SIMULATION OF OVERTAKING MANOEUVRES IN MIXED TRAFFIC ENVIRONMENT

A THESIS

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By
P.ABDUL NAZER

DEPARTMENT OF CIVIL ENGINEERING
REGIONAL ENGINEERING COLLEGE
CALICUT - 673601 KERALA INDIA

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CERTIFICATE

This is to certify that the thesis entitled **SIMULATION OF OVERTAKING MANOEUVRES IN MIXED TRAFFIC ENVIRONMENT** is a bonafied record of original research work done by **Mr. P.ABDUL NAZER** under my supervision and guidance. The thesis is submitted to the University of Calicut for the award of the degree of **Doctor of Philosophy** in Civil Engineering. The matter contained in the thesis has not been submitted elsewhere for any degree.

R.E.C, CALICUT
January 2002

18/1/2002

Dr NAGARAJ B.N
Supervisor and Guide

DR NAGARAJ B N
Professor of Civil Engineering
Regional Engineering College
Calicut - 673601

Professor and Head
Department of Civil Engineering
R.E.C, - Calicut 673 601

DEPT. OF CIVIL ENGINEERING
REGIONAL ENGINEERING COLLEGE
CALICUT

DECLARATION

I hereby solemnly declare that the work presented in the thesis entitled **SIMULATION OF OVERTAKING MANOEUVRES IN MIXED TRAFFIC ENVIRONMENT**, submitted to the University of Calicut for the award of the degree of **Doctor of Philosophy**, is a bonafide record of fully independent and original research work carried out by me in the Department of Civil Engineering, Regional Engineering College, Calicut-673 601, under the supervision and guidance of Dr Nagaraj B.N, during the period 1997 to 2002.

The matter contained in the thesis has not been submitted anywhere else for the award of any degree or diploma.

R.E.C., CALICUT

January 2002

P. ABDUL NAZER

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Calicut R.E.C.
January 2002

P.ABDUL NAZER

DEDICATED TO

MY PARENTS

ABSTRACT

Many researchers in India have contributed to the literature on simulation of traffic flow in mixed traffic environment. But most of them have confined their works to treating the overtaking manoeuvres only at a cursory level. In mixed traffic conditions prevailing on our road system, due to combination of different types of vehicles, there are innumerable number of opportunities for overtaking existing and therefore a realistic simulation of traffic flow operation in mixed traffic flow must necessarily include the overtaking possibilities that exist on our road system. This thesis is an effort towards overcoming this lacuna in the present state-of-the-art. A simulation model entitled **'AutoTRAFFIC'** has been developed for the simulation of mixed traffic in bi-directional flow conditions at highway mid-blocks which gives due importance for incorporating the effects of several types of overtaking that are normally seen on our road system.

The salient contributions of this thesis are the following:-

i. A development of equation systems for video frame analysis to extract spatial data of speed and lateral placement of both overtaking and overtaken vehicles on road stretches over a period of time.

ii. Development of automatic speed measurement system for recording speeds of different types of vehicles directly on to a laptop computer through signals received from probes fixed on the road. These signals are received through the printer port of the computer and hence this method is named as **'Computer Port Read Method'**

iii. Development of procedures for data retrieval and data analysis for easier data processing and manipulation.

iv. Development of mathematical models for passing and overtaking operations for **five** different types of overtakings' that have been observed in the field studies which are called as **Free Passing, Normal Overtaking, Forced Overtaking, Parallel Overtaking and Stream Lined Overtaking.** Equation systems have been developed for conditions varying from overtaking a single vehicle to the overtaking of a bunch of vehicles travelling with nearly identical speeds.

v. Introduction of a **Dynamic Sine Function** to handle the irregularities of the lane changing operations in the overtaking manoeuvres and development of mathematical models for simulation of the lateral placements of vehicles for various conditions and for free flow speeds.

vi. Introduction of an indigenous approach to simplify the complex manoeuvres in mixed traffic simulation through classification of vehicles into three groups, namely, Free Flowing, Overtaking and Other Disturbed Vehicles and describing the possible conditions of transition of vehicles through **STATE** number designation.

vii. Experimentation to demonstrate that the headway distribution of vehicles will become invariant irrespective of the arrival distributions of vehicles within approximately 500m from the entry point, thereby enabling a choice of 1000m as the warm up zone length on either side of the simulation zone.

viii. Effective use of **Timer Function** of the computer to simulate the parallel processing of the vehicular system on the roadway, unlike, one after another vehicle processing in the conventional simulation.

