R=R+XA(ILANE,IJ)
      IF(GX.LE.R)GO TO 11
   10 CONTINUE
      IJ=4
   11 ITIPO1(I)=IJ
  100 CONTINUE
      IF(IPRI.EQ.1)GO TO 600
  602 CONTINUE
      DO 200 ILANE=1,7
      IF(ILANE.GE.3)GO TO 234
      ADIV=TOT(ILANE)
      IF(IPRI.EQ.0)ADIV=(1-XA(ILANE,3))*ADIV
      IF(ILANE.EQ.1)GO TO 201
  234 J=IXO(ILANE-1)+1
  202 CONTINUE
      DO 200 I=J,IXO(ILANE)
      IF(ITIPO1(I).EQ.3)GO TO 203
      IF(ILANE.GE.3)GO TO 500
      CALL RANDNU(2)
      GX=GS(2)/GA
C DETERMINE IF IT IS A TURNING VEH
      IF(GX.LT.(ZD(ILANE,5)*IXO(3)/ADIV)
     1*PTU)GO TO 501
      GO TO 500
  501 P=0.
      CALL RANDNU(2)
      GX=GS(2)/GA
      DO 20 IK=1,5
      P=B(ILANE,IK)+P
      IF(GX.LE.P)GO TO 21
   20 CONTINUE
      IK=5
   21 LEGAT1(I)=IK+7
  200 CONTINUE
      RETURN
  101 J=1
      GO TO 102
  201 J=1
      GO TO 202
  203 LEGAT1(I)=2
      IF((ISC.EQ.0).AND.(IBS.NE.0))GO TO 204
      NOC=NOC+1
      IBST1(I)=NOC
      IF(IBS.EQ.0)NOC=0
      IF(NOC.EQ.IBS)NOC=0
      GO TO 200
  205 CONTINUE
      DO 30 JV=1,IBS
      PP(JV)=(1./IBS)*JV
   30 CONTINUE
      PP(IBS)=1
```

```
      GO TO 206
C DETERMINE RANDOM BUPOION GROUP
 204  CALL RANDNU(9)
      GX=GS(9)/GA
      DO 40 JV=1,IBS
      JW=JV-1
      IF(JW.EQ.0)GO TO 207
      IF((GX.GT.PP(JW)).AND.(GX.LE.PP(JV)))GO TO 208
  40  CONTINUE
      GO TO 200
 207  IF((GX.GT.0.).AND.(GX.LE.PP(1)))GO TO 208
      GO TO 40
 208  IBST1(I)=JV
      GO TO 200
 301  CONTINUE
      DO 50 JV=1,5
      DO 50 JW=1,3
      ZD(JW,JV)=ZD2(JW,JV)
  50  CONTINUE
      GO TO 302
 500  LEGAT1(I)=2
      GO TO 200
C RE-CALCULATE TURNING PROBABILITY
 600  CONTINUE
      DO 601 JW=1,5
      B(1,JW)=B(1,JW)*ZD2(1,5)+B(2,JW)*ZD2(2,5)
      B(2,JW)=0.
 601  CONTINUE
      GO TO 602
      END
C*********************************************************************
      SUBROUTINE VEHCHA
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1NUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GEN1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/CAMV/STDIS1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IBST1(4000)
      COMMON/FLOW/IXO(7)
      COMMON/CAVE/GACEL(4),GDECEL(4),GDVEL(4),
     1XMIDV(4),XMADV(4),GSDDV(4)
      COMMON/COMB/CCAR(18),PERC(18),CBUS(2),PERB(2),CTAX,CLOR
     1,WCAR(18),WBUS,WTAX,WLOR
      COMMON/STCA/GSTD,GSDST,XMIST,XMAST
      COMMON/RANS/GA,GB
      COMMON/SEED/GS(10)
      DO 100 ILANE=1,7
      IF(ILANE.EQ.1)GO TO 101
      J=IXO(ILANE-1)+1
 102  CONTINUE
      DO 100 I=J,IXO(ILANE)
      IF(ITIPO1(I).EQ.3)GO TO 10
      CALL NORMAL(3,GSTD,GSDST,XMIST,XMAST,GN)
      STDIST1(I)=GN
 100  CONTINUE
      DO 200 ILANE=1,7
      IF(ILANE.EQ.1)GO TO 201
      J=IXO(ILANE-1)+1
 202  CONTINUE
      DO 200 I=J,IXO(ILANE)
      IF((ITIPO1(I).EQ.1).OR.(ITIPO1(I).EQ.3))GO TO 205
      IF(ITIPO1(I).EQ.4)GO TO 204
      COMP1(I)=CTAX
      WID1(I)=WTAX
 200  CONTINUE
      DO 300 ILANE=1,7
      IF(ILANE.EQ.1)GO TO 301
      J=IXO(ILANE-1)+1
 302  CONTINUE
      DO 300 I=J,IXO(ILANE)
      JU=4
      IF(ITIPO1(I).EQ.3)JU=7
      CALL NORMAL(JU,GDVEL(ITIPO1(I)),GSDDV(ITIPO1(I)),
     1XMIDV(ITIPO1(I)),XMADV(ITIPO1(I)),GN)
      VELD1(I)=GN
      DEC1(I)=GDECEL(ITIPO1(I))*SQRT(VELD1(I))
      ACC1(I)=GACEL(ITIPO1(I))*SQRT(VELD1(I))
 300  CONTINUE
      RETURN
 101  J=1
      GO TO 102
 201  J=1
      GO TO 202
 301  J=1
      GO TO 302
 205  JU=5
      IF(ITIPO1(I).EQ.3)JU=8
      CALL RANDNU(JU)
      GY=GS(JU)/GA
      IF(ITIPO1(I).EQ.3)GO TO 206
      S=0.
      DO 20 NJ=1,18
      JN=NJ
      S=S+PERC(NJ)/100.
      IF(GY.LT.S)GO TO 40
  20  CONTINUE
  40  COMP1(I)=CCAR(JN)
      WID1(I)=WCAR(JN)
      GO TO 200
 206  S=0
      DO 50 NJ=1,2
      JN=NJ
      S=S+PERB(NJ)/100.
      IF(GY.LT.S)GO TO 60
  50  CONTINUE
  60  COMP1(I)=CBUS(JN)
      WID1(I)=WBUS
      GO TO 200
  10  STDIST1(I)=GSTD
      GO TO 100
 204  COMP1(I)=CLOR
      WID1(I)=WLOR
      GO TO 200
      END
C*********************************************************************
      SUBROUTINE TFKOFF
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1NUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GEN1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/CAVE/GACEL(4),GDECEL(4),GDVEL(4),
     1XMIDV(4),XMADV(4),GSDDV(4)
```

```
      COMMON/SNFB/ISNB(2)
      COMMON/PBST/BUPO(20)
      COMMON/PSSB/AVPR,XMAB,KP,CF(3)
      COMMON/FLOW/IXO(7)
      COMMON/RAN1/FLAG1(4000)
      COMMON/GLTL/XLAG(400)
      COMMON/SIGL/CYCLE,XGR(6),AMBER,OFFI(6),IWE
      COMMON/SHIF/TAU(7),TMAX(7),CHOP
      COMMON/INLE/DE(7)
      COMMON/HWFL/GAM(3),GLSTD(3)
      COMMON/SIMT/SIT
      COMMON/HEADINPLAT/KB(7)
      COMMON/LGAP/GAVGA,GSDGA,XMILA,XMALA
      COMMON/SPGT/SIEP(6)
      COMMON/PRIO/IPRI
      COMMON/RANS/GA,GB
      COMMON/SPED/GS(10)
      DIMENSION IPML(3,100),GM(3),GL(3),TA(3),TM(3)
      DIMENSION XPO(6),RED(6),SPEGI(6),SPEDO(6),Y1(6),Z1(6),W1(6)
      DIMENSION PHASE(6),TIMET(6),WM(6),NUM(6)
      DO 501 N=1,6
      OFFI(N)=0
  501 CONTINUE
      IF(IPRI.EQ.0)GO TO 702
C CALCULATE OFFSETS
  703 IF(IWE.EQ.0)GO TO 301
      IF(IWE.EQ.2)GO TO 601
      IF(IWE.EQ.3)GO TO 801
      IF(IWE.EQ.4)GO TO 401
      IF(IWE.EQ.5)GO TO 401
      DO 201 IL=1,6
      X=SIGP(IL)/GDVEL(1)
      IX=X
      R=X-IX
      IF(R.GE.0.5)IX=IX+1
      OFFI(IL)=IX
      WRITE(6,*)OFFI(IL)
  201 CONTINUE
C IF KB(IL) EQ TO 1,VEH ARE GENER IN PLATOONS
  308 ZL=3600/SIT
      DO 100 IL=1,7
      WRITE(6,*)IL
      TINHA=DE(IL)
      IF(IL.EQ.1)GO TO 101
      J=IXO(IL-1)+1
      K=IXO(IL)-IXO(IL-1)
  102 CONTINUE
      DO 300 NEH=J,IXO(IL)
      VELG1(NEH)=0.0
      TRGEN1(NEH)=0.0
      DIST1(NEH)=0.0
      VEL1(NEH)=0.0
      ACDE1(NEH)=0.0
      FLAG1(NEH)=0.
      INUM1(NEH)=NEH
      LANE1(NEH)=IL
  300 CONTINUE
C CHECK IF FLOW ALLOW PLATOONS TO BE USED
      IF(K.LT.120)KB(IL)=0
      IF(KB(IL).EQ.1)GO TO 91
C K IS MULTIPLIED BY ZL SINCE IXO IS FLOW FOR SIT MINUTES
      AX=3600./(K*ZL)
```

```
      TB1=AX
  999 TT1=TAU(IL)-(TB1-TAU(IL))*LOG(CHOP)
      TBS1=((-TAU(IL)+TT1*CHOP)/(1-CHOP))+TAU(IL)+AX
      IF(ABS(TBS1-TB1).LE.0.01)GO TO 998
      TB1=TBS1
      GO TO 999
  998 AX=TBS1
      TMAX(IL)=TT1
      DO 200 NEH=J,IXO(IL)
      CALL SHNEXP(6,TAU(IL),AX,TMAX(IL),T)
      TINHA=TINHA+T
      TPRG1(NEH)=TINHA
  200 CONTINUE
  100 CONTINUE
      MA=IXO(7)-IXO(5)
      DO 400 N=1,MA
C EVALUATE RIGHT TURNING LAGS FOR "T" LANE VEH
      CALL NORMAL(7,GAVGA,GSDGA,XMILA,XMALA,GN)
      XLAG(N)=EXP(GN)
  400 CONTINUE
      RETURN
  101 J=1
      K=IXO(1)
      GO TO 102
   91 CONTINUE
C CALCULATE NO. OF PLATOONS
      TOTLOTE=SIT/CYCLE
      IT=TOTLOTE
      TOTLOTE=IT
C CALCULATE SIZE OF PLATOON
      VAR=K
      XB=VAR/TOTLOTE
      ISIZE=XB
C EVALUATE REST
      MR=VAR-ISIZE*IT
C DISTRIBUTE REST OVER MR FIRST PLATOONS IF MR>0
      IF(MR.EQ.0)GO TO 5
      IPML(IL,1)=J
      DO 1 L=2,MR
      IPML(IL,L)=IPML(IL,L-1)+ISIZE+1
    1 CONTINUE
    5 IK=MR+1
      DO 3 L=IK,IT
      IF(L.EQ.1)GO TO 4
      IPML(IL,L)=IPML(IL,L-1)+ISIZE
    3 CONTINUE
C FIND HEADWAY BETWEEN PLATOON LEADERS
      TPRG1(IPML(IL,1))=DE(IL)
      G11=CYCLE-0.3
      G12=3.1
      T13=G11-2*G12
      T14=G11+2*G12
      DO 2 L=2,IT
      CALL NORMAL(8,G11,G12,T13,T14,G15)
      TPRG1(IPML(IL,L))=TPRG1(IPML(IL,L-1))+G15
    2 CONTINUE
C FIND FOR ALL PLATOONS, HEADWAYS BETW VEH IN PLATOONS
      DO 6 L=1,IT
      IF(L.EQ.IT)GO TO 6
      JC=IPML(IL,L+1)-1
   11 JP=IPML(IL,L)+1
      SUM=0.
```

```
      DO 9 LL=JF,JC
      TTT=LOG(TAU(IL))
      TMT=LOG(TMAX(IL))
      CALL NORMAL(R,GAH(IL),GLSTD(IL),TTT,TMT,GN)
      H=EXP(GN)
      TPRG1(LL)=TPRG1(LL-1)+H
      SUM=SUM+H
    9 CONTINUE
C CHECK IF PLATOON HEADWAYS OK
   14 IF(L.EQ.IT)GO TO 10
      ZZ=TPRG1(IPPL(IL,L+1))-TPRG1(IPPL(IL,L))
      IF(ZZ.LT.SUM+3)GO TO 12
    5 CONTINUE
      GO TO 100
    4 IPPL(IL,1)=J
      GO TO 3
    6 JC=IPPL(IL,L)+ISIZE
      GO TO 11
   10 IF(CYCLE.LT.SUM+3)GO TO 12
      GO TO 100
   12 R=0.
C SEARCH FOR BIGGEST HEADWAY IN PLATOON & CHANGE IT
      JN=JF
      DO 15 IV=JF,JC
      XX=TPRG1(IV)-TPRG1(IV-1)
      IF(XX.GT.R)JN=IV
      R=MAX(XX,R)
   15 CONTINUE
  112 TTT=LOG(TAU(IL))
      TMT=LOG(TMAX(IL))
      CALL NORMAL(R,GAH(IL),GLSTD(IL),TTT,TMT,GN)
      H=EXP(GN)
      HP=TPRG1(JN)-TPRG1(JN-1)
      IF(H.GE.HP)GO TO 112
      SUM=SUM-HP+H
C DECREASE HEADWAYS ACCORDINGLY
      TPRG1(JN)=TPRG1(JN-1)+H
      DIF=HP-H
      IF(JN.EQ.JC)GO TO 14
      DO 16 LV=JN,JC-1
      TPRG1(LV+1)=TPRG1(LV+1)-DIF
   16 CONTINUE
      GO TO 14
C CALCULATE OFFSETS TO FAVOR BUSES AT SIGNALS FOR BUSES
  301 PST=(CF(1)+CF(2)*AVPB)+CF(3)
      DO 202 IL=1,6
      DO 203 N=1,2
      IF(IL.EQ.ISNB(N))GO TO 202
  203 CONTINUE
      IF(SIGP(IL).EQ.0)GO TO 202
      A=0
      IF(IL.NE.1)GO TO 503
  504 B=SIGP(IL)
      DO 204 NI=1,20
      IF((BUPO(NI).GT.A).AND.(BUPO(NI).LT.B))
     1GO TO 207
  204 CONTINUE
      XM=B-A
      X=XM/GDVEL(3)
      IX=X
      R=X-IX
      IF(R.GE.0.5)IX=IX+1
      IF(IL.EQ.1)GO TO 303
      OFFI(IL)=OFFI(IL-1)+IX
  202 CONTINUE
C CALCULATE OFFSET FOR SIGNAL NOT FOR BUSES
      DO 205 N=1,2
      NWE=ISNB(N)
      IF(NWE.NE.0)GO TO 304
      GO TO 205
  304 IF(NWE.EQ.1)GO TO 305
      XM=SIGP(NWE)-SIGP(NWE-1)
  306 X=XM/GDVEL(1)
      IX=X
      R=X-IX
      IF(R.GE.0.5)IX=IX+1
      IF(NWE.EQ.1)GO TO 307
      OFFI(NWE)=OFFI(NWE-1)+IX
  205 CONTINUE
      WRITE(6,*)(OFFI(N),N=1,6)
      GO TO 30R
  302 RT=16+((B-A-60)/GDVEL(3))
      IF(IL.EQ.1)GO TO 309
      OFFI(IL)=OFFI(ILA)+RT+PST
      GO TO 502
  309 OFFI(IL)=RT+PST
      GO TO 502
  307 OFFI(NWE)=IX
      GO TO 205
  305 XM=SIGP(NWE)
      GO TO 306
  303 OFFI(IL)=IX
      GO TO 202
  503 ILA=IL-1
  507 A=SIGP(ILA)
      IF(A.EQ.0)GO TO 505
      GO TO 504
  505 ILA=ILA-1
      GO TO 507
  502 IX=OFFI(IL)
      R=OFFI(IL)-IX
      IF(R.LT.0.5)OFFI(IL)=IX
      IF(R.GE.0.5)OFFI(IL)=IX+1
      GO TO 202
  207 ILA=IL-1
  210 IF(SIGP(ILA).EQ.0)GO TO 209
      DO 206 N=1,2
      IF(ILA.EQ.ISNB(N))GO TO 208
  206 CONTINUE
      GO TO 302
  208 ILA=ILA-1
      A=SIGP(ILA)
      GO TO 302
  209 ILA=ILA-1
      GO TO 210
C RE-ARRANGE HEADWAY PARAMETERS & CHECK SIG PROGRESSION
  702 IF(IWE.EQ.5)IWE=4
      DO 704 N=1,3
      GM(N)=GAH(N)
      GL(N)=GLSTD(N)
      TA(N)=TAU(N)
      TM(N)=TMAX(N)
  704 CONTINUE
      N=1
```

```
      NN=3
  706 GAM(N)=GM(NN)
      SLSTD(N)=GL(NN)
      TAU(N)=TA(NN)
      TMAX(N)=TM(NN)
      IF(N.EQ.3)GO TO 703
      IF(N.EQ.2)GO TO 705
      N=2
      NN=1
      GO TO 706
  705 N=3
      NN=2
      GO TO 706
  601 CONTINUE
      DO 602 MT=1,6
      CALL RANDNU(5)
      GY=GS(5)/GA
      MW=GY/100.
      OFFI(MT)=MW
      WRITE(6,*)OFFI(MT)
  602 CONTINUE
      GO TO 306
  801 OFFI(1)=7
      OFFI(2)=22
      OFFI(3)=37
      OFFI(4)=0
      OFFI(5)=0
      OFFI(6)=57
      GO TO 308
  401 HEDWY=2
C CALCULATE NO. OF SIGNALS EFFECTIVELY USED
      NSIG=0
      DO 410 IL=1,6
      IF(SIGP(IL).EQ.0)GO TO 410
      NSIG=NSIG+1
      NUM(NSIG)=IL
  410 CONTINUE
      X=IXO(3)
      PLATI=X*2./3600.
      PLATO=PLATI
      NV=1
      IF(IWE.EQ.5)NV=3
      A=(GOVEL(NV)*3.6)/1.609
      DO 411 IL=1,NSIG
      XPO(IL)=SIGP(NUM(IL))/0.3048
      RED(IL)=(CYCLE-XGR(NUM(IL))-AMBER)/CYCLE
      SPEDI(IL)=0.6818182/A
      SPEDO(IL)=SPEDI(IL)
  411 CONTINUE
      IF(IWE.EQ.4)GO TO 499
C IF OFFSETS TO FAVOUR BUSES,
      DO 412 IL=3,NSIG
      DO 412 IK=1,2
      IF(NUM(IL-1).EQ.ISNE(IK))GO TO 414
  412 CONTINUE
      GO TO 499
  414 D1=SIGP(IL-1)-SIGP(IL-2)
      D=SIGP(IL)-SIGP(IL-2)
      RTA=T0*(1/GOVEL(3))*(D-60)
      PBT=(CF(1)+CF(2)*AVRH)*CF(3)
      RT=RTA+PBT
      RT1=(D1/D)*RTA+(PBT/2)
      RT2=RT-RT1
      A1=(D1/RT1)*3.6/1.609
      A2=((D-D1)/RT2)*3.6/1.609
      SPEDI(IL-2)=0.6818182/A1
      SPEDI(IL-1)=0.6818182/A2
      SPEDO(IL-2)=SPEDI(IL-2)
      SPEDO(IL-1)=SPEDI(IL-1)
      X=IXO(3)-IXO(2)
      PLATI=X*2./3600.
      PLATO=PLATI
      HEDWY=3600./X
      GO TO 412
C START COMPUTING OFFSETS
  499 Y1(1)=0
      Z1(1)=0
      TIME1(1)=0
      B=0.5/CYCLE
      DO 402 I=2,NSIG
      M=I-1
      A=(XPO(I)-XPO(M))*B
      SAVE=A*(SPEDO(M)+SPEDI(M))
      TIME1(I)=TIME1(M)+SAVE
      Y1(I)=Y1(M)-.5*(RED(I)-RED(M))+SAVE
      Z1(I)=Z1(M)+A*(SPEDO(M)-SPEDI(M))
C START COMPUTING FOR EQUAL BANDWIDTH
  402 CONTINUE
      BAND=0.
      DO 403 I=1,NSIG
      WMIN=3600.
      DO 404 J=1,NSIG
      A=Y1(J)-Y1(I)
      B=A-0.5
      NSAVE=A
      SAVE=NSAVE
      A=A-SAVE
      IF(A)405,406,406
  405 A=A+1.
  406 NSAVE=B
      SAVE=NSAVE
      B=B-SAVE
      IF(B)407,408,408
  407 B=B+1.
  408 IF(A-B)409,409,470
  409 PHASE(J)=0
      W1(J)=1.-A
      GO TO 471
  470 PHASE(J)=.5
      W1(J)=1.-B
  471 B=W1(J)-RED(J)
C IS CURRENT BANDWIDTH BETTER THAN PREVIOUS BEST
      IF(B-BAND)403,450,450
  450 IF(WMIN-B)404,404,472
  472 WMIN=B
  404 CONTINUE
      BAND=WMIN
      LIRST=I
C SAVE VALUES
      DO 474 K=1,NSIG
      SPEDI(K)=PHASE(K)
      SPEDO(K)=W1(K)
  474 CONTINUE
  403 CONTINUE
```

```
C CALCULATE FINAL OFFSETS
      B=Z1(LTEST)
      DO 415 I=1,NSIG
      A=Z1(I)-B*SPED1(I)
      NSAVE=A
      SAVE=NSAVE
      A=A-SAVE
      IF(A)416,415,415
  416 A=A+1
  415 PHASE(I)=A
      WMIN=0.
      DO 419 I=1,NSIG
      IF(WID(I)-WMIN)419,419,421
  421 WMIN=WID(I)
      NSAVE=I
  419 CONTINUE
      A=1.-WID(NSAVE)
      B=2.*BAND
      SAVE=PLATI+PLATO
      WMIN=PLATO
      BIN=BAND
      BOUT=BAND
      PLATI=BIN*3600./WEDWY
      PLATO=BOUT*3600./WEDWY
      BIN=BIN*CYCLE
      BOUT=BOUT*CYCLE
      DO 443 I=1,NSIG
      SAVE=WID(I)
      WM(I)=(PHASE(I)+.5*SAVE)*CYCLE
      IF(WM(I)-CYCLE)435,435,440
  440 WM(I)=WM(I)-CYCLE
  435 SAVE=SAVE*CYCLE
  443 CONTINUE
      DO 430 IL=1,NSIG
      OFF1(NUM(IL))=WM(IL)
  430 CONTINUE
      DO 431 IL=1,6
      IST=OFF1(IL)
      IF((OFF1(IL)-IST).GT.0.5)GO TO 434
      OFF1(IL)=IST
  433 IF(SIGP(IL).EQ.0)OFF1(IL)=0
      WRITE(6,*)OFF1(IL)
  431 CONTINUE
      GO TO 300
  434 OFF1(IL)=IST+1
      GO TO 433
      END
C**********************************************************************
      SUBROUTINE SIMPRO
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1INUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GER1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/CAR1/STDIS1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IEST1(4000)
      COMMON/BAN1/FLAG1(4000)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/SANA/FLAG(430)
      COMMON/FLOW/IXO(7)
      COMMON/SPOT/SIGP(6)
      COMMON/LLEN/MLAST(2)
      COMMON/VNUM/NM(430)
      COMMON/FVLI/LEADER(3)
      COMMON/ANUI/M
      COMMON/LTOT/MTOTAL(3)
      COMMON/VNVE/ML(3,143)
      COMMON/TEMP/TIME
      COMMON/GROS/IGRUC(20),STTIME(20)
      COMMON/GEST/IKRUC(2,3),STKIME(2,3)
      COMMON/GMIL/IU,IW7,IW(2)
      COMMON/NVCI/NVEC,
     1NVG7,NVIG(2)
      COMMON/GLIL/XLAL(4,C)
      COMMON/LLIT/LEAT(7)
      COMMON/FLIT/IFOLT(7),
     1DBUF(7),VBUF(7),ABUF(7)
      COMMON/GTIM/INDEX(430),NIM
      COMMON/CLAL/ISENC(4,3)
      COMMON/FSTP/IFIS(4,3)
      COMMON/EVCL/LVCH,ICLA
      COMMON/CONE/ICON(2)
      COMMON/CONS/CTOT(2)
      COMMON/AVHE/SVV(2),NVE(2)
      COMMON/SNEH/ISNE(2)
      COMMON/FRIC/IPAI
      COMMON/ALIN/AVL(4,3)
      COMMON/HOLP/IDE(4,3),IREDQ(4,3)
      COMMON/LIMT/LIT
      COMMON/MAIN/TAI,TAI,TAIP,IW7,IW2,TAI,FUE(2)
      COMMON/CIII/HED(1000,3),MHE(3),ISG(4),NADI(4),XLD1,XLD2,
     1H9(4),XLAL(1000,4)
      DIMENSION IA1(4),KIA(1000,3)
      WRITE(6,9999)
 9999 FORMAT(' ALL VEH ASSEMBLED')
      DO 9991 KV=1,4
      DO 9991 KVV=1,1000
      XLAL(KVV,KV)=0
 9991 CONTINUE
      DO 8888 KV=1,3
      DO 8888 KVV=1,1000
      HED(KVV,KV)=0.
      KIA(KVV,KV)=0
 8888 CONTINUE
      DO 8889 KV=1,3
      MHE(KV)=0
 8889 CONTINUE
      IF(1.7.E.0)GO TO 901
      DO 800 KV=1,IXO(7)
      WRITE(7,2.)ITIPO1(KV),COMP1(KV),ACC1(KV),DEC1(KV),VEL1(KV),
     1VELG1(KV),TRGER1(KV),STDIS1(KV),TPRG1(KV),INUM1(KV),DIST1(KV)
     2,VELD1(KV),ACDE1(KV),LEGAT1(KV),IEST1(KV),LANE1(KV),FLAG1(KV)
  800 CONTINUE
      MA=IXO(7)-IXO(5)
      DO 900 KP=1,MA
      WRITE(7,50)XLAL(KP)
   50 FORMAT(1X,'XLA(=',F5.2)
  900 CONTINUE
  901 CONTINUE
      DO 2 JL=1,430
```

```
      INDEX(JL)=0
      DIST(JL)=0.
      VEL(JL)=0.
      ACDE(JL)=0.
      INUM(JL)=0
      LEGAT(JL)=0
      COMP(JL)=0.
      LANE(JL)=0
      VELS(JL)=0.
      TRGER(JL)=0.
      TPRG(JL)=0.
      STDIS(JL)=0.
      VELD(JL)=0.
      ITIPO(JL)=0
      ACC(JL)=0.
      DEC(JL)=0.
      IBST(JL)=0
      FLAG(JL)=0.
    2 CONTINUE
      NI=0
      I26=0
      I27=0
      IQ(1)=0
      IQ(2)=0
      NVTG(1)=IXO(3)+1
      NVTG(2)=IXO(4)+1
      NVG6=IXO(5)+1
      NVG7=IXO(6)+1
      DO 400 NL=1,3
      DO 400 NK=1,2
      IKBUS(NK,NL)=0
      STXIME(NK,NL)=0.
  400 CONTINUE
      DO 401 JL=1,20
      IBUS(JL)=0
      STTIME(JL)=0
  401 CONTINUE
      ICON1=0
      IKEY=0
      M=0
      TIME=0.
      DO 700 NK=6,7
      LEAT(NK)=11111
      IFOLT(NK)=11111
  700 CONTINUE
      DO 1100 NP=1,3
      DO 1100 MP=1,6
      IFIS(MP,NP)=11111
 1100 CONTINUE
      MLAST(1)=0
      MLAST(2)=0
      MLAST(3)=0
      MTOTAL(1)=0
      MTOTAL(2)=0
      MTOTAL(3)=0
      LEADER(1)=1
      LEADER(2)=IXO(1)+1
      LEADER(3)=IXO(2)+1
      SVV(3)=0
      SVV(2)=0
      NVE(1)=0
      NVE(2)=0
      CTOT(1)=0
      CTOT(2)=0
      KL12=0
      KL21=0
      X3=0
      XCT=0
      AVG=0
      STDN=0
      XN2=0
      AVCT=0
      STDCT=0
      XN=0
      DO 505 JL=1,4
      ADD(JL)=0
      NADD(JL)=0
  505 CONTINUE
      TBAT=60.
      DO 200 NN=1,430
      MM(NN)=0
  200 CONTINUE
      DO 300 NL=1,143
      DO 300 NK=1,3
      ML(NK,NL)=0
  300 CONTINUE
      DO 500 JY=1,6
      ICOR(JY)=0
  500 CONTINUE
      DO 71 JL=1,6
      IA1(JL)=JL
   71 CONTINUE
      WRITE(1,82)(IA1(JL),JL=1,6)
   82 FORMAT(15X,I1,5(10X,I1))
      WRITE(1,81)
   81 FORMAT(2/,6('*',10X))
C WRITE INITIAL CONDITIONS
      CALL WINEON
      WRITE(2,7777)
 7777 FORMAT(/,5X,'TIME',5X,'JTBUS',2X,'JTCAT',1X,'AVGBUS',1X,
     1'STDBUS',1X,'NBUS',1X,'AVSCRT',1X,'STDCAT',3X,'NCAT',/)
    3 TIME=TIME+1.
      IF(TIME.EQ.TBAT)GO TO 506
  506 CONTINUE
      DO 1000 NP=1,3
      DO 1000 MP=1,6
      IXG(MP,NP)=0
      IREDN(MP,NP)=0
      NVL(MP,NP)=0
      ISEND(MP,NP)=0
 1000 CONTINUE
      LVCH=0
      IOLA=0
      CALL SIGIND
      IF(TIME.LT.TMR)GO TO 69
      DO 100 ILANE=1,3
      DO 100 MK=1,MTOTAL(ILANE)
      K=ML(ILANE,MK)
      IF(K.EQ.0)GO TO 100
C WRITE MAIN LANE VEH INFORMATION AT TIME=TIME-1.
   20 FORMAT('**',F6.1,2X,'***********************************
     1*****************************')
      WRITE(9,20)ITIPO(K),COMP(K),ACC(K),DEC(K),VELS(K),VELD(K),
     1TRGER(K),STDIS(K),TPRG(K),INUM(K),DIST(K),VEL(K),
```

```
      2ACDE(K),LEGAT(K),IPST(K),LANE(K),FLAG(K),K
   60 FORMAT(1X,I1,F6.2,2F5.2,2F6.3,F8.3,F5.3,F8.3,I5,F8.3,
     1F7.3,F8.3,3I3,F6.1,I5)
   30 FORMAT(1X,I1,F7.3,2F6.3,2F7.3,F6.3,F5.3,F8.3,I5,F8.3,
     1F7.3,F8.3,3I3,F6.1)
  100 CONTINUE
   69 IF(TIME.GT.TWR)WRITE(9,20)TIME
      IXTIME=TIME
      WRITE(6,*)IXTIME
C     WRITE(6,67)TIME,M,MTOTAL(1),MTOTAL(2),MTOTAL(3)
C 67  FORMAT(1X,'**',F7.2,30X,'TOTALVEH=',4I4)
      IF(TIME.GT.TWO)WRITE(6,80)ICOR(1),ICOR(2),ICOR(3),ICOR(4)
     1,ICOR(5),ICOR(6)
      IF(TIME.GT.TWR)WRITE(9,80)ICOR(1),ICOR(2),ICOR(3),ICOR(4)
     1,ICOR(5),ICOR(6)
   80 FORMAT(1X,'ICOR(1)=',I3,'    ICOR(2)=',I3,
C    *         ICOR(3)=',I3,'    ICOR(4)=',I3,
C    *         ICOR(5)=',I3,'    ICOR(6)=',I3)
      IF(M.EQ.0)GO TO 1
      CALL RORDER(IREM)
      CALL ELACHA
      CALL PROUPD(IREM)
      DO 89 MP=1,6
      IF((IPRI.EQ.1).AND.((MP.EQ.ISNB(1)).OR.(MP.EQ.ISNB(2)
     1)))IREDQ(MP,3)=0
   89 CONTINUE
      DO 86 NNP=1,3
      NP=4-NNP
      IF(TIME.GT.TW1)WRITE(1,83)TIME,NP,((NVL(MP,NP),IREDQ
     1(MP,NP)),MP=1,6)
   86 CONTINUE
      IF(TIME.GT.TW1)WRITE(1,84)IQ(1),IQ(2),IQ5,IQ7
   84 FORMAT(76X,4I5)
   83 FORMAT(F6.0,I2,6(I8,I3))
    1 CALL UPDELA
      CALL UPDSIL
      CALL INSVEH
      IF(TIME.EQ.FUE(2))GO TO 999
  123 IF(TIME.GT.SIT)RETURN
      IF(TIME.GT.TWR)WRITE(9,10)M,MTOTAL(1),MTOTAL(2),MTOTAL(3),
     1IREM
   10 FORMAT(1X,'TOTALNOIN3LANES=',I5,'  TOTALLANE1=',I5,
     1'  TOTALLANE2=',I5,'  TOTALLANE3=',I5,'  DECREASE=',I3)
C IF LANE  INFORMATION IS REQUIRED
      IF(TIME.GT.4000)GO TO 111
      DO 666 IAP=1,6
      IF((ICOR(IAP).NE.1).AND.(TIME.GT.TW6))WRITE(6,96)IAP
      IF((ICOR(IAP).NE.1).AND.(TIME.GT.TW6))WRITE(6,97)(IFIS
     1(IAP,II),II=1,3)
  666 CONTINUE
      IAP=3
   97 FORMAT(6X,I5)
   96 FORMAT('XXXXXX  SIGP=',I2)
      GO TO 3
  111 IF(TIME.GT.TWR)WRITE(9,40)(MM(II),II=1,M)
      IF(TIME.GT.TWR)WRITE(9,40)((ML(IA,IB),IB=1,MTOTAL(IA)),IA=1,3)
   40 FORMAT(1X,I6)
      GO TO 3
  999 VLI=(SWV(1)/NVE(1))*3.6
      VHE=(SWV(2)/NVE(2))*3.6
      XLI=((CTOT(1)/NVE(1))/(SIGP(6)-H9(1)))*1000.
      XHE=((CTOT(2)/NVE(2))/(SIGP(6)-H9(3)))*1000.
```

```
      WRITE(2,998)XLI,VLI,NVE(1),XHE,VHE,NVE(2)
  998 FORMAT(' ENERGY CONSUMPTION',/,
     1      ' LIGHT CONS IN L/KM=',F6.2,'  FOR AVER SP=',F6.2,
     2      ' SAMPLE SIZE=',I4,/,
     3      ' HEAVY CONS IN L/KM=',F6.2,'  FOR AVER SP=',F6.2,
     4      ' SAMPLE SIZE=',I4)
C     WRITE(2,997)KL12,KL21,TIME
C 997 FORMAT(/,' NO.LANE(H 1>2)=',I4,'  NO.LANE(H2>1)=',I4,
C    1'  IN TIME=',F5.0)
C IF HEADWAY INFORM IS REQUIRED, IOO.NE.0
      IOO=0
      IF(IOO.EQ.0)GO TO 123
      DO 770 KV=1,3
      WRITE(2,790)KV
      DO 771 JL=2,1000
      IF(HED(JL,KV).EQ.0)GO TO 775
      A=HED(JL-1,KV)
      B=HED(JL,KV)
      C=B-A
      E=0.
      F=0.5
      DO 772 KW=1,1000
      IF((C.GE.E).AND.(C.LT.F))GO TO 773
      E=E+0.5
      F=F+0.5
      IF(KW.EQ.1000)WRITE(2,791)
  772 CONTINUE
  771 CONTINUE
  790 FORMAT(//,'LANE=',I3,/)
  791 FORMAT('DOM. WRONG',//)
  775 CONTINUE
      DO 774 JM=1,1000
      IF((JM.GT.50).AND.(KTA(JM,KV).EQ.0))GO TO 774
      WRITE(2,*)JM,KTA(JM,KV)
  774 CONTINUE
  770 CONTINUE
      GO TO 123
  773 KTA(KW,KV)=KTA(KW,KV)+1
      GO TO 771
  506 TBAT=TBAT+60.
      XJL=NADD(1)+NADD(2)
      XAD=ADD(1)+ADD(2)
      XJK=NADD(3)
      IF(XJK.EQ.0.)GO TO 509
      XB=ADD(3)/XJK
  511 IF(XJL.EQ.0.)GO TO 510
      XCT=XAD/XJL
  512 CONTINUE
      NL=1
      X2=0
      X=0
  514 CONTINUE
      DO 513 NK=1,NADD(NL)
      X=XLAL(NK,NL)+X
      X2=XLAL(NK,NL)**2+X2
  513 CONTINUE
      IF(NL.EQ.2)GO TO 515
      NL=2
      GO TO 514
  515 XN=NADD(1)+NADD(2)
      IF(XN.LE.1)GO TO 517
      STDCT=SQRT((X2-(1/XN)*(X**2))/(XN-1))
```

```
      AVCT=X/XN
 517  NL=3
      X2=0
      X=0
      DO 516 NK=1,NADD(NL)
      X=XLAL(NK,NL)+X
      X2=XLAL(NK,NL)**2+X2
 516  CONTINUE
      XN2=NADD(NL)
      IF(XN2.LE.1)GO TO 518
      STDB=SQRT((X2-(1/XN2)*(X**2))/(XN2-1))
      AVB=X/XN2
 518  WRITE(2,507)TIME,XN,XCT,AVB,STDB,XN2,AVCT,STDCT,XN
 507  FORMAT(3X,9F7.2)
      GO TO 508
 509  XB=0.
      GO TO 511
 510  XCT=0.
      GO TO 512
      END
C*************************************************************************
      SUBROUTINE RORDER(IREM)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/VNUM/MM(430)
      COMMON/ANUI/M
      COMMON/NUMP/DISTA(430)
      OB=0.00001
      DO 100 LL=1,M
      IF(LANE(MM(LL)).EQ.20)GO TO 3
      DISTA(MM(LL))=DIST(MM(LL))
 100  CONTINUE
      MK=M
 1    FLAGA=0.
      MK=MK-1
      DO 300 I=1,MK
      IF(DISTA(MM(I)).GE.DISTA(MM(I+1)))GO TO 300
      N=MM(I)
      MM(I)=MM(I+1)
      MM(I+1)=N
      FLAGA=1.
 300  CONTINUE
      IF(FLAGA.NE.0.)GO TO 1
      IF(IREM.EQ.0)RETURN
C TURN ZERO THE VEH THAT WENT TO LANE 20
      DO 200 J=1,IREM
      JJ=J-1
      MM(M-JJ)=0
 200  CONTINUE
C DECREASE ACTUAL NUMBER OF VEH IN MAIN LANES
      M=M-IREM
      RETURN
 3    OB=OB+0.00001
      DISTA(MM(LL))=OB
      GO TO 100
      END
C*************************************************************************
      SUBROUTINE ELACHA
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/BANA/FLAG(430)
      COMMON/PEST/BUPO(20)
      COMMON/INTE/PITE(12),WA(12)
      COMMON/VNUM/MM(430)
      COMMON/ANUI/M
      COMMON/LTOT/MTOTAL(3)
      COMMON/WRIN/TWR,TW6,TW6E,IW7,IW27,TW1,FUE(2)
      COMMON/TEMP/TIME
      COMMON/PRIO/IPRI
      MTOTAL(1)=0
      MTOTAL(2)=0
      MTOTAL(3)=0
      DO 100 KK=1,M
C NEED IS A VARIABLE TO INDICATE NECESSITY OF CHANG. LANES
      NEED=0
      K=MM(KK)
      IF(TIME.GT.TW6E)WRITE(6,1000)K
 1000 FORMAT(10X,I4)
      NFRO=11111
      NRFR=11111
      NLFR=11111
C IF NO LANE CHANGE IS DESIRED INSERT NEXT LINE AS:
C "GO TO 1"
      IF((LANE(K).EQ.1).AND.(LEGAT(K).GT.5).AND.(IPRI.EQ.1))GO TO 1
C IF VEH IS BUS IN PRIORITY LANE
      IF((ITIPO(K).EQ.3).AND.(IPRI.EQ.1))GO TO 1
      IF(DIST(K).LT.10.)GO TO 1
      IF(IEST(K).EQ.25)GO TO 11
C NEXT 3 DECISIONS: IS VEH ALLOWED TO CHANGE LANES?