ix. Development of visual monitoring system for **AutoTRAFFIC** to check the simulation process and to get the traffic flow models as close as possible to the theoretical speed-flow-density relationships. This visual monitoring system has the ability to zoom and pan through the simulation stretch of road.

x. Development of a new feature to view the real time graph of steam speed, flow and density with a user friendly input and output dialogue boxed with an option to change the simulation scan update in intervals of 0.1s from 0.1-1s.

xi. The major outcome of the simulation experiments conducted using the simulation package **AutoTRAFFIC** developed in this study are:

a) Successful simulation of traffic flow speed density characteristics including the observance of points on the lower portion of the speed-flow relationship, resembling the theoretical relationship even in mixed traffic conditions also.

b) Development of relationship between the change in capacity with the width of road both in urban and rural situations. Under mixed traffic conditions, while, the capacity change appears to be linear and smooth in urban conditions, on the other hand, the capacity change appears to follow a step function in rural situation.

c) Development of relationship between number of overtakings with the flow for all types of vehicles. It has been observed that the number of overtakings increases with the flow up to certain flow levels, beyond which, this number decreases. The rate of this decrease will be different for different mix of vehicles.

d) Development of **Dynamic PCU** values under conditions of ban introduced to different types of vehicles. It has been observed that maximum improvement in speeds of buses and mini buses can be obtained by the ban introduced to the flow of two wheelers and auto rickshaws. It is these modes of traffic, which create maximum disturbances for the smooth operation of public transport system, and hence there is a need to introduce separate lanes for two wheelers and auto traffic on our road system to improve the level of service for public transport system.

Thus the study has been successful to simulate the mixed traffic flow conditions with capabilities to take into account all types of overtaking operations that happen on our road system. This study is concluded by pointing out some of its limitations and scope for further research in this area.

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CHAPTER - 1

INTRODUCTION

1.1 OVERVIEW

In planning, design and operation of road transportation facilities, knowledge of the traffic flow characteristics and the associated analytical techniques are absolutely essential. On most of the urban roads in India, the traffic consists of unsegregated flow of different types of vehicles which include both slow and fast moving vehicles. Due to this mixed traffic flow, the planners and the designers have to deal with several problems in designing the traffic facilities. These problems are due to the variations in the vehicular and driver characteristics of different classes of vehicles and the variations in the proportion and arrival pattern of these vehicles. Added to these, there are variations in roadway factors and other traffic regulations and control measures. Due to the various factors mentioned above, the mixed traffic flow characteristics and the flow relations become more complex than those under predominantly homogeneous traffic prevalent in most of the developed countries.

1.2 FORMULATION OF THE RESEARCH PROBLEM

Effective utilisation of the transportation system needs the basic understanding of the vehicular, the roadway, the driver and the environmental characteristics. The system becomes more complex due to the wide ranges of vehicular, the driver and the traffic conditions. This complex system can be analysed through micro level studies. Such micro level studies are performed using simulation approach.

Overtaking manoeuvres are very common on Indian roads due to the wide range of vehicular characteristics. Drivers decision for overtaking depend on many factors including the risk involved in the operation. The decision making for an overtaking operation when a fast moving vehicle follows a slow moving vehicle and the overtaking phenomenon are the two important processes in the mixed traffic flow.

So overtaking plays an important role in the simulation analysis.

Most of the Indian highways are two way without lane separation for slow and fast moving vehicles. Therefore a simulation model has to be built for two way mixed traffic flow, considering all types of vehicles seen on Indian highways.

1.3 JUSTIFICATION FOR THE RESEARCH TOPIC

There have been several studies in India that have been conducted by researchers in mixed mode environment. Among the studies, the work carried out by Marwah (1976), Ramanayya (1980), Katti(1983), Thuladhar(1987), Badarinath (1993) and Kuncheria(1995) are worthy of special mention.

However, most of the works carried out in India are mostly related to simulation of mixed traffic flow in one directional flow condition only. Since the flow on most of our roads is bi-directional, most of those studies have very limited application in the design and the operation of our road system. Even in those simplistic one directional flow conditions also, overtaking behaviour of drivers in mixed mode environment has been studied only at a passing glance. In the absence of detailed effort in modelling overtaking behaviour of drivers, quite often, researchers have come out with unrealistic values of service volumes and capacities. Therefore, there is a need for building up of simulation models in mixed traffic environment in bi-directional flow conditions, which give due importance for understanding and modelling of overtaking behaviour of drivers.