      IF(ITIPO(K).NE.3)GO TO 11
      IF((LANE(K).EQ.1).AND.(DIST(K).GT.BUPO
     1(IEST(K))-200.).AND.(DIST(K).LE.BUPO(IEST(K))))GO TO 1
 11   IF((LEGAT(K).GT.5).AND.(DIST(K).GT.PITE(LEGAT(K))+200.)
     1.AND.(LANE(K).EQ.1))GO TO 1
      IF(FLAG(K).NE.0.)GO TO 10
 12   IF(KK.EQ.1)GO TO 2
      IF(LANE(K).EQ.1)GO TO 2
      IF(LANE(K).EQ.3)GO TO 4
C THEN LANE(K)=2
      J=KK-1
 5    IF(LANE(MM(J)).EQ.LANE(K)+1)GO TO 52
      IF(LANE(MM(J)).EQ.LANE(K))GO TO 51
C THEN LANE(MM(J)) MUST BE = LANE(K)-1
      IF(NRFR.EQ.11111)NRFR=MM(J)
      J=J-1
      GO TO 6
 51   IF(NFRO.EQ.11111)NFRO=MM(J)
      J=J-1
      GO TO 6
 52   IF(NLFR.EQ.11111)NLFR=MM(J)
      J=J-1
 6    IF((NLFR.NE.11111).AND.(NRFR.NE.11111).AND.(NFRO.NE.
     111111))GO TO 7
      IF(J.EQ.0)GO TO 7
      GO TO 5
 4    J=KK-1
 8    IF(LANE(MM(J)).EQ.LANE(K)-1)GO TO 42
      IF(LANE(MM(J)).EQ.LANE(K))GO TO 41
```

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43   J=J-1
     IF((NFRO.NE.11111).AND.(NRFR.NE.11111))GO TO 7
     IF(J.EQ.0)GO TO 7
     GO TO 8
41   IF(NFRO.EQ.11111)NFRO=MM(J)
     GO TO 43
42   IF(NRFR.EQ.11111)NRFR=MM(J)
     GO TO 43
2    IF(LEGAT(K).GT.3)GO TO 25
     GO TO 1
25   IF(LANE(K).NE.1)GO TO 7
     GO TO 1
5    J=KK-1
9    IF(LANE(MM(J)).EQ.LANE(K)+1)GO TO 32
     IF(LANE(MM(J)).EQ.LANE(K))GO TO 31
33   J=J-1
     IF((NLFR.NE.11111).AND.(NFRO.NE.11111))GO TO 7
     IF(J.EQ.0)GO TO 7
     GO TO 9
31   IF(NFRO.EQ.11111)NFRO=MM(J)
     GO TO 33
32   IF(NLFR.EQ.11111)NLFR=MM(J)
     GO TO 33
7    CALL WCHLAT(KK,K,NFRO,NRFR,NLFR,
    1LEFT,IRIGHT,NEED)
     IF((LEFT.EQ.0).AND.(IRIGHT.EQ.0))GO TO 1
     IF(IRIGHT.EQ.2)GO TO 72
     CALL WCHLA2(KK,K,NLFR,NRFR,LEFT,IRIGHT
    1,NEED,DFRO,VFRO)
     IF(LEFT.EQ.1)GO TO 72
     IF(IRIGHT.EQ.1)GO TO 72
1    CALL LALIST(K,KK)
100  CONTINUE
     RETURN
72   CALL LACHAN(IRIGHT,LEFT,K)
     GO TO 1
10   ILA=FLAG(K)
     IF(LANE(ILA).GT.LANE(K))GO TO 1
     GO TO 12
     END
C*****************************************************************************
     SUBROUTINE WCHLAT(KK,K,NFRO,NRFR,NLFR,
    1LEFT,IRIGHT,NEED)
     IMPLICIT REAL*4(A-F,H,O-Z)
C
     DIMENSION IBLE(5)
     COMMON/LCHC/RAX(5)
     COMMON/INFA/DIST(430),VEL(430),ACDE(430),
    1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
     COMMON/CANA/STDIS(430),VELD(430),ITIPO(430),
    1ACC(430),DEC(430),IBST(430)
     COMMON/BANA/FLAG(430)
     COMMON/BEST/BUPO(20)
     COMMON/SPOT/SIGP(6)
     COMMON/INTE/PITE(12),HA(12)
     COMMON/VAOR/MM(430)
     COMMON/ANLI/P
     COMMON/RANS/CA,CB
     COMMON/SLED/GS(10)
     COMMON/FRIO/IPRI
     NEED=0
     IRIGHT=0
     LEFT=0
     IF(NFRO.EQ.11111)GO TO 1
     VFRO=VEL(NFRO)
     DFRO=DIST(NFRO)
     CFRO=COMP(NFRO)
91   IF(NRFR.EQ.11111)GO TO 2
     VRFR=VEL(NRFR)
     DRFR=DIST(NRFR)
     CRFR=COMP(NRFR)
92   IF(NLFR.EQ.11111)GO TO 3
     VLFR=VEL(NLFR)
     DLFR=DIST(NLFR)
     CLFR=COMP(NLFR)
C IS VEH A BUS ALREADY SERVED AT ITS BUS STOP?
93   IF(IBST(K).EQ.25)GO TO 1234
C DOES VEH NEED A FORCED LANE CHANGE?(NEXT 2 DECISIONS)
     IF(ITIPO(K).NE.3)GO TO 1234
     IF((LANE(K).EQ.2).AND.(VEL(K).EQ.0.).AND.
    1(DIST(K).EQ.BUPO(IBST(K))-20.))GO TO 450
1234 IF((LEGAT(K).GT.3).AND.(DIST(K).GE.PITE(LEGAT(K))-20.).AND.
    1(VEL(K).EQ.0.).AND.(LANE(K).NE.1))GO TO 601
C WILL A VEH BE FACING A FORCED LANE CHANGE SOON?(NEXT 2 DECISIONS)
1236 IF(ITIPO(K).NE.3)GO TO 1235
     IF(IBST(K).EQ.25)GO TO 1235
     IF((LANE(K).EQ.2).AND.(DIST(K).GT.
    1(BUPO(IBST(K))-200.)).AND.(DIST(K).LT.BUPO
    2(IBST(K))))GO TO 5
1235 IF((LEGAT(K).GT.3).AND.(LANE(K).EQ.[illegible]).AND.(DIST(K).GT.
    1(PITE(LEGAT(K))-250.)).AND.(DIST(K).LT.PITE
    2(LEGAT(K))))GO TO [illegible]
     IF((LEGAT(K).GT.3).AND.(LANE(K).EQ.2).AND.(DIST(K).GT.
    1(PITE(LEGAT(K))-2[illegible].)).AND.(DIST(K).LT.PITE
    2(LEGAT(K))))GO TO [illegible]
     IF((LANE(K).NE.1).[illegible]
     IF((ITIPO(K).NE.3).[illegible]
C IS FRONT VEH MOVING FASTER THAN THIS ONE?
1242 IF(VFRO.GT.VEL(K))RETURN
C CAN VEH CHANGE TO LEFT
     IF(LANE(K).NE.[illegible])GO TO [illegible]
C CAN VEH CHANGE TO RIGHT?
5    IF(LANE(K).NE.1)GO TO 7
     RETURN
6    IF((LANE(K).EQ.2).AND.(IPRI.EQ.1))GO TO 5
     IF(DLFR-DIST(K).GT.CLFR*2)GO TO 61
     GO TO 8
61   IF(VLFR.GT.VFRO+1.5)GO TO 62
     IF((VLFR.EQ.VFRO).AND.(VFRO.EQ.0.))GO TO 612
     GO TO 8
612  IF(DLFR.GT.DFRO+4.)GO TO 62
     GO TO 8
62   IF((ITIPO(K).EQ.3).AND.(LANE(K).EQ.2))GO TO 5
     LEFT=1
     GO TO 8
7    IF(DRFR-DIST(K).GT.CRFR*2)GO TO 71
     RETURN
71   IF(VRFR.GT.VFRO+1.5)GO TO 72
     IF((VRFR.EQ.VFRO).AND.(VFRO.EQ.0.))GO TO 712
     RETURN
712  IF(DRFR.GT.DFRO+4.)GO TO 72
     RETURN
72   IRIGHT=1
     RETURN
```

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    5 IF(DRFR-DIST(K).GT.CRFR+STDIS(K))GO TO 51
      RETURN
   51 IRIGHT=1
      NEED=1
      RETURN
  400 ICASE=1
      GO TO 4
  401 ICASE=2
    4 IF(FLAG(K).NE.0.)GO TO 41
      DO 402 JLM=1,5
      IBLE(JLM)=0
  402 CONTINUE
      CALL RANDNU(9)
      GN=GS(9)/GA
      TVI=0
      DO 9999 JTVI=1,5
      JTVV=JTVI
      TVE=MAX(JTVI)
      IF((GN.GE.TVI).AND.(GN.LT.TVE))GO TO 9998
      TVI=TVE
 9999 CONTINUE
C L IS THE VEH AT LANE LANE(K)-1 THAT WILL ALLOW THIS ONE, (K), TO MOVE
C TO LANE LANE(K)-1 IN FRONT OF IT, (L)
 9998 L=JTVV
      WRITE(6,3000)K,LANE(K),L,DIST(K)
      ICONTA=0
      J=KK+1
   10 IF(J.GT.M)GO TO 11
      IF(LANE(MM(J)).EQ.LANE(K)-1)GO TO 12
    9 J=J+1
      GO TO 10
   12 IF(((DIST(K)-DIST(MM(J))).GT.COMP(K)+STDIS(MM(J))).
     1AND.(FLAG(MM(J)).EQ.0.))GO TO 112
      GO TO 119
  112 ICONTA=ICONTA+1
      IBLE(ICONTA)=J
      WRITE(6,5000)ICONTA,MM(J),DIST(MM(J)),LEGAT(MM(J)),IBST(MM(J))
 5000 FORMAT('S ICONTA=',I1,1X,'MM(J=',I4,1X,'DIST(MM(J=',F5.1,1X,
     1'LEGAT(MM(J=',I2,1X,'IBST(MM(J=',I1)
      GO TO 999
   11 IF(ICONTA.EQ.0)GO TO 111
      J=IBLE(ICONTA)
      L=ICONTA
      GO TO 413
 3000 FORMAT(15X,'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$',/,'S',4X,
     1'VEH TRYING A FLAG=',I4,3X,'LANE(K)=',I2,1X,'L=',I2,1X,'DIST(K)=',
     2F5.1)
   13 FLAG(K)=MM(J)
      FLAG(MM(J))=K
      WRITE(6,1000)K,FLAG(K),MM(J),FLAG(MM(J))
 1000 FORMAT(1X,'REQUIRING FLAG=',I6,2X,'FLAG=',F6.1,2X,
     1'RECEIVING FLAG=',I6,2X,'FLAG=',F6.1)
      IF((NED.EQ.0).AND.((L.EQ.1).OR.(JCJ.EQ.1)))GO TO 14
      RETURN
  111 WRITE(6,4000)
 4000 FORMAT('S     THERE IS NO VEH IN LANE BEING SEARCHED')
      DRBA=0.
      SRBA=1.5
      GO TO 44
   14 NRBA=MM(J)
   49 DRBA=DIST(NRBA)
      SRBA=STDIS(NRBA)
   44 IF((DIST(K).LT.DRFR-CRFR-STDIS(K)).
     1AND.(DIST(K)-COMP(K)-SRBA.GE.DRBA))GO
     2TO 45
      RETURN
   45 IRIGHT=2
      FLAG(MM(J))=0.
      FLAG(K)=0.
      WRITE(6,2000)K,MM(J)
 2000 FORMAT(1X,'DELETING FLAGS OF=',I6,2X,'AND=',I6)
      RETURN
   41 J=KK+1
   43 IF(LANE(MM(J)).EQ.LANE(K)-1)GO TO 42
      J=J+1
      GO TO 43
   42 NRBA=MM(J)
      IF(FLAG(K).EQ.FLOAT(NRBA))GO TO 49
      RETURN
    1 VFRO=30.
      DFRO=11111.1
      CFRO=3.
      GO TO 91
    2 VRFR=30.
      DRFR=11111.1
      CRFR=3.
      GO TO 92
    3 VLFR=30.
      DLFR=11111.1
      CLFR=3.
      GO TO 93
  999 IF(DIST(K)-DIST(MM(J)).GT.60.)GO TO 414
      GO TO 996
  414 ICONTA=ICONTA-1
      IF(ICONTA.EQ.0)GO TO 777
  776 L=ICONTA
      J=IBLE(ICONTA)
  413 JCJ=ICONTA
      WRITE(6,6000)JCJ,MM(J)
 6000 FORMAT('S         REAL VALUE OF L=',I2,2X,'FIRST VEH TO BE CHECKED=
     1,I4)
C CHECK POSSIBILITY OF HAVING THIS VEH AS FLAG
      IF(ICASE.EQ.1)GO TO 415
  417 IF(ITIPO(MM(J)).NE.3)GO TO 416
      IF(IBST(MM(J)).EQ.25)GO TO 416
      IF(SUPO(IBST(MM(J))).GT.DIST(K))GO TO 416
  418 JCJ=JCJ-1
      IF(JCJ.LE.0)GO TO 1237
      J=IBLE(JCJ)
      GO TO 417
C CHECK DISTANCE BETWEEN CAR REQUESTER & CAR FOLLOWER
  416 IF((DIST(K)-DIST(MM(J))).GT.COMP(K)+STDIS(MM(J)))GO TO 413
      GO TO 418
  415 IF(LEGAT(MM(J)).LE.3)GO TO 419
      IF(PITE(LEGAT(MM(J))).GT.DIST(K))GO TO 419
  420 JCJ=JCJ-1
      IF(JCJ.LE.0)GO TO 1237
      J=IBLE(JCJ)
      GO TO 415
C CHECK DISTANCE BETWEEN GAP REQUESTER & GAP FOLLOWER
  419 IF((DIST(K)-DIST(MM(J))).GT.COMP(K)+STDIS(MM(J)))GO TO 13
      GO TO 420
 1237 WRITE(6,7000)K
 7000 FORMAT('S     NO FLAG WAS FOUND TO=',I4,' CHECK IF IT CHANGED LANE
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      1IN NEAR FUTURE')
      GO TO 1236
  998 IF(ICONTA.EQ.L)GO TO 413
      GO TO 9
  777 WRITE(6,8000)
 8000 FORMAT('1     THERE IS NO POSSIBLE FLAG SINCE FOLLOWER IS',/,
     1'$      TOO FAR AWAY, REALLY VEH SHOULD HAVE ALREADY',/,
     2'$      CHANGED LANES,BUT FLAG IS GIVEN TO THIS FAR VEH')
      ICONTA=1
      GO TO 778
  119 MFD=1
      WRITE(6,8001)
 8001 FORMAT('1     A CLOSE VEH WAS NOT CONSIDERED, MFD=1')
      GO TO 9
 1239 BX1=BUFU(1)
      BX2=BLP(2)
      IF((DIST(K).GE.BX1).AND.(DIST(K).LT.BX2))BXX=BX2
      IF(DIST(K).GE.BX2)BXX=11111.1
      IF(DIST(K).LT.BX1)BXX=BX1
      BXY=11112.1
      IF(LEGAT(K).GT.3)BXY=BITE(LEGAT(K))
      BXT=BXX-200.
      IF((DIST(K).GE.BXT).AND.(BXY.GT.BXX))GO TO 1240
      GO TO 1242
 1240 IF((DLFF-DIST(K)).GT.((CLFR+STDIS(K)))GO
     1TO 1241
      RETURN
 1241 LEFT=1
      NEED=1
      RETURN
      END
C*************************************************************************
      SUBROUTINE VEHLA2(KK,K,NLFR,NRFR,LEFT,IRIGHT
     1,NEED,DFFL,VFRO)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/TEMP/TIME
      COMMON/MAIN/IWR,IW6,IW6P,IW7,IW27,IW1,FUE(2)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/EF-A/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),SEC(430),IEST(430)
      COMMON/CANN/FLAG(430)
      COMMON/CTSE/CS
      COMMON/ANUM/MM(430)
      COMMON/ANLI/M
      NLEA=11111
      NREA=11111
      IF((LEFT.EQ.1).AND.(IRIGHT.EQ.1))GO TO 1
      IF(LEFT.EQ.1)GO TO 2
C THEN, IRIGHT MUST BE=1
      J=KK+1
   32 IF(J.GT.M)GO TO 3
      IF(LANE(MM(J)).EQ.LANE(K)-1)GO TO 31
      J=J+1
      GO TO 32
   31 IF(NREA.EQ.11111)GO TO 33
      J=J+1
      GO TO 32
   33 NREA=MM(J)
    3 IF(LEFT.EQ.1)GO TO 4
    5 IF(IRIGHT.EQ.1)GO TO 6
      RETURN
    1 J=KK+1
   14 IF(J.GT.M)GO TO 3
      IF(LANE(MM(J)).EQ.LANE(K)+1)GO TO 11
      IF(LANE(MM(J)).EQ.LANE(K))GO TO 12
C THEN,LANE(MM(J))=LANE(K)-1
      IF(NREA.EQ.11111)NREA=MM(J)
   12 J=J+1
      IF((NLEA.NE.11111).AND.(NREA.NE.11111))GO TO 3
      GO TO 14
   11 IF(NLEA.EQ.11111)NLEA=MM(J)
      GO TO 12
    2 J=KK+1
   24 IF(J.GT.M)GO TO 3
      IF(LANE(MM(J)).EQ.LANE(K)+1)GO TO 21
   23 J=J+1
      GO TO 24
   21 IF(NLEA.EQ.11111)GO TO 22
      GO TO 23
   22 NLEA=MM(J)
      GO TO 3
    4 IF(NLFR.EQ.11111)GO TO 41
C CHECK IF GAP IS ENOUGH
      IF(VEL(K).EQ.0.)GO TO 41
      AFR=DIST(NLFR)-DIST(K)
      TAFR=(AFR-COMP(NLFR))/VEL(K)
      IF(TAFR.LT.1.5)GO TO 42
C IF FRONT FASTER, NO NEED TO CHECK IF K IS TOO FAST
      IF(VEL(NLFR).GE.VEL(K))GO TO 41
C IF NEXT COND. +, NO NEED TO CHECK TOO
      IF((ACDE(K).LT.-DE((K)).AND.(DIST(NLFR).GT.DFFG)
     1.AND.(VEL(NLFR).[illegible]))GO TO 41
      IF(TIME.GT.TW[illegible])[illegible]
  996 FORMAT(1X,I[illegible],'  WANTS TO CHANGE,TEST LFRONT')
      CALL LACHGE(K,NLFR,NEED,IOK)
      IF(IOK.EQ.1)GO TO 41
C NOT POSSIBLE TO CHANGE TO LEFT
   42 LEFT=0
      GO TO 5
   41 IF(NLEA.EQ.11111)GO TO 5
      ATA=DIST(K)-DIST(NLEA)
      IF(ATA-2*COMP(K).GT.0.)GO TO 420
      GO TO 42
  420 IF(VEL(NLEA).EQ.0.)GO TO 5
      VATA=(ATA-COMP(K))/VEL(NLEA)
      IF(VATA.LT.1.5)GO TO 42
C IF K IS FASTER, NO NEED TO CHECK IF FOLL TOO FAST
      IF(VEL(K).GE.VEL(NLEA))GO TO 5
      IF(TIME.GT.TW6)WRITE(6,995)K
  995 FORMAT(1X,I6,'  WANTS TO CHANGE,TEST LBACK')
      CALL LACHGE(NLEA,K,NEED,IOK)
      IF(IOK.EQ.1)GO TO 5
      GO TO 42
    6 IF(NRFR.EQ.11111)GO TO 61
      IF(NEED.EQ.1)GO TO 61
      IF(VEL(K).EQ.0.)GO TO 61
      AFR=DIST(NRFR)-DIST(K)
      TAFR=(AFR-COMP(NRFR))/VEL(K)
      IF(TAFR.LT.1.5)GO TO 62
C IF FRONT FASTER, NO NEED TO CHECK IF K IS TOO FAST
      IF(VEL(NRFR).GT.VEL(K))GO TO 61
C IF NEXT COND. +, NO NEED TO CHECK TOO
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      IF((ACDE(K).LT.-DEC(K)).AND.(DIST(NRFR).GT.DFRO)
     1.AND.(VEL(NRFR).GE.VFRO))GO TO 61
      IF(TIME.GT.TW6)WRITE(6,997)K,NEED
 997  FORMAT(1PX,I5,'  WANTS TO CHANGE,TEST RFRONT',
     1'   NEED=',I3)
      CALL LACHDE(K,NRFR,NEED,IOK)
      IF(IOK.EQ.1)GO TO 61
C NOT POSSIBLE TO CHANGE TO RIGHT
  62  IRIGHT=0
      RETURN
  61  IF(NRBA.EQ.11111)GO TO 7
      ATA=DIST(K)-DIST(NRBA)
      IF(ATA-COMP(K).GT.STDIS(NRBA))GO TO 620
      GO TO 62
 620  IF(VEL(NRBA).EQ.0.)GO TO 7
      VATA=(ATA-COMP(K))/VEL(NRBA)
      IF(VATA.LT.1.5)GO TO 62
C IF K IS FASTER, NO NEED TO CHECK IF FOLL TOO FAST
      IF(VEL(K).GE.VEL(NRBA))GO TO 7
      IF(TIME.GT.TW6)WRITE(6,998)K,NEED
 998  FORMAT(1PX,I6,'  WANTS TO CHANGE,TEST RBACK',
     1'   NEED=',I3)
      CALL LACHDE(NRBA,K,NEED,IOK)
      IF(IOK.EQ.1)GO TO 7
      GO TO 62
C IF VEH CAN GO BOTH RIGHT AND LEFT,SELECT BEST ALTERN.
   7  IF((IRIGHT.EQ.1).AND.(LEFT.EQ.1))GO TO 71
      RETURN
  71  IF(NLEA.EQ.11111)GO TO 72
      IF(NRBA.EQ.11111)GO TO 73
      IF(DIST(NLEA).GE.DIST(NRBA))GO TO 73
  72  IRIGHT=0
      RETURN
  73  LEFT=0
      RETURN
      END
C***********************************************************************
      SUBROUTINE LACHDE(IV,LR,NEED,IOK)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/WRIN/IWR,TW6,TW6R,IW7,IW27,TW1,FUE(2)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IBST(430)
      COMMON/TEMP/TIME
      IOK=0
      XP=DIST(LR)-DIST(IV)
      AD=ACDE(IV)
      VE=VEL(IV)
      DI=DIST(IV)
      IF(AD.GE.0.)GO TO 1
   2  A=0.167*AD
      B=0.667*VE+0.333*VEL(LR)
      D=DIST(LR)
      IF(VEL(LR).EQ.0.)D=D-COMP(LR)-STDIS(IV)
      C=DI-D
      SQ=B**2-4.*A*C
      IF(SQ.LT.0.)SQ=0.
      TP=(-B+SQRT(SQ))/(2.*A)
      SL=(VEL(LR)-VE-(AD*TP))/(TP**2/2.)
      IF(TIME.GT.TW6)WRITE(6,10)VEL(LR),VEL(IV),ACDE(LR)
     1,ACDE(IV),XP,SL,TP
  10  FORMAT(20X,'VFR=',F5.1,'   VHK=',F5.1,
     1        3X,'AFR=',F5.2,'   ABK=',F5.2,
     2        3X,'D=',F6.1,/,
     3        20X,'SLOPE(K=',F5.2,
     4        3X,'TIME=',F5.2)
      IF(SL.GE.0.)GO TO 4
      DECMAX=-(AD+SL*TP)
      IF(TIME.GT.TW6)WRITE(6,20)DECMAX
  20  FORMAT(30X,'DECMAX=',F5.2)
      IF(C.LT.-100.)GO TO 4
      IF(NEED.EQ.1)GO TO 3
      IF(DECMAX.GT.DEC(IV))RETURN
C POSSIBLE TO CHANGE LANES
   4  IOK=1
      IF(TIME.GT.TW6)WRITE(6,30)
  30  FORMAT(30X,'POSSIBLE LANE CHANGE')
      RETURN
   3  IF(DECMAX.GT.DEC(IV)*1.5)RETURN
      GO TO 4
   1  SX=-(AD+0.1)
      VE=VE+AD+0.5*SX
      DI=DI+VE+0.5*AD+0.167*SX
      AD=-0.1
      GO TO 2
      END
C***********************************************************************
      SUBROUTINE LACHAN(IRIGHT,LEFT,K)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/DVEL/LVCH,IOLA
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/TEMP/TIME
      COMMON/WRIN/IWR,TW6,TW6R,IW7,IW27,TW1,FUE(2)
      COMMON/COLD/HED(1000,3),MHE(3),ADD(4),NADD(4),KL21,KL12,
     1H9(4),XLAL(1700,4)
      IF(IRIGHT.NE.0)GO TO 1
      IF(LEFT.EQ.1)GO TO 2
      RETURN
   1  LVCH=K
      IOLA=LANE(K)
      LANE(K)=LANE(K)-1
      KL21=KL21+1
      IF(TIME.GT.TW6R)WRITE(6,10)K
      IF(TIME.GT.TWR)WRITE(9,10)K
  10  FORMAT(1X,'+++++++  VEH=',I6,2X,'+++++++ CHANGED LANE
     1 TO RIGHT')
      RETURN
   2  LVCH=K
      IOLA=LANE(K)
      LANE(K)=LANE(K)+1
      KL12=KL12+1
      IF(TIME.GT.TW6R)WRITE(6,20)K
      IF(TIME.GT.TWR)WRITE(9,20)K
  20  FORMAT(1X,'+++++++  VEH=',I6,2X,'+++++++ CHANGED LANE
     1 TO LEFT')
      RETURN
      END
C***********************************************************************
      SUBROUTINE LALIST(K,KK)
      IMPLICIT REAL*4(A-F,H,O-Z)
```

```
C
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IHST(430)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COPP(430),LANE(430),WID(430)
      COMMON/ANUI/M
      COMMON/LTOT/MTOTAL(3)
      COMMON/VNUL/ML(3,143)
      COMMON/SIMP/ISAM(6)
      COMMON/CLAL/ISEND(6,3)
      COMMON/FSTP/IFIS(6,3)
      COMMON/DVCL/LVCH,ICLA
      COMMON/EPUT/SIGP(6)
      COMMON/INTE/PITE(12),RA(12)
      COMMON/AMBR/GAVCRT,GSDCRT,XMICRT,XMACRT
      COMMON/PRIO/IPRI
      COMMON/TEMP/TIME
      COMMON/WEIN/TWR,TWP,TW6B,IW7,IW27,TW1,FUE(2)
      ITRY=TIME
      IF((ITRY.EQ.2062).AND.(K.EQ.302))GO TO 9999
 9998 IF(TIME.GT.TW6B)WRITE(6,1000)K
 1000 FORMAT(12X,I4)
      IF(LANE(K).GT.3)WRITE(9,30)TIME
      IF(LANE(K).GT.3)WRITE(6,30)TIME
 30   FORMAT(1X,'PROBABLY A VEH HAS BEEN GENERATED IN MAIN LANES
     1WITH DIST. LE. 0.000',/,' TIME= ',F6.1)
      JHH=0
      IF((IPRI.EQ.1).AND.(LANE(K).NE.3).AND.(ITIPO(K).EQ.3))
     1WRITE(6,50)
      IF((IPRI.EQ.1).AND.(LANE(K).EQ.3).AND.(ITIPO(K).NE.3))
     1WRITE(6,40)
 40   FORMAT(//////,' INVASION OF BUS LANE HAS OCCURRED',///)
 50   FORMAT(//////,' BUS LEFT BUS LANE',///)
      MTOTAL(LANE(K))=MTOTAL(LANE(K))+1
      ML(LANE(K),MTOTAL(LANE(K)))=K
      IF(KK.EQ.M)GO TO 1
      GO TO 2
 1    DO 100 J=1,3
      N=MTOTAL(J)+1
      DO 200 L=N,143
      IF(ML(J,L).EQ.0)GO TO 100
      ML(J,L)=0
  200 CONTINUE
  100 CONTINUE
 2    CALL TSPANE(K,MSTP)
      IF(MSTP.EQ.44)RETURN
      IF((LEGAT(K).GT.3).AND.(PITE(LEGAT(K)).LT.
     1SIGP(MSTP)))GO TO 13
      IF(ISEND(MSTP,LANE(K)).EQ.1)GO TO 3
 6    IF(ISAM(MSTP).EQ.1)GO TO 4
      IF(IFIS(MSTP,LANE(K)).EQ.0)RETURN
      IF(K.EQ.LVCH)GO TO 5
      IF(JHH.EQ.0)GO TO 12
      IF(IFIS(MSTP,LANE(K)).NE.K)RETURN
      ISEND(MSTP,LANE(K))=1
      IFIS(MSTP,LANE(K))=11111
      RETURN
 3    IFIS(MSTP,LANE(K))=K
      ISEND(MSTP,LANE(K))=0
      GO TO 6
 13   JHH=1
      GO TO 6
 4    IF(IFIS(MSTP,LANE(K)).NE.11111)RETURN
      IF(JHH.EQ.1)RETURN
C DECIDE IF THIS VEH IS GOING TO STOP
      TARGET=SIGP(MSTP)-STDIS(K)
      DST=TARGET-DIST(K)
      IF(VEL(K).EQ.0.)GO TO 7
      TITA=DST/VEL(K)
      IF(TITA.LE.XMICRT)RETURN
      IF(TITA.GT.XMACRT)GO TO 7
      CALL NORMAL(9,GAVCRT,GSDCRT,XMICRT,XMACRT,GN)
      IF(TITA.GT.GN)GO TO 7
      RETURN
 7    IFIS(MSTP,LANE(K))=K
      RETURN
 5    IF(K.EQ.IFIS(MSTP,ICLA))GO TO 8
      IF(JHH.EQ.1)RETURN
      IF(IFIS(MSTP,LANE(K)).EQ.11111)GO TO 7
      IF(DIST(K).GT.DIST(IFIS(MSTP,LANE(K))))GO TO 10
      RETURN
 10   IF(IFIS(MSTP,ICLA).EQ.0)GO TO 9
      IF(IFIS(MSTP,ICLA).EQ.11111)GO TO 9
      IF(DIST(K).LT.DIST(IFIS(MSTP,ICLA)))GO TO 9
      RETURN
 9    IFIS(MSTP,LANE(K))=K
      RETURN
 8    ISEND(MSTP,ICLA)=1
      IFIS(MSTP,ICLA)=11111
      IF(IFIS(MSTP,LANE(K)).EQ.11111)GO TO 11
      IF(DIST(K).GT.DIST(IFIS(MSTP,LANE(K))))GO TO 11
      RETURN
 11   IF(JHH.EQ.1)RETURN
      GO TO 9
 12   IF(IFIS(MSTP,LANE(K)).EQ.11111)IFIS
     1(MSTP,LANE(K))=K
      RETURN
 9999 WRITE(9,*)K,LANE(K),ICLA,LVCH
      DO 9997 JVV=1,6
      WRITE(9,*)(IFIS(JVV,JCC),JCC=1,3)
 9997 CONTINUE
      DO 9996 JVV=1,6
      WRITE(9,*)(ISEND(JVV,JCC),JCC=1,3)
 9996 CONTINUE
      GO TO 9998
      END
C*********************************************************************
      SUBROUTINE PROUPD(IREN)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/LASTVEHAFTERSIGNAL/LVAS(6,3)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IHST(430)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/PEST/BUPO(20)
      COMMON/SPOT/SIGP(6)
      COMMON/INTE/PITE(12),RA(12)
      COMMON/LTOT/MTOTAL(3)
      COMMON/VNUL/ML(3,143)
      COMMON/CHAL/AFL(3),
     1BBL(3),CCL(3),ESTL(3)
      COMMON/FFCN/AA,BB,CC
      COMMON/LLIT/LEAT(7)
```

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      COMMON/FLTT/IFOLT(7),
     1DBUF(7),VBUF(7),ABUF(7)
      COMMON/STCA/GSTD,GSDST,XMIST,XMAST
      COMMON/CORE/ICOR(6)
      COMMON/FLOW/IXO(7)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/RGUE/IRG(6,7),INLDW(6,3)
      COMMON/WRIN/TWR,TWK,TWCH,IW7,IW27,TW1,FUE(2)
      COMMON/TEMP/TIME
      COMMON/COLD/HED(1000,3),MHE(3),ADD(4),NADD(4),KL21,KL12,
     1H9(4),XLAL(1700,4)
      IREM=0
      DO 6000 L=1,3
      DO 6000 J=1,6
      LVAS(J,L)=0
 6000 CONTINUE
C TAKING LANES 2 AND 3
      DO 600 L=2,3
      IF(MTOTAL(L).EQ.0)GO TO 600
      DO 330 II=1,MTOTAL(L)
      I=ML(L,II)
      IF(II.EQ.1)GO TO 2
      JR=ML(L,II-1)
   21 XSFR=XSTOP
      CALL UPDATE(I,JR,L,XSTOP)
      IF((IW27.EQ.1).AND.(L.EQ.3).AND.(ITIPO(I).EQ.3))WRITE(27,111)
     1DIST(I),TIME,INUM(I)
  111 FORMAT(1X,2F8.3,I6)
      IF((CC.LT.H9(ITIPO(I))).AND.(DIST(I).GT.H9(ITIPO(I))))GO TO 999
  997 IF((DIST(I).GT.H9(ITIPO(I))).AND.(INJM(I).LE.IXO(3)).AND.
     1(TPRG(I).LT.FUE(2)-200).AND.(TPRG(I).GT.FUE(1)).AND.
     2(LEGAT(I).LE.3))CALL FUELCO(I)
      IF((BB.LT.0.05).AND.(VEL(I).LT.0.05).AND.(DIST(I).GT.XSTOP
     1-10.).AND.(DIST(I).LT.XSTOP).AND.(VEL(I).NE.0.))WRITE(6,63)
     2I,XSTOP,DIST(I),VEL(I),ACDE(I),LANE(I)
   63 FORMAT('SLOW=',I4,2X,'XSTOP=',F6.2,2X,'DIST=',
     1F5.2,2X,'VEL=',F4.2,2X,'ACDE=',F4.2,2X,'LANE=',I2)
      CALL REMOST(I,IREM)
      CALL LINKFD(I,L)
      CALL TSPAHE(I,MSTP)
      IF(MSTP.EQ.44)GO TO 330
      IF((XSTOP.GT.SIGP(MSTP)-XMAST).
     1AND.(XSTOP.LT.SIGP(MSTP)))GO TO 121
      IF(JR.EQ.0)GO TO 221
      IF((DIST(JR).GT.SIGP(MSTP)).AND.(DIST(JR).
     1LT.SIGP(MSTP)+10.7))LVAS(MSTP,L)=22222
      GO TO 221
  330 CONTINUE
C DUE TO GENERATION REQUIREMENTS,
      AAL(L)=AA
      BBL(L)=BB
      CCL(L)=CC
      LSTL(L)=I
  600 CONTINUE
C TAKING LANE 1
      L=1
      IF(MTOTAL(L).EQ.0)RETURN
      DO 100 II=1,MTOTAL(L)
      I=ML(L,II)
      IF(II.EQ.1)GO TO 4
      JR=ML(L,II-1)
   42 IF(II.EQ.MTOTAL(L))GO TO 5
      IBOB=ML(L,II+1)
      DIBOB=DIST(IBOB)
      VIBOB=VEL(IBOB)
      ACIBOB=ACDE(IBOB)
   51 DO 1000 KT=6,7
      IF((DIST(I).GT.PITE(KT)).AND.(DIBOB.LT.PITE
     1(KT)))GO TO 6
 1000 CONTINUE
      XSFR=XSTOP
      CALL UPDATE(I,JR,L,XSTOP)
      IF((CC.LT.H9(ITIPO(I))).AND.(DIST(I).GT.H9(ITIPO(I))))GO TO 999
  998 IF((DIST(I).GT.H9(ITIPO(I))).AND.(INJM(I).LE.IXO(3)).AND.
     1(TPRG(I).LT.FUE(2)-200).AND.(TPRG(I).GT.FUE(1)).AND.
     2(LEGAT(I).LE.3))CALL FUELCO(I)
      IF((BB.LT.0.05).AND.(VEL(I).LT.0.05).AND.(DIST(I).GT.XSTOP
     1-10.).AND.(DIST(I).LT.XSTOP).AND.(VEL(I).NE.0.))WRITE(6,53)
     2I,XSTOP,DIST(I),VEL(I),ACDE(I),LANE(I)
      CALL REMOTU(I,IREM)
      CALL REMOST(I,IREM)
      CALL LINKFD(I,L)
      CALL TSPAHE(I,MSTP)
      IF(MSTP.EQ.44)GO TO 100
      IF((XSTOP.GT.SIGP(MSTP)-XMAST).
     1AND.(XSTOP.LT.SIGP(MSTP)))GO TO 121
      IF(JR.EQ.0)GO TO 221
      IF((DIST(JR).GT.SIGP(MSTP)).AND.(DIST(JR).
     1LT.SIGP(MSTP)+10.7))LVAS(MSTP,L)=22222
      GO TO 221
  100 CONTINUE
      AAL(L)=AA
      BBL(L)=BB
      CCL(L)=CC
      LSTL(L)=I
      RETURN
   12 LVAS(MSTP,L)=JR
      GO TO 330
    2 JR=0
      XSTOP=11111.1
      GO TO 21
    4 DO 1100 LL=6,7
      IF(DIST(I).LT.PITE(LL))GO TO 41
 1100 CONTINUE
      JR=0
      XSTOP=11111.1
      GO TO 42
   41 LEAT(LL)=11111
      IFOLT(LL)=I
      DBUF(LL)=DIST(I)
      VBUF(LL)=VEL(I)
      ABUF(LL)=ACDE(I)
      IF(TIME.GT.TWR)WRITE(9,10)LL,LEAT(LL),IFOLT(LL)
   10 FORMAT(1X,'++++++','TLANENO=',I2,2X,'VEHINFRONTOFT=',I5
     1,2X,'VEHINBACKOFT=',I5)
      GO TO 1100
    5 IBOB=11111
      DIBOB=0.
      VIBOB=0.
      ACIBOB=0.
      GO TO 51
    6 LEAT(KT)=I
      IFOLT(KT)=IBOB
      DBUF(KT)=DIBOB
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      VDUF(KT)=VIHOB
      ADUF(KT)=ACIHOB
      IF(TIME.GT.TWR)WRITE(9,10)KT,LEAT(KT),IFOLT(KT)
      GO TO 100
 71   LVAS(MSTP,L)=JR
      GO TO 100
 999  DV=(HE+VEL(I))/2.
      DD=DIST(I)-H9(ITIPO(I))
      DT=DD/DV
      TPAG(I)=TIME-DT
      MHE(L)=MHE(L)+1
      HED(MHE(L),L)=TPRG(I)
      IF(L.EQ.1)GO TO 998
      GO TO 997
 121  IF(ICOR(MSTP).EQ.1)GO TO 122
      IF((VEL(I).EQ.0).AND.(DIST(I).EQ.XSTOP))GO TO 123
 122  IF(L.EQ.1)GO TO 71
      GO TO 12
 123  IXG(MSTP,L)=I
      IREDG(MSTP,L)=1
      GO TO 122
 221  IF(JR.NE.IXG(MSTP,L))GO TO 222
      IF(VEL(I).NE.0)GO TO 222
      IF(JR.EQ.0)GO TO 222
      IF((DIST(JR)-DIST(I)).GT.30)GO TO 222
      IXG(MSTP,L)=I
      IREDG(MSTP,L)=IREDG(MSTP,L)+1
 222  IF(L.EQ.1)GO TO 100
      GO TO 330
      END
C*************************************************************************
      SUBROUTINE LINKPG(I,L)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/SPOT/SIGP(7)
      COMMON/NLIN/NVL(6,3)
      DO 1 JK=1,6
      JB=7-JK
      JA=6-JK
      XB=SIGP(JB)
    5 IF(JA.EQ.0)GO TO 2
      XA=SIGP(JA)
      IF(XA.EQ.0)GO TO 4
 3    IF((DIST(I).LE.XB).AND.(DIST(I).GT.XA))NVL(JB,L)=NVL(JB,L)+1
 1    CONTINUE
      RETURN
 2    XA=0
      GO TO 3
 4    JA=JA-1
      GO TO 5
      END
C*************************************************************************
      SUBROUTINE WVEHRE(KK,J,JR)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1INUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GEN1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/CAN1/STDIS1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IEST1(4000)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/TEMP/TIME
      COMMON/CHPL/AAL(3),
     1BBL(3),CCL(3),LSTL(3)
      COMMON/ITGF/BB1(3),CC1(3),D(3)
      COMMON/CTSE/CS
      AA=AAL(KK)
      BB=BBL(KK)
      CC=CCL(KK)
      AL=(COMP(JR)+COMP1(J))/2.
      T=TPRG1(J)-(TIME-1.)