A number of works reported from abroad in the area of micro simulation of traffic flow are all for homogeneous traffic with lane discipline, which has very little use in Indian conditions.

1.4 OBJECTIVES OF THE STUDY

The present study is a step in the direction of realistic micro level simulation of mixed traffic flow in two way, highway mid blocks. It is aimed at the operational analysis of traffic flow with due emphasis on overtaking manoeuvres through simulation modelling, incorporating the true traffic behaviour as per the field observations. The broad objectives of the study are:

i) To conduct field studies at selected sections on some of the National highways and to propose theories for understanding the overtaking behaviour of vehicles / drivers in two way mixed mode environment.

ii) To develop a complete simulation model for simulating the two way mixed traffic flow environment representing the true behaviour on the Indian highway mid blocks.

iii) To develop a user friendly software package for conducting experiments in two way mixed traffic flow condition.

iv) To conduct various simulation experiments with the model to observe the behaviour of traffic under varying conditions.

1.5 SCOPE OF THE STUDY

The present research work focuses on the development of simulation model for mixed traffic flow in bi-directional condition at mid blocks only. Merging, diverging and crossing manoeuvres that are quite prevalent at road intersections are outside the scope of the study. Similarly, the effect of curves, the pedestrians and the cycles on the traffic flow are outside the scope of the study.

1.6 STUDY PHASES

The present study involves the following phases:

- Traffic flow behavioural studies of free flowing vehicles at highway mid blocks
- Traffic flow behavioural studies of overtaking vehicles at highway mid blocks
- Development of new techniques for data collection
- Building of free flow models
- Analysis and building of simulation models for overtaking operation
- Development of all other sub models
- Validation of the sub models
- Development of the micro simulation model for two way mixed traffic
- Validation of the simulation model
- Conduct of various simulation experiments

1.7 ORGANISATION OF THE THESIS

The thesis is organised in eight chapters. **Chapter 1** on **Introduction**, highlights the background and the need for developing a simulation model for understanding the overtaking behaviour of vehicles. This chapter also clearly spells out the objectives of the present study.

Chapter 2 on **Review of Literature**, presents the review of the earlier work carried out in the area relevant to the present work.

Chapter 3 on **Distance and Speed Measurement Techniques**, describes the new technique developed for the collection of a complete overtaking information using video analysis. An accurate speed measurement method is also presented in this chapter.

Chapter 4 on **Mixed Traffic Behaviour**, discusses on the speed, the headway and the lateral position of vehicles in the two way mixed traffic stream.

Chapter 5 on **A Study of Overtaking Characteristics of Vehicles in Mixed Mode Environment** describes the several type of overtaking operations and the development of models for overtaking manoeuvres.

Chapter 6 on **Development of Simulation Model AutoTRAFFIC** is exclusively set apart for describing the component models and the simulation model titled "AutoTRAFFIC". The validation of the component models and the simulation model are also presented in this chapter.

Chapter 7 on **Real Time Experiments on AutoTRAFFIC** is reserved for presentation of results of real time experiments carried out using the simulation model developed.

The total work carried out is summarised and the important outcomes of the study are presented in **Chapter 8**. This chapter also discusses the limitations of the present study and highlights the scope for further research in this area.

CHAPTER - 2

REVIEW OF LITERATURE

2.1 GENERAL

The traffic stream can be analysed either by using analytical techniques or by computer simulation. The validity of the model depends on how the model incorporates the various field data like the vehicle arrivals, the speed etc., which greatly influence the solution of traffic problems Many researchers have solved different types of problems in the field of traffic and transportation by simulation method. It is necessary to review the work already carried out on mixed traffic flow with special emphasis to simulation modelling so as to make the present work more appropriate to mixed traffic flow characteristics in India. The literature pertaining to the studies carried out under mixed traffic flow have been reviewed and reported in this chapter.

2.2 SIMULATION STUDIES ON HOMOGENEOUS TRAFFIC

Extensive research has been carried out by several researchers for homogeneous traffic conditions on lanes, which are clearly demarcated and the drivers strictly observe the lane discipline. This has lead to the development of large number of simulation models, many of which were developed considering only some specific aspects. Those models were developed mainly for a vehicular mix consisting of predominantly cars and very small percentages of buses, trucks and recreational vehicles. Even though those models may not be in a position to be used in mixed traffic conditions, a study of those models will give an insight into the methodology of simulation modelling of traffic flow.