C CALCULATE POS & SPEED OF LEADER AT EXACT TIME GEN FOLL
      S=ACDE(JR)-AA
      BB1(KK)=BB+AA*T+0.5*S*T*T
      CC1(KK)=CC+BB*T+AA*T*T/2.+0.167*S*T*T*T
C CONSIDERING SPEED OF FOLL=SPEED OF LEADER,AND LEADER
C APLLYING  MAX BREAK STOP,INITIAL SEPAR BETWEEN VEH=D
      D(KK)=STDIS1(J)+BB1(KK)
      IF(BB1(KK).EQ.0.)GO TO 5
C CALCULATE MINIMUM HEADWAY REQUIRED BY LEADER
    6 TMIN=(COMP(JR)+D(KK))/BB1(KK)
      HEDNOW=CC1(KK)/BB1(KK)
      IF(TMIN.GT.HEDNOW)GO TO 7
      DA=COMP(JR)+D(KK)
      DB=DA-CC1(KK)
      IF(DB.LE.0.)GO TO 2
      XT=DB/BB1(KK)
      GO TO 1
    7 XT=TMIN-HEDNOW
      GO TO 1
    2 TRGER1(J)=TPRG1(J)
      RETURN
    1 TRGER1(J)=TPRG1(J)+XT
C CHECK SO THAT VEH IS NOT TOO MUCH DELAYED
      KT=TRGER1(J)
      KA=TPRG1(J+1)
      IF(KT.GE.KA)GO TO 3
      RETURN
    3 TRGER1(J)=(KA-1)+0.999
      RETURN
    5 IF(CC1(KK).GT.30.)GO TO 2
      BB1(KK)=0.01
      GO TO 6
      END
C*************************************************************************
      SUBROUTINE UPDATE(I,JR,L,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/STCA/GSTD,ESDST,XMIST,XMAST
      COMMON/FRCN/AA,BB,CC
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/CTSE/CS
      COMMON/FBST/NUPOS(20)
      COMMON/INTE/PITE(12),KA(12)
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      COMMON/SPOT/SIGP(6)
      COMMON/RGRE/DSONL
      COMMON/TEMP/TIME
      COMMON/WRIN/TWR,TW6,TW68,IW7,IW27,TW1,FUE(2)
      COMMON/CORE/ICOR(6)
      COMMON/PRIO/IPRI
      COMMON/BUSF/IBS,ISC
      COMMON/SNFE/ISNB(2)
      ITURN=0
      ICO=0
      LICO=0
      MICO=0
      IF(JR.EQ.0)GO TO 997
      IF((IPRI.EQ.1).AND.(L.EQ.3).AND.(INUM(JR).GT.
     1INUM(I)))GO TO 999
  997 XSFR=XSTOP
      CALL STOPOS(I,JR,L,XSTOP)
      IF(XSTOP.GT.10000.)XSTOP=11111.1
      IF(JR.EQ.0)GO TO 123
      XL=(COMP(JR)+COMP(I))/2.
      DF=CC-COMP(JR)-(STDIS(I)+XL)*EXP(BB/CS)+XL
  124 IF(TIME.GT.TWR)WRITE(9,10)XSTOP,I,JR,DF
   10 FORMAT(1X,'XSTOP=',F9.3,2X,'I=',I5,2X,'JR=',I5,
     12X,'FCLDIS=',F5.3)
      IF((DIST(I).GE.XSTOP-0.2).AND.(VEL(I).LE.1.))GO TO 7
C IF VEH IS A CAP ALLOWER THAT HAS TO REACT TO STOP ONLY
      IF(DSONL.EQ.1)GO TO 222
      DO 100 K=1,6
      IF((XSTOP.GE.SIGP(K)-XMAST).AND.(XSTOP.LE.SIGP
     1(K)).AND.(ICOR(K).NE.1))GO TO 103
  100 CONTINUE
      IF((ITIPO(I).EQ.3).AND.(IBST(I).NE.85))GO TO 11
      IF(LEGAT(I).GT.3)GO TO 13
   17 DETU=0.
   12 IF(JR.EQ.0)GO TO 14
      CALL WDECLE(I,JR,LICO)
      IF(LICO.EQ.0)GO TO 15
C  HERE  CHECK WHICHDECELISBIGGER:TO
C  TURN OR TO LEADER
      CALL WDTULE(DETU,I,JR,ITURN)
      IF(ITURN.EQ.1)GO TO 141
   26 CALL DECLEA(I,JR,XSTOP)
      RETURN
   15 IF(DETU.EQ.0.)GO TO 151
      GO TO 141
C CHECK IF THIS SIGNAL IS RELEVANT FOR BUSES'
  103 IF(IPRI.EQ.0)GO TO 778
      IF(ITIPO(I).NE.3)GO TO 778
      DO 777 NF=1,2
      IF(K.EQ.ISNB(NF))GO TO 100
  777 CONTINUE
C HOWEVER,IF XSTOP OF FRONT VEH IS BEFORE SIGP,
  778 IF((XSFR.GT.XSTOP).AND.(XSFR.LT.SIGP
     1(K)))GO TO 104
      GO TO 101
  104 WRITE(6,105)
  105 FORMAT(6X,'A VEH WILL STOP BETWEEN THIS AND SIGP',/)
      GO TO 100
  111 CALL WDECST(I,XSTOP,ICO)
      IF(ICO.EQ.1)GO TO 16
      GO TO 151
   11 BUST=BUPO(IBST(I))
      IF((XSTOP.GE.BUST-30.).AND.(XSTOP.LE.BUST))GO TO 18
      GO TO 17
   18 IF(JR.EQ.0)GO TO 101
      IF(CC.LE.BUST)GO TO 20
      GO TO 101
   20 IF(ITIPO(JR).EQ.3)GO TO 21
      GO TO 22
   21 IF(IBST(JR).EQ.IBST(I))GO TO 23
      GO TO 301
   23 CALL WDECLE(I,JR,LICO)
      IF(LICO.EQ.1)GO TO 26
  151 CALL KSPACC(I,JR,XSTOP)
      RETURN
   22 CALL WDECLE(I,JR,LICO)
      CALL WDECST(I,XSTOP,ICO)
      IF((LICO.EQ.0).AND.(ICO.EQ.0))GO TO 151
      IF((LICO.EQ.0).AND.(ICO.EQ.1))GO TO 16
      IF((ICO.EQ.1).AND.(LICO.EQ.1))GO TO 27
      IF((ICO.EQ.0).AND.(LICO.EQ.1))GO TO 26
   27 CALL WDSTLE(I,JR,XSTOP,MICO)
      IF(MICO.EQ.1)GO TO 26
   16 CALL DECSTO(I,XSTOP)
      RETURN
   13 IF(LANE(I).NE.1)GO TO 1010
      CALL WDECTU(I,DETL,XSTOP)
      GO TO 12
   14 IF((DETU.NE.0.).AND.(LEGAT(I).GT.3))GO TO 141
      GO TO 151
 1010 IF(DIST(I).GT.PITE(LEGAT(I))-50.)WRITE(6,1011)I,INUM(I),
     1DIST(I),VEL(I),LANE(I)
 1011 FORMAT(1X,'VEH=',I4,2X,'INUM=',I5,2X,'IS IN RUNNING TROUBLE AT'
     1,F6.3,2X,'VEL=',F6.3,2X,'LANE=',I2,/)
      GO TO 222
C BEFORE RETURNING EVALIATE AA,BB,CC SO THAT FOLL. CAN BE UPDAT
    7 AA=0.
      BB=5.
      CC=XSTOP
      DIST(I)=XSTOP
      RETURN
  123 DF=0.
      GO TO 124
  141 CALL DECTUR(DETU,I)
      RETURN
  222 IF(JR.EQ.0)GO TO 101
      GO TO 22
  301 IF((IPRI.EQ.0).OR.(IBS.EQ.0))GO TO 22
      IGR=2
      IF(IBST(I).LE.IBS)IGR=1
C ARE ORDERED PLATOONS USED?
      IF(ISC.EQ.1)GO TO 302
C THEN NO ORDERED PLATOONS,ISC=0
      IF((IBST(JR).GT.(IBS*IGR)).AND.((DIST(JR)-
     1COMP(JR)-STDIS(I)).GT.BUST))GO TO 101
      IF(IBST(JR).LT.(IBST(I)-2))GO TO 22
      GO TO 23
  302 IF((IBST(JR).GT.(IBS*IGR)).AND.((DIST(JR)-
     1COMP(JR)-STDIS(I)).GT.BUST))GO TO 101
      GO TO 23
  999 WRITE(6,998)TIME
      WRITE(9,998)TIME
  998 FORMAT(////,'BUS JUMP OVER ANOTHER AT=',F7.2)
      STOP
      END
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C*****************************************************************************
      SUBROUTINE STOPOS(I,JR,L,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/CORE/ICOR(6)
      COMMON/BANA/FLAG(430)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CANA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),LEC(430),IBST(430)
      COMMON/FRON/AA,BB,CC
      COMMON/PEST/BUPO(20)
      COMMON/BUAR/LBA1,LBA2
      COMMON/XSBA/XSBA1,XSBA2
      COMMON/SPOT/SIGP(6)
      COMMON/INTE/PITE(12),WA(12)
      COMMON/HGRE/DSONL
      COMMON/CLAL/ISENL(6,3)
      COMMON/FSTP/IFIS(6,3)
      COMMON/IVCL/LVEH,IOLA
      COMMON/STCA/GSTD,GSDST,XPIST,XPAST
      COMMON/BUSP/IBS,ISC
      COMMON/PRIO/IPRI
      MV=1
      IF(IPRI.EQ.1)MV=3
      DSONL=0
      IREST=0
      IMA=0
C IF THIS VEH HAS TO ALLOW ANOTHER TO MOVE FROM LANE 2OR3 IN FRONT OF IT
      IF(FLAG(I).NE.0.)GO TO 124
  125 CALL ISPARE(I,MSTP)
      IF(MSTP.EQ.44)GO TO 1
      SIGNAL=SIGP(MSTP)-STDIS(I)
   13 IF(JR.EQ.0)GO TO 2
      K=JR
C IS VEH BUS NOT SERVED YET & LANE =MV
      IF((ITIPO(I).EQ.3).AND.(IBST(I).NE.85).AND.
     1(LANE(I).EQ.MV))GO TO 169
C IF VEH IS STOPPED INSIDE FRONTS AREA& FRONT VEH STOPPED
  168 IF((VEL(I).EQ.0.).AND.(DIST(I).GE.DIST(K)-COMP(K)-
     1STDIS(I)-0.3).AND.(BB.EQ.0.))GO TO 3
C HAS VEH ALREADY BEEN SERVED AT BUSTOP?
    2 IF(IBST(I).EQ.85)GO TO 221
      IF(ITIPO(I).NE.3)GO TO 22
C IF BUS PLATOONS ARE USED AT THE BUS STOPS,
      IF(IBS.NE.0)GO TO 44
      IF((DIST(I).GE.BUPO(IBST
     1(I))-30.).AND.(DIST(I).LE.BUPO(IBST(I))).AND.
     2(LANE(I).EQ.MV).AND.(VEL(I).EQ.0.))GO TO 4
   22 IF(JR.EQ.0)GO TO 5
C IF FRONT VEH IS STOPPED, AND FOLLOW(I) NOT STOPPED
      IF((VEL(JR).EQ.0.).AND.(VEL(I).NE.0.))GO TO 69
      XSTOPFRONT=XSTOPFRONT-COMP(K)-STDIS(I)
   68 IF(XSTOPFRONT.LT.DIST(I))XSTOPFRONT=DIST(I)
      IF((ITIPO(I).EQ.3).AND.(IMA.EQ.0))GO TO 6
C IF VEH IS A TURNING ONE IN WRONG LANE ALMOST AT TURNING POINT,
      IF((LEGAT(I).GT.3).AND.(LANE(I).NE.1).AND.(DIST(I).LE.
     1PITE(LEGAT(I))).AND.(DIST(I).GT.PITE
     2(LEGAT(I))-200.))GO TO 7
      BUSTOP=11111.1
      TURN=11111.1
      GO TO 8
  169 IF((DIST(I).GE.BUPO(IBST(I))-30.).AND.(DIST(I).
     1LE.BUPO(IBST(I))))GO TO 2
      GO TO 168
    3 XSTOP=CC-COMP(K)-STDIS(I)
      IF(XSTOP.LT.DIST(I))XSTOP=DIST(I)
      XSTOPFRONT=XSTOP
      RETURN
    6 IF(LANE(I).EQ.MV)GO TO 61
C THEN THIS IS A BUS THAT HAS NOT BOARD/ALIGHT YET AND IS
C IN LANE .NE. MV
      TURN=11111.1
      BUSTOP=BUPO(IBST(I))-30.
      GO TO 8
   61 TURN=11111.1
      BUSTOP=BUPO(IBST(I))
    8 X=MIN(XSTOPFRONT,BUSTOP,TURN)
      IF(X.LT.SIGNAL)GO TO 9
      GO TO 10
    9 XSTOP=X
      XSTOPFRONT=XSTOP
      RETURN
    7 TURN=PITE(LEGAT(I))-20.
      BUSTOP=11111.1
      GO TO 8
    5 IF((ITIPO(I).EQ.3).AND.(IMA.EQ.0))GO TO 11
C IF VEH IS A TURNING ONE IN WRONG LANE ALMOST AT TURNING POINT,
      IF((LEGAT(I).GT.3).AND.(LANE(I).NE.1).AND.(DIST(I).LE.
     1PITE(LEGAT(I))).AND.(DIST(I).GT.PITE
     2(LEGAT(I))-200.))GO TO 12
      BUSTOP=11111.1
      TURN=11111.1
      XSTOPFRONT=11111.1
      GO TO 10
   12 TURN=PITE(LEGAT(I))-20.
      BUSTOP=11111.1
      XSTOPFRONT=11111.1
      GO TO 10
    1 SIGNAL=11111.1
      GO TO 13
   11 IF(LANE(I).EQ.MV)GO TO 111
      XSTOPFRONT=11111.1
C THEN THIS IS A BUS THAT HAS NOT BOARD/ALIGHT YET AND THAT IS
C IN LANE .NE. MV
      TURN=11111.1
      BUSTOP=BUPO(IBST(I))-30.
      GO TO 10
  111 XSTOPFRONT=11111.1
      TURN=11111.1
      BUSTOP=BUPO(IBST(I))
   10 IF((SIGNAL.EQ.11111.1).OR.(MSTP.EQ.44))GO TO 14
      IF(ICOR(MSTP).EQ.1)GO TO 15
      IF(ICOR(MSTP).EQ.2)GO TO 16
      IF((DIST(I).GE.SIGNAL-0.5).AND.(DIST(I).LE.SIGNAL+
     10.5).AND.(VEL(I).EQ.0.))GO TO 14
      IF(VEL(I).EQ.0.)GO TO 14
      GO TO 17
   14 XSTOP=MIN(XSTOPFRONT,SIGNAL,BUSTOP,TURN)
      XSTOPFRONT=XSTOP
      RETURN
   15 SIGNAL=11111.1
      GO TO 14
   16 IF((DIST(I).GE.SIGNAL-0.5).AND.(DIST(I).LE.SIGNAL+
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     10.5).AND.(VEL(I).EQ.0.))GO TO 14
 17  IF(IFIS(MSTP,L).EQ.I)GO TO 14
     IF(IFIS(MSTP,L).EQ.11111)GO TO 15
     IF(DIST(I).GT.DIST(IFIS(MSTP,L)))GO TO 15
     GO TO 14
  4  CALL BSTIM1(I,IMA,IREST)
445  IF(IREST.EQ.1)GO TO 222
     GO TO 22
 69  XSTOPFRONT=DIST(JK)-STDIS(I)-COMP(JR)
     GO TO 69
221  IMA=1
     GO TO 22
222  XSTOP=DIST(I)
     XSTOPFRONT=XSTOP
     RETURN
123  XSTOP1=XSTOPFRONT-COMP(JR)-STDIS(I)
     XSTOP2=DIST(IFLAG)-COMP(IFLAG)-STDIS(I)
     CALL TSPAHE(I,MSTP)
     IF(MSTP.EQ.44)GO TO 1000
     SIGNAL=SIGP(MSTP)-STDIS(I)
     IF(ICOR(MSTP).EQ.1)GO TO 1000
     IF(IFIS(MSTP,L).EQ.I)GO TO 1003
     IF(IFIS(MSTP,L).EQ.11111)GO TO 1003
     IF(DIST(I).GT.DIST(IFIS(MSTP,L)))GO TO 1000
1003 XSTOP=MIN(XSTOP1,XSTOP2,SIGNAL)
     XSTOPFRONT=XSTOP
     IF(XSTOP.EQ.XSTOP2)DSONL=1
     RETURN
1000 SIGNAL=11111.1
     GO TO 1003
124  IFLAG=FLAG(I)
     IF(LANE(IFLAG).GT.LANE(I))GO TO 123
     GO TO 125
 44  IF((DIST(I).GE.BUPO(IBST(I))-XFAST).AND.
    1(DIST(I).LE.BUPO(IBST(I))).AND.
    2(LANE(I).EQ.MV).AND.(VEL(I).EQ.0.))GO TO 444
     GO TO 22
444  CALL BSTIM2(I,IMA,IREST)
     GO TO 445
     END
C*************************************************************************
     SUBROUTINE BSTIM1(I,IMA,IREST)
     IMPLICIT REAL*4(A-F,H,O-Z)
C
     COMMON/INFA/DIST(430),VEL(430),ACDE(430),
    1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
     COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
    1ACC(430),DEC(430),IBST(430)
     COMMON/BSTP/BUPO(20)
     COMMON/TEMP/TIME
     COMMON/BUST/IKBUS(2,3),STXIME(2,3)
     COMMON/PSSE/AVPB,XMAB,KP,CF(3)
     COMMON/KRIN/TWR,TW6,TW6B,IW7,IW27,TW1,FUE(2)
     N=IBST(I)
C IS VEH ALREADY PLACED IN QUEUE OF STOPPED VEH?
     DO 100 IK=1,3
     IF(IKBUS(N,IK).EQ.I)GO TO 1
100  CONTINUE
C SELECT A PLACE FOR THIS BUS IN THE QUEUE, IF POSSIBLE
     DO 200 IK=1,3
     IJ=4-IK
     IF(IKBUS(N,IJ).NE.0)GO TO 2
200  CONTINUE
C QUEUE IS EMPTY
     IJ=0
     GO TO 4
C IS IT TIME TO LEAVE BUS STOP?
  1  IF(TIME.GT.STXIME(N,IK))GO TO 3
     IREST=1
     RETURN
  3  IKBUS(N,IK)=0
     STXIME(N,IK)=0.
     IF((N.EQ.1).AND.(BUPO(2).NE.0))GO TO 6
C FLAG TO INDICATE THAT VEH HAS ALREADY BEEN SERVED
     IBST(I)=55
  5  IMA=1
     WRITE(6,20)I
     IF(TIME.GT.TWR)WRITE(9,20)I
 20  FORMAT(2X,'THIS BUS IS LEAVING=',I6/)
     RETURN
C IS LAST PLACE (NO.3) AT BUS STOP TAKEN BY A BOARD./ALIGHT. BUS?
  2  IF(IJ.EQ.3)RETURN
  4  KVA=IJ+1
     IKBUS(N,IJ+1)=I
     IF(KP.EQ.1)GO TO 8
     PB=AVPB
     GO TO 7
C SELECT STOP TIME FOR BUS
  8  CALL NEGEXP(10,AVPB,XMAB,PB)
  7  TS=(CF(1)+CF(2)*PB)*CF(3)
     ITS=TS
     R=TS-ITS
     IF(R.GE.0.5)ITS=ITS+1
     STXIME(N,IJ+1)=TIME+ITS
     WRITE(6,10)I,KVA,STXIME(N,IJ+1),N
     IF(TIME.GT.TWR)WRITE(9,10)I,KVA,STXIME(N,IJ+1),N
 10  FORMAT(3X,'NO.VEH=',I6,4X,'NO.IN BUS QUEUE=',I2,
    14X,'STOPTIME=',F8.2,'     BUS STOP=',I3)
     RETURN
  6  IBST(I)=2
     GO TO 5
     END
C*************************************************************************
     SUBROUTINE BSTIM2(I,IMA,IREST)
     IMPLICIT REAL*4(A-F,H,O-Z)
C
     COMMON/INFA/DIST(430),VEL(430),ACDE(430),
    1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
     COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
    1ACC(430),DEC(430),IBST(430)
     COMMON/TEMP/TIME
     COMMON/BUSP/IBS,ISC
     COMMON/BUOS/IGBUS(20),STTIME(20)
     COMMON/PSSE/AVPB,XMAB,KP,CF(3)
     COMMON/KRIN/TWR,TW6,TW6B,IW7,IW27,TW1,FUE(2)
     N=IBST(I)
C IS VEH ALREADY PLACED IN QUEUE OF STOPPED VEH?
     IF(IGBUS(N).EQ.I)GO TO 1
C SELECT A PLACE FOR THIS BUS IN THE QUEUE, IF POSSIBLE
     IGBUS(N)=I
     GO TO 4
C IS IT TIME TO LEAVE BUS STOP?