Elvarez, Brey and Casado (1990) formulated a dynamic simulation model in which stochastic interactions among cars were described by means of probability of passing. In this model, each car is assigned a desired speed, according to an assumed probabilistic law. They assumed that the desired speed is characteristic of each driver, reflecting his/her own plans and it is not related to the presence of other cars. They established equations of motions by establishing the dynamics of the relaxation of each car towards its desired speed.

Thomas Frizsche (1994) developed a microscopic single-lane car-following model by considering the characteristic properties of the driver (perception, intention, etc.,) and the vehicle (braking and accelerating performance). The model was developed for one way two lane highways by considering left to right and right to left lane changing process. He assumed that, any vehicle in the stream interacted with four vehicles; nearest leader and follower in the same lane and in the other lane. When a driver changes his lane from left to right, in one way flow environment, he need not revert to the left lane again and he may continue to move through the same lane. But in a two way two lane road, once the driver changes his lane to the right, he will continuously try to get to the left lane, immediately after overtaking a vehicle in the left lane.

Saad Yousif and John Hunt (1995) have suggested an empirical model for traffic flow based on the data collected under different traffic flow conditions in U.K. A computer simulation program was developed to present the lane changing behaviour with respect to the flow in multi lane unidirectional highways. It is observed that, whenever the flow is very less, most of the vehicles utilise the first lane. As the flow increases, percentage of vehicles utilizing the second and third lanes increases. Or in other words, when the flow increases, the percentage of vehicles which are likely to change lanes also increases. This model can be applied only for the one way multi lane traffic and cannot be directly applied to two way two lane traffic, in which vehicles change lane, only when opportunities do exists for a complete overtaking.

Kumud, Sanwal, Kalpetty, Jean Walrand and Youssef Fawaz (1996) have presented a model of traffic on highways based on the macroscopic description of traffic as a compressible fluid. In applications where the interest is in mass phenomena and real time computations, a macroscopic model is preferable to a microscopic model. The influence of incidents on the highway is included in the model and it is possible to tune its parameters for flow under incidents. This allows the model the effect of incidents on flow capacity using field data. Since this is a macroscopic model, individual driver behaviour is not considered. Therefore the application of the model is limited.

Peter Hidas (1998) has described a car-following model specifically developed for urban interrupted traffic situations in microscopic simulation models with one second scanning update time. The model is based on a desired spacing criterion which is assumed to be a linear function of the speed.

The model is based on the assumption that, when approaching and following a leader vehicle(n-1) at any time, the driver of the follower (n) attempts to adjust his acceleration so as to reach a desired spacing after a time-lag, which takes T seconds. This condition can be described by the following equation:

$$X_{n-1}(t+T) - X_n(t+T) = D_n(t+T) \quad \text{------------------------- Eq. 2.1}$$

Where: $X_i(t)$ is the position and $D_i(t)$ is the desired spacing of vehicle i at time t.

The desired spacing is assumed to be a linear function of the vehicle speed:

$$D_n(t+T) = A.V_n(t+T) + B. \quad \text{-------------------------------- Eq. 2.2}$$

Where: $V_i(t)$ is the speed of vehicle i, and A and B are constants.

He has derived equations for acceleration for conditions- (1) when following close to the desired distance and (2) approaching from a large distance. This microscopic model has found a good representation of the vehicle movements in a simple form. But this model describes only the above two conditions: one for approaching of a vehicle moving at slower speed and the other for describing the motion while following that vehicle. So the applicability of this model is limited to one way single lane road.

2.3 SIMULATION STUDIES ON MIXED TRAFFIC AT MID BLOCKS

Sinha and Decabooter (1972) developed a model to study the characteristics of freeway movement. This model took into consideration freeway lanes on ramps and off ramps. Paul (1967) considered different speeds and varied density on a long two lane two-way road to study the traffic interaction through simulation.

William and May (1976) developed simulation model SIMTOL in FORTRAN language for capacity evaluation of two lane two-way highways. The model has the capability of taking grade sections and no passing zones. The validation of the model was done using the data from Highway Capacity Manual. The model values were found to be closer to the field values for a two lane two-way highway.

Marwah(1976) proposed a simulation model to study the mixed traffic behaviour on two lane two way roads. In another study Marwah and Ramaseshan(1978) have discussed the interaction between vehicles in mixed traffic flow using simulation technique. Palaniswamy(1983) developed a generalised simulation model for vehicular behaviour under heterogeneous traffic conditions. The different situations considered by him in his study are single lane, intermediate lane and two lane roads. Pathak(1983) in his simulation study developed exponential distribution upto a volume of 500 vph; shifted exponential distribution between 500 to 1000 vph and composite headway distribution for still higher volumes.A comprehensive review of simulation models is reported by Katti and Pathak(1985). The influence of slow moving traffic on the stream behaviour is given emphasis in their study.

Ramanayya (1977) introduced Equivalent Design Vehicle Unit (EDVU) in place of PCU based on the percentages of slow moving traffic. The headway distributions adopted by him are different at different volume levels. Upto 500 vph exponential distribution is adopted; shifted exponential is adopted from 500 to 650 vph; and log normal distribution is proposed for volumes higher than 650 vph upto 900 vph. Ramanayya observed that more than one vehicle can move in a road width of 3.8m in mixed traffic scenario.

An elaborate review of simulation works carried out earlier is reported by Popat et al (1990) suggesting further scope. In their studies they used simulation modelling to study the delays and queue lengths at uncontrolled T - intersections. They took stopped time delays as a figure of merit for the assessment of the intersection performance and for various major road and minor road volumes, delays are estimated through the simulation model.

Badarinath(1992) introduced the concept of group in the process of developing level of service standards under varying road widths and mixed traffic conditions. He developed a simulation model for managing traffic in multi-mode environment. The absence of lane discipline, the multiple movement of smaller vehicles and the non uniform lane widths were given due consideration in the model development. A variety of headway distributions were adopted by him in the model development. He assumed exponential pattern upto 500 vph; shifted exponential distribution from 500 to 800 vph; log normal distribution from 800 to 1100 vph; Erlang distribution from 1100 to 1500 vph; and beyond 1500 vph and upto 2000 vph, triple exponential composite distribution are adopted. Problems and prospects of using simulation models for road traffic were thoroughly discussed by Agarwal(1992). Bhanu murthy and Reddy(1998) have reported that the saturation flow rate changes with the proportion of smaller vehicles such as 2/3 wheelers. In another study Bhanu murthy(1998) has developed a simulation model that computes the delays and queue lengths for a given set of roadway and traffic factors. An exhaustive review of simulation models as applied to traffic studies is reported by Bhuvanesh Singh et al (1998). But their review has not covered the simulation models developed for Indian urban traffic conditions. Kumar and Rao (1998) have studied the headway distributions under mixed traffic conditions. They have observed that in case of mixed traffic conditions where the arrivals do not follow the lane discipline, negative exponential distribution is more suitable.

May and Pratt (1968) developed a model to simulate one directional flow in microscopic detail. The normal distribution was used to assign desired speed and Schuhl's distribution for headway generation. The model used only one class of cars and six subclasses of trucks. Only cars were allowed to overtake in accordance with an empirical gap acceptance distribution under favourable traffic conditions.

2.4 INTERSECTION SIMULATION

Katti(1982) developed a simulation model for priority type intersections under mixed traffic conditions. The concept of lane was avoided by him and he introduced an Approach Density Index to reflect the quality of mix in the stream. Simulation of signalized intersection under heterogeneous traffic conditions have been reported by Sudhakar Reddy et al (1998). They have taken the delays suffered by the vehicles as a measure of intersection performance. Raghavachari et al (1992) have reported a study on simulation modelling of urban uncontrolled intersections with pedestrian crossings. They have used the conflict distances as the basis for simulating the gap acceptance behaviour of pedestrians. Animation of intersection traffic flows along with simulation is discussed by Marwah(1995).

2.5 OVERTAKING STANDARDS BY THE SPECIFICATION AND STANDARDS COMMITTEE OF THE INDIAN ROAD CONGRESS

2.5.1 Safe Overtaking Distance

During the overtaking operation, the overtaking vehicle may have, under certain conditions forced to use that portion of the road meant for traffic coming in the opposite direction. Now, a road is used at its maximum efficiency when all the vehicles using it are kept moving at the design speed of the road. Under these conditions the road will be capable of carrying its maximum traffic. If a vehicle is moving at a much slower speed than the design speed, it should be made possible for other vehicles to overtake it safely so as to increase the capacity of the road. The distance within which an overtaking manoeuvre can be undertaken is thus an important factor in road design. The overtaking manoeuvre can be split up into three distinct operations as indicated in the Fig 2.1