  1  IF(TIME.GT.STTIME(N))GO TO 3
     IREST=1
```

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      RETURN
    3 IBUS(N)=0
      STTIME(N)=0
      IF(N.LE.IBS)GO TO 2
C FLAG TO INDICATE THAT VEH HAS ALREADY BEEN SERVED
      IBST(I)=55
    5 I-A=1
      WRITE(6,20)I
      IF(TIME.GT.TWR)WRITE(9,20)I
   20 FORMAT(5X,'THIS BUS IS LEAVING=',I6/)
      RETURN
    4 IF(KP.EQ.1)GO TO 8
      PB=AVPH
      GO TO 7
C SELECT STOP TIME FOR BUS
    8 CALL NEGEXP(10,AVPE,XMAB,PB)
    7 TS=((CF(1)*CF(2)*PB)+CF(3)
      ITS=TS
      R=TS-ITS
      IF(R.GE.0.5)ITS=ITS+1
      STTIME(N)=TIME+ITS
      WRITE(6,10)I,N,STTIME(N),DIST(I)
      IF(TIME.GT.TWR)WRITE(9,10)I,N,STTIME(N),DIST(I)
   10 FORMAT(5X,'NO.VEH=',I6,4X,' BUS STOP=',I2,
     14X,'STOPTIME=',F8.3,4X,'DIST=',F8.3)
      RETURN
    2 N=N+IBS
      IBST(I)=N
      GO TO 5
      END
C**********************************************************************
      SUBROUTINE TSPARE(I,MSTP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IBST(430)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/SPOT/SIGP(6)
      COMMON/PRIO/IPRI
      COMMON/SNBB/ISNB(2)
      MSTP=44
      IF((IPRI.EQ.1).AND.(ITIPO(I).EQ.3))GO TO 2
      DO 1 JK=1,6
      JY=7-JK
      IF(DIST(I).LE.SIGP(JY)-STDIS(I))MSTP=JY
    1 CONTINUE
      RETURN
    2 CONTINUE
      DO 3 JK=1,6
      JY=7-JK
      DO 4 JV=1,2
      IF(JY.EQ.ISNB(JV))GO TO 3
    4 CONTINUE
      IF(DIST(I).LE.SIGP(JY)-STDIS(I))MSTP=JY
    3 CONTINUE
      RETURN
      END
C**********************************************************************
      SUBROUTINE KSPACE(I,JR,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IBST(430)
      COMMON/FRON/AA,BB,CC
      COMMON/CTSE/CS
      FCC=CC
      FBB=BB
      FAA=AA
      AA=ACDE(I)
      BB=VEL(I)
      CC=DIST(I)
      IF(JR.EQ.0)GO TO 1
      XL=(COMP(JR)+COMP(I))/2.0
      W=(STDIS(I)+XL)*EXP(FBB/CS)
      U=FCC-COMP(JR)-CC+XL
      IF(AA.EQ.0.)GO TO 7
   11 IF(U.LE.W-0.1)GO TO 3
      AF=1000.
      GO TO 4
    3 AF=-(FBB-BB)**2/(L*LOG(U/W))
    4 S=-0.5*ACC(I)**2/VELD(I)
      AA=SQRT(ACC(I)**2-2*S*(-BB))
      AMA=AA+S
      AFIN=MIN(AF,AMA)
      IF(AFIN.EQ.AF)GO TO 5
      GO TO 6
    1 S=-0.5*ACC(I)**2/VELD(I)
      AA=SQRT(ACC(I)**2-2*S*(-BB))
    6 ACDE(I)=AA+S
      VEL(I)=BB+AA+0.5*S
      DIST(I)=CC+BB+0.5*AA+0.167*S
   12 IF(VEL(I).GE.0.99*VELD(I))GO TO 7
      IF(JR.EQ.0)GO TO 9
C CHECK IF MERGE
      DAFT=(XL+STDIS(I))*EXP(VEL(JR)/CS)-XL
      X=DIST(JR)-COMP(JR)-DAFT
      IF((ABS(VEL(JR)-VEL(I)).LE.0.2).AND.(DIST(I)
     1.GE.(X-1.)).AND.(DIST(I).LE.(X+1.)))GO TO 8
    9 IF(DIST(I).LE.XSTOP-0.2)RETURN
      DIST(I)=XSTOP
      VEL(I)=0.
      ACDE(I)=0.
      RETURN
    8 VEL(I)=VEL(JR)
      IF(VEL(I).GE.VELD(I))GO TO 10
      ACDE(I)=ACDE(JR)
      DIST(I)=X
      GO TO 9
    2 IF(BB.EQ.VELD(I))GO TO 10
      GO TO 11
   10 DIST(I)=CC+VELD(I)
    7 VEL(I)=VELD(I)
      ACDE(I)=0.
      RETURN
    5 DIST(I)=CC+BB+AF/2.
      VEL(I)=BB+AF
      ACDE(I)=AF
      GO TO 12
      END
C**********************************************************************
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      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      IF(ACDE(I).GT.0.)GO TO 1
      C=VEL(I)
      A=DIST(I)
      B=ACDE(I)
      S=-0.5*DEC(I)**2/VELD(I)
      X=-SQRT(DEC(I)**2-2*S*(-C))
      IF(B.LT.X)B=X
    4 DX=((-0.667*C*C)*(B-2.0*DEC(I)))/((B-DEC(I))*
     1(--DEC(I)))
      DATO=ASTOP-A
      IF(DX.GT.DATO)ICO=1
      RETURN
    1 S=-ACDE(I)
      C=VEL(I)+ACDE(I)+0.5*S
      A=DIST(I)+VEL(I)+0.5*ACDE(I)+0.167*S
      B=0.0
      GO TO 4
      END
C*************************************************************************
      SUBROUTINE RELVEH(I,JR,KK)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/ITRF/BB1(3),CC1(3),D(3)
      COMMON/CTSE/CS
      COMMON/CHAL/AAL(3),
     1BBL(3),CCL(3),LSTL(3)
      COMMON/TEMP/TIME
      IF(JR.EQ.0)GO TO 1
      T=TIME-TRGER(I)
      IF(TRGER(I).EQ.TPRG(I))GO TO 4
C REAVALIATE CHARACT OF LAST VEH IN LANE
      AA=AAL(KK)
      BB=BBL(KK)
      CC=CCL(KK)
      S=ACDE(JR)-AA
      TT=1-T
      BB1(KK)=BB+AA*TT+0.5*S*TT*TT
      CC1(KK)=CC+BB*TT+AA*TT*TT*0.5+0.167*S*TT*TT*TT
      D(KK)=STDIS(I)+BB1(KK)
    4 VEL(I)=VELD(I)
      XL=(COMP(JR)+COMP(I))/2.
      U=CC1(KK)-COMP(JR)+XL
      IF(U.LE.0)WRITE(9,100)KK,JR,I,DIST(JR),VEL(JR),ACDE(JR)
      W=(XL+STDIS(I))*EXP(BB1(KK)/CS)
      IF(U.LE.W+0.1)GO TO 2
      S=-0.5*DEC(I)**2/VELD(I)
    3 IF(VEL(I).LT.BB1(KK))GO TO 11
C CHECK VISUAL ANGLE
      XW=WID(JR)
      IF((XW*(VEL(I)-BB1(KK))/CC1(KK)**2).LE.0.0005)GO TO 11
C CALCULATE REQUIRED DECEL & COMPARE
      DF=-(BB1(KK)-VEL(I))**2/(U*LOG(U/W))
      DF2=CS*(BB1(KK)-VEL(I))/U
      IF(DF2.GT.DF)DF=DF2
      X=-SQRT(DEC(I)**2-2.*S*(-VEL(I)))
      IF(DF.GT.X)GO TO 11
      VEL(I)=VEL(I)-0.5
      GO TO 3
    2 IF(VEL(I).LT.BB1(KK))GO TO 11
      VEL(I)=CS*LOG(U/(STDIS(I)+XL))
      VEL(I)=MIN(VEL(I),VELD(I),(BB1(KK)-0.1))
   11 VELG(I)=VEL(I)
      GO TO 10
C GENERATE VEHICLE AT ITS DESIRED SPEED
    1 VELG(I)=VELD(I)
      TRGER(I)=TPRG(I)
      T=TIME-TRGER(I)
   10 DIST(I)=VELG(I)*T
      IF((VELG(I).LT.0).OR.(DIST(I).LT.0))GO TO 200
      ACDE(I)=0.
C DUE TO GENERATION REQUIREMENTS,
C AA,BB,CC ARE EVALUATED NOW, AT THE FINAL,SINCE VEH IS REL
C EASED WHE TIME GT TRGER(I)
      AAL(KK)=ACDE(I)
      BBL(KK)=VEL(I)
      CCL(KK)=DIST(I)
      LSTL(KK)=I
  100 FORMAT(//,'ERROR IN GENERATION',/,'LANE=',I3,2X,
     1         'LAST VEH=',I6,'     VEH IN=',I5,/,3F8.3)
      RETURN
  200 WRITE(6,*)I,JR,U,XL,T,VEL(I),DIST(I)
      WRITE(9,*)I,JR,U,XL,T,VEL(I),DIST(I)
      CE=SQRT(-10.)
      RETURN
      END
C*************************************************************************
      SUBROUTINE WDECLE(I,JR,LICO)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/FRON/AA,BB,CC
      COMMON/CTSE/CS
      COMMON/TEMP/TIME
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/WRIN/IWR,IW6,IW66,IW7,IW27,IW1,FUE(2)
      IF(VEL(I).LT.BB)RETURN
C VEH IS FASTER OR EQUAL TO ITS LEADER
      XL=(COMP(JR)+COMP(I))/2.
      DSEF=(STDIS(I)+XL)*EXP(BB/CS)-XL
      X=CC-COMP(JR)-DSEF
      IF(DIST(I).GE.X-0.001)GO TO 1
C CHECK VISUAL ANGLE
      XW=WID(JR)
      IF((XW*(VEL(I)-BB)/(CC-DIST(I))**2).GT.0.0005)GO TO 1
      RETURN
    1 LICO=1
      IF(TIME.GT.TWR)WRITE(9,10)I
   10 FORMAT(1X,'VEH=',I5,' MAY REACT TO LEADER')
      RETURN
      END
C*************************************************************************
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      SUBROUTINE DECSTO(I,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1NUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/FRON/AA,BB,CC
      AA=ACDE(I)
      BB=VEL(I)
      CC=DIST(I)
      IF(ACDE(I).GT.0.)GO TO 1
    7 C=4.*VEL(I)*VEL(I)
      D=2.*VEL(I)
      F=6.*(XSTOP-DIST(I))
      S=-0.5*DEC(I)**2/VELD(I)
      X=-SQRT(DEC(I)**2-2*S*(-VEL(I)))
      IF(ACDE(I).LT.X)ACDE(I)=X
      IF(-(F*ACDE(I)).GE.0)GO TO 5
      E=SQRT((4.C*VEL(I)*VEL(I))+(6.0*(XSTOP-DIST(I))*ACDE(I)))
    3 DRQT=(-ACDE(I))-((C+D*E)/F)
      S=0.5*((ACDE(I)*ACDE(I))-(DRQT*DRQT))/VEL(I)
      IF(S.GT.0.)GO TO 6
      IF(ACDE(I)+S.LT.-4.2)S=-4.2-ACDE(I)
    2 VEL(I)=VEL(I)+AA+0.5*S
      IF(VEL(I).LE.0.)VEL(I)=0.
      IF(VEL(I).GT.VELD(I))ACDE(I)=0.0
      IF(VEL(I).GT.VELD(I))VEL(I)=VELD(I)
      DIST(I)=DIST(I)+BB+0.5*AA+0.167*S
      IF(DIST(I).GE.(XSTOP-0.2))GO TO 4
      ACDE(I)=ACDE(I)+S
      RETURN
    1 S=-ACDE(I)
      GO TO 2
    5 E=0.
      GO TO 3
    6 ACDE(I)=0.9*ACDE(I)
      WRITE(9,20)I,ACDE(I)
   20 FORMAT(4X,'NEW ACCEL OF',I6,'HAD TO BE DECREASED TO=',F8.3)
      GO TO 7
    4 VEL(I)=0.0
      ACDE(I)=0.0
      DIST(I)=XSTOP
      RETURN
      END
C***********************************************************************
      SUBROUTINE WDSTLE(I,JR,XSTOP,MICO)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1NUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/FRON/AA,BB,CC
      COMMON/COPA/HACDE,DECEL
      COMMON/CTSE/CS
      COMMON/WFIN/TWR,IW6,IW26,IW7,IW27,IW1,FUE(2)
      COMMON/TEMP/TIME
      XL=((COMP(I)+COMP(JR))/2.
      U=CC-COMP(JR)-DIST(I)+XL
      W=(XL+STDIS(I))*EXP(BB/CS)
      IF(U.LE.W+0.1)GO TO 1
      DECEL=-(BB-VEL(I))**2/(U*LOG(U/W))
      DF2=CS*(BB-VEL(I))/U
      IF(DF2.GT.DECEL)DECEL=DF2
      GO TO 4
    1 DECEL=CS*(BB-VEL(I))/U
    4 IF(-4.2.GT.DECEL)DECEL=-4.2
      IF(ACDE(I).GT.0.0)GO TO 5
      C=4.0*VEL(I)*VEL(I)
      D=2.0*VEL(I)
      F=6.*(XSTOP-DIST(I))
      S=-0.5*DEC(I)**2/VELD(I)
      X=-SQRT(DEC(I)**2-2*S*(-VEL(I)))
      IF(ACDE(I).LT.X)ACDE(I)=X
      IF(-(F*ACDE(I)).GE.0)GO TO 6
      E=SQRT((4.0*VEL(I)*VEL(I))+(6.0*(XSTOP-
     1DIST(I))*ACDE(I)))
    3 DRQT=(-ACDE(I))-((C+D*E)/F)
      S=0.5*((ACDE(I)*ACDE(I))-(DRQT*DRQT))/VEL(I)
      HACDE=ACDE(I)+S
      IF(HACDE.LT.-4.2)HACDE=-4.2
    2 IF(TIME.GT.TWR)WRITE(9,10)DECEL,HACDE,I
   10 FORMAT(1X,2F10.3,I6)
      IF(DECEL.LE.HACDE)MICO=1
      RETURN
    6 E=0.
      GO TO 3
    5 HACDE=0.
      GO TO 2
      END
C***********************************************************************
      SUBROUTINE DECLEA(I,JR,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1NUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/FRON/AA,BB,CC
      COMMON/CTSE/CS
      XL=(COMP(I)+COMP(JR))/2.
      U=CC-COMP(JR)-DIST(I)+XL
      W=(XL+STDIS(I))*EXP(BB/CS)
      IF(U.LE.W+0.1)GO TO 1
      DF=-(BB-VEL(I))**2/(U*LOG(U/W))
      DF2=CS*(BB-VEL(I))/U
      IF(DF2.GT.DF)DF=DF2
      GO TO 2
    1 DF=CS*(BB-VEL(I))/U
    2 IF(-4.2.GT.DF)DF=-4.2
      AA=ACDE(I)
      BB=VEL(I)
      CC=DIST(I)
      VEL(I)=BB+DF
      DIST(I)=CC+BB+DF/2.
      ACDE(I)=DF
      IF(VEL(I).LT.0.)GO TO 5
    6 DAFT=(XL+STDIS(I))*EXP(VEL(JR)/CS)-XL
      X=DIST(JR)-COMP(JR)-DAFT
      IF((ABS(VEL(JR)-VEL(I)).LE.0.2).AND.(DIST(I)
     1.GE.(X-1.)).AND.(DIST(I).LE.(X+1.)))GO TO 4
    5 IF(DIST(I).LE.XSTOP-0.2)RETURN
      DIST(I)=XSTOP
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      VEL(I)=0.
      ACDE(I)=0.
      RETURN
    3 VEL(I)=0.
      ACDE(I)=0.
      DIST(I)=CC+BB*(-BB/2.)
      GO TO 6
    4 VEL(I)=VEL(JR)
      IF(VEL(I).GE.VELD(I))GO TO 7
      ACDE(I)=ACDE(JR)
      DIST(I)=X
      GO TO 5
    7 VEL(I)=VELD(I)
      DIST(I)=CC+VELD(I)
      ACDE(I)=0.
      GO TO 5
      END
C***********************************************************************
      SUBROUTINE INSVEH
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/GER1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/GERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/LGEN/MLAST(3)
      COMMON/VNLM/MM(430)
      COMMON/FVCE/LEADER(3)
      COMMON/ANLI/M
      COMMON/LTOT/MTOTAL(3)
      COMMON/VNUL/ML(3,143)
      COMMON/CHAL/AAL(3),
     1BBL(3),CCL(3),LSTL(3)
      COMMON/TEMP/TIME
      DO 100 KK=1,3
      IF(MLAST(KK).EQ.0)GO TO 1
  100 CONTINUE
      DO 200 KK=1,3
      IF(MLAST(KK).EQ.0)GO TO 200
      IPE=MLAST(KK)+1
      JR=LSTL(KK)
      IF(TRGER1(IPE).NE.0.)GO TO 3
      IF((TPRG1(IPE).GE.TIME-1.).AND.(TPRG1(IPE).LT.TIME))GO TO 4
  200 CONTINUE
      RETURN
    1 IF((TPRG1(LEADER(KK)).GE.TIME-1.).AND.(TPRG1(LEADER(KK)
     1).LT.TIME))GO TO 11
      GO TO 100
   11 M=M+1
      MTOTAL(KK)=MTOTAL(KK)+1
      MLAST(KK)=LEADER(KK)
      CALL POOLTR(LEADER(KK),J)
      ML(KK,MTOTAL(KK))=J
      MM(M)=J
      JR=0
      CALL RELVEH(J,JR,KK)
      GO TO 100
    4 CALL NVEHRE(KK,IPE,JR)
    3 IF((TRGER1(IPE).GE.TIME-1.).AND.(TRGER1(IPE).LT.TIME))GO TO 31
      GO TO 200
   31 M=M+1
      CALL POOLTR(IPE,J)
      MTOTAL(KK)=MTOTAL(KK)+1
      ML(KK,MTOTAL(KK))=J
      MLAST(KK)=IPE
      MM(M)=J
      CALL RELVEH(J,JR,KK)
      GO TO 200
      END
C***********************************************************************
      SUBROUTINE NDECTU(I,DETU,XSTOP)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),NID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IBST(430)
      COMMON/CTSE/CS
      COMMON/INTE/PITE(12),RA(12)
      COMMON/FRON/AA,BB,CC
      COMMON/CAVE/CACEL(4),CDECEL(4),CDVEL(4),
     1XMIDV(4),XMADV(4),CSDDV(4)
      COMMON/NFIN/TWL,TW(,T*6F,IW7,IW27,IW1,FUE(2)
      COMMON/TEMP/TIME
      IF(DIST(I).GT.PITE(LEGAT(I))-200.)GO TO 1
   11 DETU=0.
      RETURN
    1 IF(XSTOP.GT.PITE(LEGAT(I)))GO TO 2
      GO TO 11
    2 VB=1.61*SQRT(RA(LEGAT(I)))
      DVETU=(VELD(I)/CDVEL(ITIPO(I)))*VB
      IF(VEL(I).GT.DVETU)GO TO 3
      GO TO 11
    3 Z=-0.5*DEC(I)**2/VELD(I)
      IF(ACDE(I).GE.0.)GO TO 4
      V=VEL(I)
      D=DIST(I)
      AD=ACDE(I)
    8 DECMAX=-SQRT(DEC(I)**2-2*Z*(-DVETU))
      S=0.5*(AD*AD-DECMAX*DECMAX)/(V-DVETU)
      T=(DECMAX-AD)/S
      PI=PITE(LEGAT(I))-V*T-0.5*AD*T*T-0.167*S*T*T*T
      IF(D.GT.PI)GO TO 5
      GO TO 11
    5 IF(ACDE(I).GE.0.)GO TO 6
      A=0.167*AD
      B=0.667*V+0.333*DVETU
      C=D-PITE(LEGAT(I))
      IF((B*B).LT.(4.*A*C))GO TO 7
      F=SQRT(B*B-4.*A*C)
    9 T=(-B+F)/(2.*A)
      SLOPE=2.*(DVETU-V-AD*T)/(T*T)
      SLOPE=MAX(SLOPE,-1)
      DETU=AD+SLOPE
      IF(TIME.GT.T*6F)WRITE(6,10)I,DETU,DVETU
      IF(TIME.GT.T*H)WRITE(9,10)I,DETU,DVETU
   10 FORMAT(5X,'ZZZZ VEH=',I6,2X,'DECELTOTURN=',F8.3,
     1'DESVELTOTURN=',F5.3)
      RETURN
    4 AD=-SQRT(DEC(I)**2-2*Z*(-VEL(I)))
      SL=AD-ACDE(I)
      V=VEL(I)+ACDE(I)+0.5*SL
      D=DIST(I)+VEL(I)+0.5*ACDE(I)+0.167*SL
      GO TO 8
```

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    6 DETU=AD
      IF(TIME.GT.TW66)WRITE(6,10)I,DETU,DVETU
      IF(TIME.GT.TWR)WRITE(9,10)I,DETU,DVETU
      RETURN
      END
C**********************************************************************
      SUBROUTINE WDTULE(DETU,I,JR,ITURN)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IST(430)
      COMMON/CTSE/CS
      COMMON/FRON/AA,BB,CC
      IF(DETU.EQ.0.)RETURN
      XL=(COMP(I)+COMP(JR))/2.
      U=CC-COMP(JR)-DIST(I)+XL
      W=(XL+STDIS(I))*EXP(BB/CS)
      IF(U.LE.W+0.1)GO TO 1
      DECEL=-(BB-VEL(I))**2/(U*LOG(U/W))
      DF2=CS*(BB-VEL(I))/U
      IF(DF2.GT.DECEL)DECEL=DF2
      GO TO 4
    1 DECEL=CS*(BB-VEL(I))/U
    4 IF(-4.2.GT.DECEL)DECEL=-4.2
      IF(DETU.LT.DECEL)ITURN=1
      RETURN
      END
C**********************************************************************
      SUBROUTINE DECTUR(DETU,I)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/FRON/AA,BB,CC
      COMMON/TEMP/TIME
      COMMON/WRIN/TWR,TW6,TW66,IW7,IW27,TW1,FUE(2)
      S=DETU-ACDE(I)
      AA=ACDE(I)
      BB=VEL(I)
      CC=DIST(I)
      DIST(I)=CC+BB+0.5*AA+0.167*S
      VEL(I)=BB+AA+0.5*S
      ACDE(I)=DETU
      IF(TIME.GT.TW66)WRITE(6,10)I,VEL(I),DIST(I),DETU
   10 FORMAT(1X,'TURNING VEH=',I6,2X,'IS TRAVELING AT=',F8.3,
     12X,'DIST=',F8.3,2X,'DEC=',F8.3)
      RETURN
      END
C**********************************************************************
      SUBROUTINE REMOTU(I,IREM)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/CLAL/ISEND(6,3)
      COMMON/FSTP/IFIS(6,3)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/KANA/FLAG(430)
      COMMON/INTE/PITE(12),RA(12)
      COMMON/TEMP/TIME
      COMMON/FLOW/IXO(7)
      COMMON/OTIM/INDEX(430),NIM
      COMMON/FRON/AA,BB,CC
      COMMON/LALE/IXW(12)
      COMMON/WRIN/TWR,TW6,TW66,IW7,IW27,TW1,FUE(2)
      IF(LEGAT(I).LE.3)RETURN
      IF(DIST(I).GT.PITE(LEGAT(I)))GO TO 2
      RETURN
    2 IREM=IREM+1
      CALL TSPAHE(I,MSTP)
      IF(MSTP.EQ.44)GO TO 6
      IF(IFIS(MSTP,LANE(I)).EQ.I)GO TO 7
    8 IPI=LEGAT(I)
      IXW(LEGAT(I))=I
      LANE(I)=20
      INDEX(I)=0
      VAVER=(VEL(I)+BB)/2.
      D=DIST(I)-PITE(LEGAT(I))
      TRE=D/VAVER
      T=TIME-TPRG(I)-TRE
      IF(TIME.GT.TW66)WRITE(6,10)I,INUM(I),TPRG(I),T
      IF(FLAG(I).NE.0.)WRITE(6,30)
   30 FORMAT(///,' VEH WITH FLAG IS LEAVING - ERROR')
      IF(TIME.GT.TWR)WRITE(9,10)I,INUM(I),TPRG(I),T
   10 FORMAT(1X,'...VEH IN LANE 20=',I4,'>',I6,
     12X,'...T REALGLP=',F6.2,2X,'+-TIME IN SYSTEM=',F6.2)
      IF(INUM(I).LE.IXO(3))GO TO 6
      DO 5 J=4,7
      JJ=J
      IF((INUM(I).GT.IXO(J-1)).AND.(INUM(I).LE.IXO(J))) GO TO 4
    5 CONTINUE
    4 VV=(PITE(LEGAT(I))-PITE(JJ))/T
    3 CONTINUE
      RETURN
    6 VV=PITE(LEGAT(I))/T
C IF TURNING DATA IS REQUIRED, 400 HAS TO BE REPLACED BY (PITE(I)
      IF(DIST(I).GT.400)VV=(PITE(LEGAT(I))-400)/T
      GO TO 3
    7 ISEND(MSTP,LANE(I))=1
      IFIS(MSTP,LANE(I))=11111
      GO TO 8
      END
C**********************************************************************
      SUBROUTINE REMOST(I,IREM)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/CLAL/ISEND(6,3)
      COMMON/FSTP/IFIS(6,3)
      COMMON/INTI/PITE(12),RA(12)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IPSI(430)
      COMMON/CERA/VELG(430),TRGER(430),TPRG(430)
      COMMON/KANA/FLAG(430)
      COMMON/SPOT/SIGP(2)
      COMMON/TEMP/TIME
      COMMON/FLOW/IXO(7)
      COMMON/OTIM/INDEX(430),NIM
      COMMON/FRON/AA,BB,CC
      COMMON/TYPE/SVV(2),NVE(2)
      COMMON/LALE/IXW(12)
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      COMMON/WRIN/TWR,TW6,TW66,IW7,IW27,TW1,FUE(2)
      COMMON/COLD/MED(1000,3),MHE(3),ADD(4),NADD(4),KL21,KL12,
     1H9(4),XLAL(1700,4)
      IF(LEGAT(I).GT.3)RETURN
      IF(DIST(I).GT.SIGP(6))GO TO 1
      RETURN
    1 IREM=IREM+1
      IF(IFIS(6,LANE(I)).EQ.I)GO TO 7
    8 IPT=LANE(I)
      IXW(LANE(I))=I
      LANE(I)=27
      INLEX(I)=0
      VAVER=(VEL(I)+EB)/2.
      D=DIST(I)-SIGP(6)
      TRE=D/VAVER
      T=TIME-TPRG(I)-TRE
      IF(TIME.GT.TW66)WRITE(6,10)I,INUM(I),TPRG(I),T
      IF(FLAG(I).NE.0.)WRITE(6,30)
   30 FORMAT(///,' VEH WITH FLAG IS LEAVING(STRAIGHT) - ERROR')
      IF(TIME.GT.TWR)WRITE(9,10)I,INUM(I),TPRG(I),T
   10 FORMAT(1X,'...VEH IN LANE 20=',I4,'>',I6,
     12X,'...T REALGEK=',F6.2,2X,'+-TIME IN SYSTEM=',F6.2)
      IF(INUM(I).LE.IXO(3))GO TO 6
      DO 5 J=4,7
      IF((INUM(I).GT.IXO(J-1)).AND.(INUM(I).LE.IXO(J)))GO TO 4
    5 CONTINUE
      J=7
    4 VV=(SIGP(6)-PITE(J))/T
    3 CONTINUE
      RETURN
    6 VV=(SIGP(6)-H9(ITIPO(I)))/T
      IF(TPRG(I).LT.FUE(1))GO TO 3
      IF(TPRG(I).GT.FUE(2)-200)GO TO 3
      ADD(ITIPO(I))=ADD(ITIPO(I))+T
      NADD(ITIPO(I))=NADD(ITIPO(I))+1
      XLAL(NADD(ITIPO(I)),ITIPO(I))=VV
      IT=1
      IF(ITIPO(I).GE.3)IT=2
      SVV(IT)=SVV(IT)+VV
      NVE(IT)=NVE(IT)+1
      GO TO 3
    7 ISEND(6,LANE(I))=1
      IFIS(6,LANE(I))=11111
      GO TO 8
      END
C**********************************************************************
      SUBROUTINE SIGIND
      IMPLICIT REAL*4(A-F,H,O-Z)
      COMMON/FSIP/IFIS(6,3)
      COMMON/SAME/ISAM(6)
      COMMON/CORE/ICOR(6)
      COMMON/SILL/CYCLE,XGR(6),AMBER,OFFI(5),IWE
      COMMON/SIIN/JP(2)
      COMMON/SGRE/IFSG(2)
      COMMON/TEMP/TIME
      IFSG(1)=0
      IFSG(2)=0
      DO 20 J=1,6
      ISAM(J)=0
      IANTES=ICOR(J)
      IF(TIME.LT.OFFI(J))GO TO 3
      R=(TIME-OFFI(J))/CYCLE
      I=R
      X=(R-I)*CYCLE
    4 IF((X.GE.0.).AND.(X.LT.XGR(J)-0.1))GO TO 1
      IF(X.GE.CYCLE-0.1)GO TO 1
      IF((X.GE.XGR(J)-0.1).AND.(X.LT.(XGR(J)+AMBER-0.1)))GO
     1TO 2
      ICOR(J)=3
   20 CONTINUE
      RETURN
    3 R=(OFFI(J)-TIME)/CYCLE
      I=R
      A=R-I
      X=CYCLE-(A*CYCLE)
      GO TO 4
    2 ICOR(J)=2
      IF(IANTES.NE.1)GO TO 20
      ISAM(J)=1
      DO 1000 L=1,3
      IFIS(J,L)=11111
 1000 CONTINUE
      GO TO 20
    1 ICOR(J)=1
      IF((J.EQ.JP(1)).AND.(IANTES.EQ.3))IFSG(1)=1
      IF((J.EQ.JP(2)).AND.(IANTES.EQ.3))IFSG(2)=1
      DO 2000 L=1,3
      IFIS(J,L)=0
 2000 CONTINUE
      GO TO 20
      END
C**********************************************************************
      SUBROUTINE UPDELA
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/QMIL/I66,I67,IW(2)
      COMMON/NVGT/NVG6,
     1NVG7,NVTS(2)
      COMMON/GERT/VELGT(4000),TRGERT(4000),IP...(4000)
      COMMON/TEMP/TIME
      COMMON/WRIN/TWR,TW6,TW66,IW7,IW27,TW1,FUE(2)
      LLANE=6
      NOW=NVG6
      IQUEUE=I66
C IS TIME TO GENERATE VEH = NOW?
    4 IF((TPRGT(NOW).GT.TIME-1.).AND.(TPRGT(NOW).LT.
     1TIME))GO TO 1
    6 IF(IQUEUE.GT.0)GO TO 2
    8 IF(LLANE.EQ.6)GO TO 3
      I67=IQUEUE
      NVG7=NOW
      IF(TIME.GT.TW6)WRITE(6,30)LLANE,I67,NVG7
   30 FORMAT(1X,'LANE=',I4,2X,'QUEUE=',I4,2X,'LASTINQUEUE=',I4)
      RETURN
    3 I66=IQUEUE
      NVG6=NOW
      IF(TIME.GT.TW6)WRITE(6,30)LLANE,I66,NVG6
      LLANE=7
      NOW=NVG7
      IQUEUE=I67
      GO TO 4
    1 NOW=NOW+1
      IQUEUE=IQUEUE+1
      IN=NOW-IQUEUE
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      IF(IQUEUE.EQ.1)GO TO 5
      GO TO 6
    2 IN=NOW-IQUEUE
C EVALUATE 'GAP' IN LANE 1 AND SEE IF VEH=IN IS INSERTED
      CALL EVAGAP(LLANE,IN,INS)
    9 IF(INS.EQ.1)GO TO 7
      GO TO 8
C EVALUATE 'LAG' IN LANE 1 AND SEE IF VEH=IN IS INSERTED
    5 CALL EVALAG(LLANE,IN,INS)
      GO TO 9
    7 TRGER1(IN)=TIME
      CALL POOLTR(IN,NIM)
      CALL INSERT(NIM,1)
      IQUEUE=IQUEUE-1
      GO TO 8
      END
C*************************************************************************
      SUBROUTINE EVAGAP(LLANE,IN,INS)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1INUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/CAR1/STDIST1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IEST1(4000)
      COMMON/FLOW/IXO(7)
      COMMON/INTE/PITE(12),RR(12)
      COMMON/LLTT/LEAT(7)
      COMMON/FLTT/IFOLT(7),
     1DBUF(7),VBUF(7),ABUF(7)
      COMMON/GLTL/XLAG(400)
      INS=0
      III=IN-IXO(5)
C HAS VEH HAD ITS INITIAL MOVING CHARACT ALREDY EVALUATED?
      IF(DIST1(IN).NE.0.)GO TO 1
C EVALUATE INITIAL MOVING CHARACT FOR TIME=1 SEC
      S=-0.5*ACC1(IN)*ACC1(IN)/VELD1(IN)
      DIST1(IN)=PITE(LLANE)+0.5*ACC1(IN)+0.167*S
      VEL1(IN)=ACC1(IN)+0.5*S
      ACDE1(IN)=ACC1(IN)+S
C IS THERE A FOLLOWER?
    1 IF(IFOLT(LLANE).NE.11111)GO TO 2
C IS THERE A LEADER?
    5 IF(LEAT(LLANE).NE.11111)GO TO 3
    6 INS=1
      RETURN
C IS LAG ENOUGH?
    2 DD=DBUF(LLANE)+XLAG(III)*VBUF(LLANE)
      IF(DD.LT.PITE(LLANE))GO TO 4
      RETURN
C IS FOLLOWER FAR ENOUGH?
    4 IF(DIST(IFOLT(LLANE)).LT.DIST1(IN)-COMP1(IN)-STDIS(IFOLT
     1(LLANE)))GO TO 5
      RETURN
C IS LEADER FAR ENOUGH?
    3 AB=(VEL1(IN)/MAX(VEL(LEAT(LLANE)),0.1))*STDIST1(IN)
      IF(AB.GT.7.)AB=7.
      IF(DIST1(IN).LT.DIST(LEAT(LLANE))-COMP(LEAT(LLANE))-
     1STDIST1(IN)-AB)GO TO 6
      RETURN
      END
C*************************************************************************
      SUBROUTINE EVALAG(LLANE,IN,INS)
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/CARA/STDIS(430),VELD(430),ITIPO(430),
     1ACC(430),DEC(430),IEST(430)
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1INUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GER1/VELG1(4000),TGER1(4000),TPRO1(4000)
      COMMON/CAR1/STDIST1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IEST1(4000)
      COMMON/FLOW/IXO(7)
      COMMON/INTE/PITE(12),RR(12)
      COMMON/TEMP/TIME
      COMMON/LLTT/LEAT(7)
      COMMON/FLTT/IFOLT(7),
     1DBUF(7),VBUF(7),ABUF(7)
      COMMON/GLTL/XLAG(400)
      INS=0
      III=IN-IXO(5)
      T=TPRO1(IN)-(TIME-1.)
C EVALUATE DIST & VEL & ACDE OF IN
      S=-0.5*ACC1(IN)*ACC1(IN)/VELD1(IN)
      DIST1(IN)=PITE(LLANE)+0.5*ACC1(IN)*T*T+0.167*S*T*T*T
      VEL1(IN)=ACC1(IN)*T+0.5*S*T*T
      ACDE1(IN)=ACC1(IN)+S*T
C IS THERE A FOLL?
      IF(IFOLT(LLANE).NE.11111)GO TO 1
C IS THERE A LEADER?
    2 IF(LEAT(LLANE).NE.11111)GO TO 3
    6 INS=1
      RETURN
C EVALUATE DATA OF FOLL. AT TIME OF PROPOSED GENER OF IN
    1 S=ACDE(IFOLT(LLANE))-ABUF(LLANE)
      VFOLL=VBUF(LLANE)+ABUF(LLANE)*T+0.5*S*T*T
      DFOLL=DBUF(LLANE)+VBUF(LLANE)*T+
     10.5*ABUF(LLANE)*T*T+0.167*S*T*T*T
C IS LAG ENOUGH?
      DD=DFOLL+XLAG(III)*VFOLL
      IF(DD.LT.PITE(LLANE))GO TO 4
C CHARACT OF VEH HAVE TO BE = ZERO AGAIN DUE TO EVALUATEGAP
    5 DIST1(IN)=0.
      VEL1(IN)=0.
      ACDE1(IN)=0.
      RETURN
C IS FOLLOWER FAR ENOUGH?
    4 IF(DIST(IFOLT(LLANE)).LT.DIST1(IN)-COMP1(IN)-STDIS(IFOLT
     1(LLANE)))GO TO 2
      GO TO 5
C IS LEADER FAR ENOUGH?
    3 AB=(VEL1(IN)/MAX(VEL(LEAT(LLANE)),0.1))*STDIST1(IN)
      IF(AB.GT.7.)AB=7.
      IF(DIST1(IN).LT.DIST(LEAT(LLANE))-COMP(LEAT(LLANE))-
     1STDIST1(IN)-AB)GO TO 6
      GO TO 5
      END
C*************************************************************************
      SUBROUTINE INSERT(NIM,L)
```

```
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/VNUM/MR(430)
      COMMON/ANUI/M
      COMMON/LTOT/MTOTAL(3)
      COMMON/VNUL/ML(3,143)
      COMMON/INIT/PITE(12),KA(12)
      COMMON/FSTP/IFIS(6,3)
      COMMON/SPOT/SIGP(6)
      COMMON/WRIN/TWR,TW6,TW6B,IW7,IW27,TW1,FUE(2)
      COMMON/TEMP/TIME
      LANE(NIM)=L
      IF(TIME.GT.TWGB)WRITE(6,1)INUM(NIM),NIM,L
    1 FORMAT(1X,'------*****----  IVEH IN=  'I6,'  > ',I4,'  LANE=',I4)
      M=M+1
      MR(M)=NIM
      MTOTAL(L)=MTOTAL(L)+1
      ML(L,MTOTAL(L))=NIM
C IF VEH HAS BEEN INSERTED IN FRONT OF FIRSTOSTOP IN LANE ,
C THIS VEH WILL STOP AT SIGNAL
      CALL TSPAHE(NIM,MSTP)
      IF(MSTP.EQ.44)RETURN
      IF((LEGAT(NIM).GT.3).AND.(PITE(LEGAT(NIM)).LT.
     1SIGP(MSTP)))RETURN
      IF(IFIS(MSTP,L).EQ.0)RETURN
      IF(IFIS(MSTP,L).EQ.11111)GO TO 2
      IF(DIST(NIM).GT.DIST(IFIS(MSTP,L)))GO TO 2
      RETURN
    2 IFIS(MSTP,L)=NIM
      RETURN
      END
C*************************************************************************
      SUBROUTINE UPDSIL
      IMPLICIT REAL*4(A-F,H,O-Z)
      COMMON/INF1/DIST1(4000),VEL1(4000),ACDE1(4000),
     1INUM1(4000),LEGAT1(4000),COMP1(4000),LANE1(4000),WID1(4000)
      COMMON/GEN1/VELG1(4000),TRGER1(4000),TPRG1(4000)
      COMMON/CAR1/STDIS1(4000),VELD1(4000),ITIPO1(4000),
     1ACC1(4000),DEC1(4000),IEST1(4000)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430),WID(430)
      COMMON/SPOT/SIGP(6)
      COMMON/TEMP/TIME
      COMMON/WMIL/IG6,IG7,IG(2)
      COMMON/NVGT/NVG6,
     1NVG7,NVTG(2)
      COMMON/CORE/ICOR(6)
      COMMON/LASTVEHAFTERSIGNAL/LVAS(6,3)
      COMMON/SIRE/IFSG(2)
      COMMON/SIIN/JP(2)
      COMMON/DEDI/XDIF(2)
      COMMON/PRIO/IPRI
      DO 111 K=1,2
      NOW=0
C MZ= MAIN LANE WHERE VEH ARE TO BE INSERTED
      MZ=2
C TIME TO GENERATE AT BACK OF QUEUE?
      IF((TPRG1(NVTG(K)).GT.(TIME-1.0)).AND.(TPRG1(NVTG(K)).LT.
     1TIME))GO TO 1
C IS THERE A QUEUE?
      IF(IG(K).EQ.0)GO TO 111
      GO TO 2
  111 CONTINUE
      RETURN
    1 NOW=NVTG(K)
C GENERATE VEH AND INCREASE QUEUE
      NVTG(K)=NVTG(K)+1
      IG(K)=IG(K)+1
C GET FIRST IN QUEUE
    2 IN=NVTG(K)-IG(K)
C IS SIGNAL GREEN FOR THIS APPROACH?
      IF(ICOR(JP(K)).EQ.3)GO TO 3
C IS IT FIRST SECOND OF RED?
      IF(IFSG(K).EQ.1)GO TO 4
   10 IF(NOW.EQ.0)GO TO 111
      IF(IG(K).EQ.1)GO TO 5
      DIST1(NOW)=DIST1(NOW-1)-COMP1(NOW-1)-STDIS1(NOW)
      GO TO 111
    5 DIST1(NOW)=SIGP(JP(K))-XDIF(K)-STDIS1(NOW)
      GO TO 111
C RESET ALL VEH IN QUEUE
    4 WRITE(6,48)JP(K)
   48 FORMAT(10X,'+++++++++++++',/,
     1          10X,'RESET VEH MINORSIGLANE=',I4,//)
      DO 100 I=IN,NVTG(K)-1
      VEL1(I)=0.
      ACDE1(I)=0.
      IF(I.EQ.IN)GO TO 6
      DIST1(I)=DIST1(I-1)-COMP1(I-1)-STDIS1(I)
  100 CONTINUE
      GO TO 111
    6 DIST1(I)=SIGP(JP(K))-XDIF(K)-STDIS1(I)
C     WRITE(3,7000)DIST1(I)
      GO TO 100
C IS INTERSECTION CLEARED?
    3 MW=3
      IF(IPRI.EQ.1)MW=2
      DO 200 K2=1,MW
      N=LVAS(JP(K),K2)
C PRINT WARNING IF INTERSECTION BLOCKED
      IF(N.EQ.22222)GO TO 11
 8000 FORMAT(10X,'+++++++++++++',/,
     1          10X,'INTERSECTION BLOCKED=',I4,//)
      IF(N.EQ.0)GO TO 200
      X=DIST(N)-COMP(N)
      IF(X.LT.SIGP(JP(K)))GO TO 11
  200 CONTINUE
C IS LAST VEH IN MZ LANE STOPPED CLOSE TO INTERSECTION?
    9 N=LVAS(JP(K),MZ)
      IF(N.EQ.0)GO TO 201
      X=DIST(N)-COMP(N)
      IF((X.LT.SIGP(JP(K))+20.).AND.(VEL(N).EQ.0.))GO TO 7
      NN=INUM(N)
  201 CALL UPDSIG(IN,NOW,N,NN,K)
      X=DIST1(IN)-COMP1(IN)
      IF(X.LE.SIGP(JP(K)))GO TO 111
C INSERT VEHICLE
      TRGER1(IN)=TIME
      CALL POOLTR(IN,NIM)
      CALL INSERT(NIM,MZ)
      IG(K)=IG(K)-1
      GO TO 111
```

```
      COMMON/CONS/CTOT(2)
      COMMON/INFA/DIST(430),VEL(430),ACDE(430),
     1INUM(430),LEGAT(430),COMP(430),LANE(430)
      COMMON/CARA/STDIS(430),VLLD(430),ITIPO(430),
     1ACC(430),SEC(430),IPST(430)
      DIMENSION W(2),CS(2)
      W(1)=10..
      W(2)=11/..
      CS(1)=0.72
      CS(2)=1.59
      V=(VEL(I)+EE)/2.
      IT=1
      IF(ITIPO(I).GE.3)IT=2
      XI=0.
      D=DIST(I)-CC
      AI=AA
      AF=ACDE(I)
      V=V*3.6
      A=(AF+AI)/2.
      IF(IT.EQ.1)GO TO 1
      IF(V.EQ.0.)GO TO 2
      IF(A.LT.-0.3)GO TO 2
      RR=(7.6+0.056*V)*(W(2)/1000.)
      RA=0.0215*V**2
      RG=(W(2)*XI)/100.
      RS=(W(2)/9.81)*A
      F=12.65
      XR=1.1
      XNI=(6.25+0.4938*V)/100.
  200 PT=XR*((RR+RA+RG)*V/273.69+(RS*D/76.04))
      CHOUR=PT/(XNI*F)
      IF(CHOUR.LT.CS(IT))CHOUR=CS(IT)
      C=CHOUR/3600.
  111 CTOT(IT)=CTOT(IT)+C
      RETURN
    1 IF(V.EQ.0.)GO TO 3
      IF(A.LT.-0.3)GO TO 3
      RR=(0.0112+0.022*(V/100.)**2.5)*W(1)
      RA=0.0052*V**2
      RG=(W(1)*XI)/100.
      RS=(W(1)/9.81)*A
      F=10.35
      XR=1.1
      XNI=(1.+0.305*V)/100.
      IF(V.GT.0.)XNI=(25.2+0.0283*V)/100.
      GO TO 200
    2 C=CS(2)/3600.
      GO TO 111
    3 C=CS(1)/3600.
      GO TO 111
      END
C*************************************************************************
      SUBROUTINE WINCON
      IMPLICIT REAL*4(A-F,H,O-Z)
C
      COMMON/FLOW/IXO(7)
      COMMON/COMO/XA(7,4),ZD(3,5),ZD2(3,5)
      COMMON/TENI/B(2,5)
      COMMON/RIST/PUPU(20)
      COMMON/USP/IES,ISC
      COMMON/SPGI/SIGP(6)
      COMMON/CTSE/CS
      COMMON/SISL/CYCLE,XGR(6),AMBER,CFFI(5),IWE
      COMMON/STCA/GSTC,GCCST,XMIST,XPAST
      COMMON/INTE/PITE(12),KK(12)
      COMMON/SHIF/IZO(7),IMAX(7),CHOP
      COMMON/HWFL/CAP(3),CLSTD(3)
      COMMON/INSF/IK(7)
      COMMON/FSSF/AVI..,IPAR,KP,CF(3)
      COMMON/SIIP/JH(2)
      COMMON/SIMT/S..
      COMMON/NEATINPLAT/KP(7)
      COMMON/SNFE/ISNF(2)
      COMMON/PRIO/IPRI
      COMMON/INIT/..,PF(4),PTU,IG(7)
      DIMENSION P(12)
      DO 1000 I=1,12
      P(I)=I
 1000 CONTINUE
      IF(IPRI.EQ.1)GO TO 100
      WRITE(2,1)
  101 IF(IES.EQ.0)GO TO 102
      WRITE(2,3)IES
      IF(ISC.EQ.1)GO TO 104
      WRITE(2,6)
  103 CONTINUE
      DO 2000 I=1,7
      IF(KP(I).EQ.1)GO TO 106
 2000 CONTINUE
      WRITE(2,19)
  105 WRITE(2,7)
      WRITE(2,20)
      WRITE(2,8)
      WRITE(2,9)(PITE(I),I=4,12)
      WRITE(2,10)
      WRITE(2,12)(SIGP(I),I=1,6)
      WRITE(2,13)(CF(I),I=1,3)
      IF(IPRI.EQ.1)WRITE(2,16)(ISNF(I),I=1,2)
      WRITE(2,11)(PUPU(I),I=1,20)
      WRITE(2,17)
      WRITE(2,22)
      IF(IWE.EQ.0)WRITE(2,26)
      IF(IWE.EQ.2)WRITE(2,29)
      IF(IWE.EQ.3)WRITE(2,30)
      IF(IWE.EQ.4)WRITE(2,32)
      IF(IWE.EQ.5)WRITE(2,33)
      IF(IWE.EQ.1)WRITE(2,25)
      WRITE(2,31)(CFFI(I),I=1,6)
      DO 3000 I=1,6
      IF(SIGP(I).EQ.0)GO TO 3000
      Z=CYCLE-XGR(I)-AMBER
      WRITE(2,18)I,CYCLE,XGR(I),AMBER,Z
 3000 CONTINUE
      WRITE(2,34)KPG
      WRITE(2,21)(IXO(I),I=1,7)
      WRITE(2,23)((XA(I,J),I=1,7),J=1,4)
      WRITE(2,27)(TAU(I),I=1,7)
      RETURN
  100 WRITE(2,2)
      GO TO 101
  102 WRITE(2,4)
      GO TO 103
  104 WRITE(2,5)
```

```
106   WRITE(2,14)(KB(I),I=1,7)
      GO TO 105
1     FORMAT(///,10X,'DO NOTHING SITUATION - CHECK POS OF TRAFF SIG!!!')
2     FORMAT(///,10X,'PRIORITY SITUATION')
3     FORMAT(10X,'SIZE OF BUS PLATOONS AT BUS STOP=',I3)
4     FORMAT(10X,'NO PLATOONS AT BUS STOPS')
5     FORMAT(10X,'ORDERED BUS PLATOONS USED')
6     FORMAT(10X,'NON-ORDERED BUS PLATOONS USED')
7     FORMAT(/,14X,'GEOMETRIC CHARACTERISTICS')
20    FORMAT(14X,'********* ***************',/)
8     FORMAT(10X,'POSITION OF INTERSECTIONS (M)',/,
     1        15X,'C >',4(3X,'*',2X),5(3X,'o',2X),/,
     2        15X,'O >',2(3X,'*',2X))
9     FORMAT(15X,'O >',9I6.0)
10    FORMAT(/,20X,'* - MINOR INBOUND  LANES',/,
     1              20X,'o - MINOR OUTBOUND LANES',/,
     2              20X,'* - INSERT DURING RIGHT SIGNAL PHASE',/)
11    FORMAT(10X,'POSITION OF BUS STOPS (M)',/,4(15X,5F9.2,/))
12    FORMAT(10X,'POSITION OF TRAFFIC SIGNALS',/,15X,6F6.0,/)
13    FORMAT(10X,'SIGNAL INT FOR MINOR INBOUND TRAF',/,15X,2I6,/)
14    FORMAT(10X,'HEADWAYS TAKEN FROM PLATOONS IN LANES WHERE CST.=1'
     1      ,/,15X,7I4,/)
15    FORMAT(10X,'HEADWAYS TAKEN AT RANDOM FOR ALL LANES',/)
16    FORMAT(10X,'TRAFFIC SIG NOT EFFECTIVE FOR BUSES',/,15X,2I6,/)
18    FORMAT(10X,'NO.SIGNAL=',I4,'  CYCLE=',F4.0,'  GREEN=',F4.0,
     1              '  AMBER=',F4.0,'  RED=',F4.0)
19    FORMAT(/,14X,'FLOW CHARACTERISTICS')
28    FORMAT(14X,'**** ***************',/)
21    FORMAT(10X,'CUM. FLOWS AT INPUT LANES IN VEH/H',/,23X,7I6,/)
23    FORMAT(10X,'COMPOSITION OF INPUT LANES IN %',/,
     115X,'TYPE1',5X,7F6.2,/,
     215X,'TYPE2',5X,7F6.2,/,
     315X,'TYPE3',5X,7F6.2,/,
     415X,'TYPE4',5X,7F6.2,/)
25    FORMAT(10X,'OFFSETS CALCULATED TO FAVOUR CARS')
26    FORMAT(10X,'OFFSETS CALCULATED TO FAVOUR BUSES')
32    FORMAT(10X,'OFFSETS CALCULATED BY BANDWIDTH FOR CARS')
33    FORMAT(10X,'OFFSETS CALCULATED BY BANDWIDTH FOR BUSES')
27    FORMAT(10X,'MINIMUM HEADWAYS FOR INPUT LANE',/,23X,7F6.1,/)
29    FORMAT(10X,'OFFSETS RANDOMLY DETERMINED')
30    FORMAT(10X,'OFFSETS ARE INPUTED')
31    FORMAT(15X,6F7.1,/)
34    FORMAT(/,10X,'INPUT FLOW OF BUSES=',I5,/)
      END
```

```
***  END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE  ***
***  END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE  ***
***  END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE   END OF FILE  ***
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16. APPENDIX 3: FURTHER CONSIDERATIONS INTO THE APPLICABILITY OF SIBULA

16.1 The limits of the investigation

It must be emphasised that SIBULA has been only applied to obtain estimates of the travel time and fuel consumption of vehicles travelling along a representative section of an urban arterial road. These measures of effectiveness have been used in the comparative assessment of alternative geometric configurations under variable traffic demand as described in chapter 12. Although investigations conducted in section 12.4.5 have included indications of the average delays involved in forming ordered bus platoons of different sizes, the delays occurring in the settling down distance before vehicles are inserted into the sampling section have not been included (refer to section 12.3 and figure 12.5 for definitions). Such delays are only relevant for input flows above system capacity when they would rapidly exceed the running times over the sampling section.

The relationship between travel time and flow, produced by the investigations described on section 16.2 and represented by the cluster of points in figure 16.1, follows the pattern normally observed in travel time - flow studies. Increments in traffic demand at low flow conditions lead to relatively small increases in average travel times. As input flows approach the maximum flow that can be discharged from the system (i.e., system capacity), average travel times increase rapidly. Travel time - flow relationships can adequately express the traffic conditions on a simulated section of a road operating below capacity. They also provide a means of estimating the capacity inherent to a particular system. However, during oversaturated conditions, where the average arrival flow exceeds the capacity of the system, traffic conditions over the simulated sections are not fully represented by this model. Under such traffic demands, steadily increasing queues would be formed at the bottlenecks. Because the simulation is only being used to evaluate travel times on a section of a road, such bottlenecks would not be trully describing overall delays as the main delay build up would occur outside the system. In addition, the mechanisms, logic and parameters used in the model were calibrated during non saturated conditions and may therefore also be unrepresentative of the radical changes which may occur in factors such as gap acceplance. Furthermore, it is reasonable to expect that, in 'real arterial road conditions', as vehicle density increases, the behaviour of accelerating vehicles discharging from the section would be affected by queues tailing back from sections of the road beyond the simulated one. This effect has not been represented by SIBULA. On the other hand it is also reasonable to assume that, in practice, when long queues are formed, approaching drivers may divert to some alternative route. However such divertion is not applicable to buses since their frequency is dependent on scheduling.

16.2 Performance of different streams of vehicles

By using computer simulation techniques alternative systems under identical traffic conditions can be tested. Whenever a microscopic model is adopted as a tool to investigate different road configurations, it is common to use an identical combination of vehicle and driver characteristics for different runs. The effect of different road configurations on selected measures of effectiveness will be best reflected by such a procedure.

Preliminary investigations are required to evaluate the extent to which different combinations of vehicle and driver characteristics affect the output of the model. The method of approach adopted consisted of selecting three different sets of random seeds and running SIBULA under a bus priority configuration for five levels of flow: 100, 175, 250, 275 and 300 buses per hour. For these fifteen runs output flows and average bus travel times over the study section (represented in 12.5) were sampled at five minute intervals. SIBULA is automatically terminated when queues tail back to the main generation point. Hence at input flows higher than 300 buses per hour, the simulation runs were interrupted before the one hour simulated period had elapsed.

The results are plotted in figure 16.1 and in figure 16.2 for each set of random seeds. It is possible to observe that a similar pattern of results is produced in each case. Therefore it is reasonable to use a single random stream of vehicles to compare the different alternatives described in chapter 12.

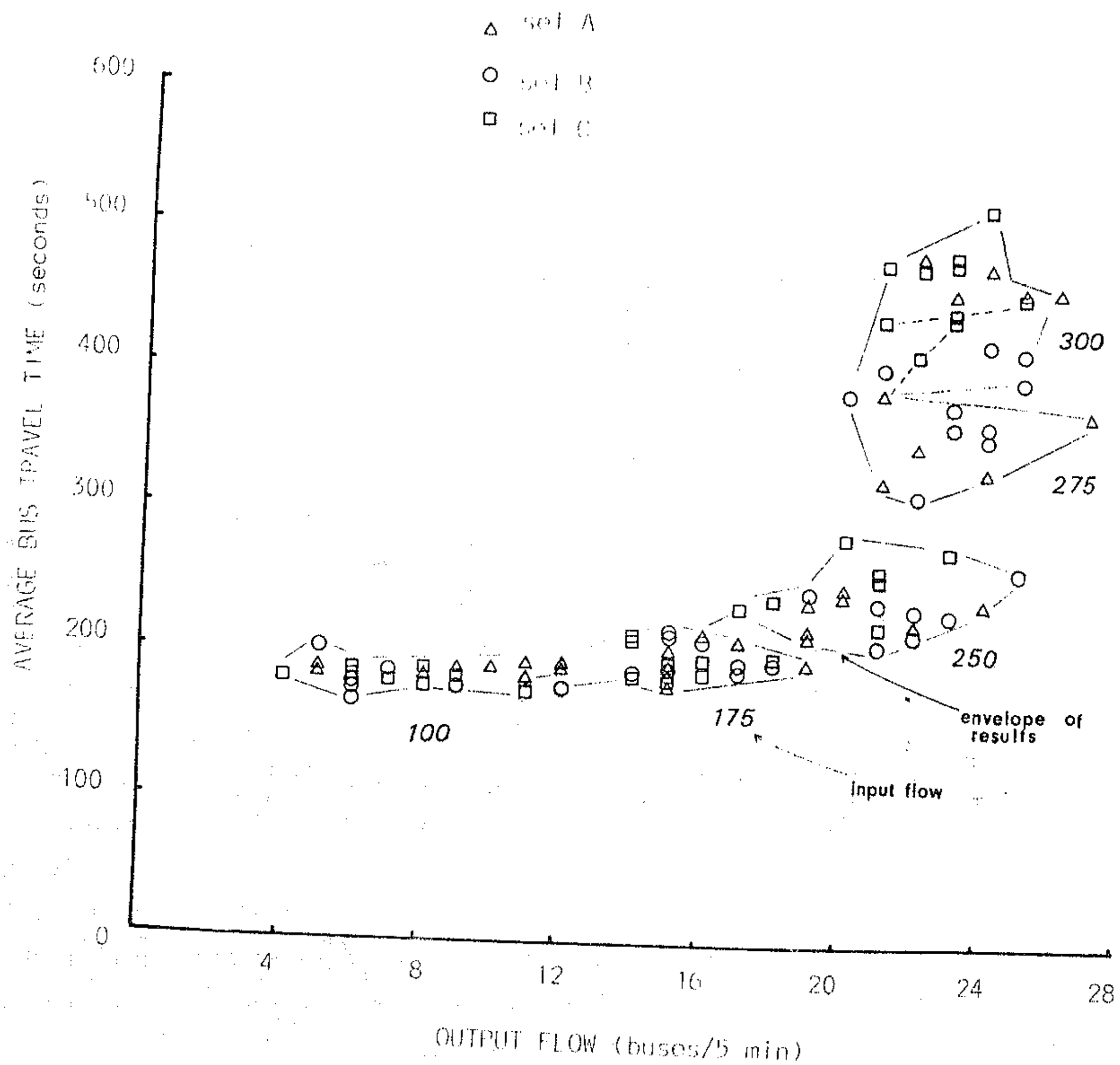

Figure 16.1 Combined results for the three different traffic streams

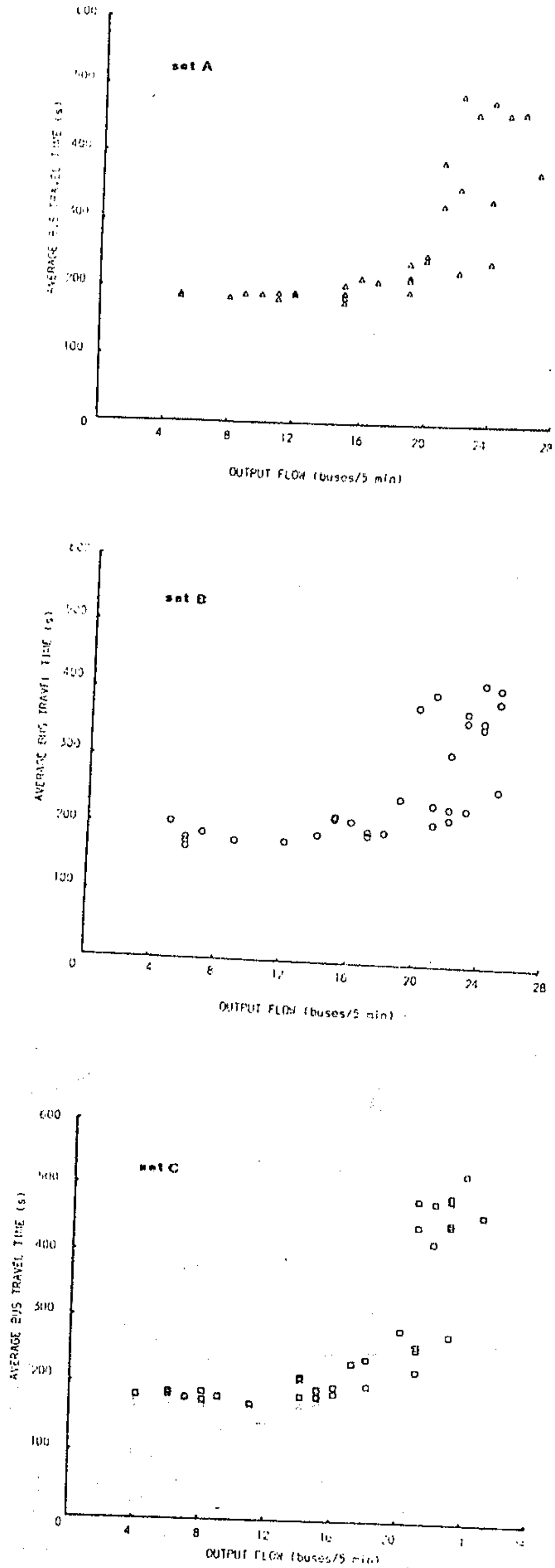

Figure 16.2 Separate results produced by each set of random seeds