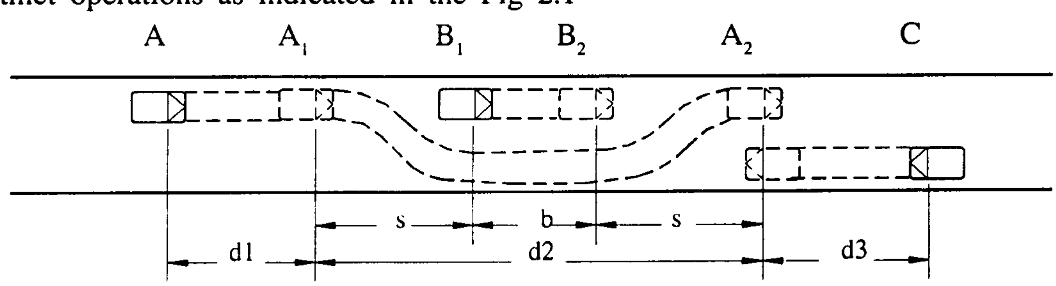


Fig 2.1 Overtaking manoeuvre

In Fig 2.1, A is the overtaking driver and B_1 is the overtaken driver moving at less than the design speed. A has been travelling at the design speed V_a miles per hour till he reached the position A_1 where he is compelled to slow down to the speed of B_1 say V_b equal to $(V_b - m)$ where m is the speed difference, and keeps behind B_1 at a distance S from it. It takes some time for A to size up the situation and in this interval he will have travelled to position A_1 . This time interval is assumed as 2 seconds and the distance covered may be termed d_1 .

At A_1 the overtaking driver turns his vehicle out of its own path, accelerates, overtakes B_1 return to his own path at A_2 , and then proceeds again at the design speed. Thus, from the relative position of A_1 B_1 the vehicles have taken the position B_2 A_2 after the manoeuvre and therefore the vehicle A has gained a distance of 2S relative to the overtaken vehicle B_1 by accelerating its speed. In the meanwhile, B_1 will have travelled the distance "b" from B_1 to B_2 . Thus, the total distance d_2 involved in the actual manoeuvre is made up to 2S plus b.

During the operation of the overtaking of the vehicle B_1 by the vehicle A_1 it is possible that a vehicle C travelling in the opposite direction at the design speed of the road, will approach the vehicles A_1 and B_1 . This opposing traffic may come into view as soon as the passing manoeuvre is begun by A_1 and hence the overtaking minimum sight distance should include, in the case of undivided highways, the distance traversed by the opposing traffic during the period of passing manoeuvre. This distance is designated d_3 in Fig 2.1

The determination of these distances is described underneath.

2.5.2 Spacing of Moving Vehicles

When vehicles move at the same speed in the same direction in a traffic lane, the spacing of vehicles should be such that if one vehicle driver applies his brakes, the driver of the vehicle behind will have sufficient time to do likewise and avoid a collision. The average brake reaction time may be taken as half a second in this case because the average driver following closely on the rear of another vehicle will naturally be alert. Assuming in this case a perception time also of half a second, the total perception and brake reaction time will be one second. Assuming equal brake efficiency in both the vehicles, the theoretical safe spacing for vehicles should be the distance covered in one second plus the length of vehicle. The length of a vehicle may be assumed to be 20ft as this covers the case of most passenger vehicles. The theoretical spacing of vehicles thus arrived at is given in the Table 2.1 below.

However, actual observations made through an aerial traffic survey and by means of a photographic method of studying traffic behaviour have shown that the actual spacing followed in practice is much less than the theoretical spacing and that this actual spacing closely follows a general simple formula expressed as

$S = V + 20$ where S is the spacing in feet, and V is the speed in miles per hour. The values for different speeds are given in Table 2.1

Table 2.1 Spacing of Moving Vehicles

Speed of vehicles		Spacing	
V mph.	ft per sec	Theoretical feet.	Observed and adopted in the design V+20 Ft.
15	22	42	35
20	29	49	40
25	37	57	45
30	44	64	50
35	51	71	55
40	59	79	60
45	66	86	65
50	73	93	70

Before the operation of overtaking is begun, the two vehicles move at the beginning of the operation at the speed of the slower vehicle i.e. V_b , and the spacing between the two vehicles A_1 and B_1 will be $V_b + 20$.

2.5.3 Time required to cover the distance 2S by acceleration

The rate of acceleration of a vehicle varies considerably depending on the driving ability and habits of the driver, the horse-power-load ratio of the vehicle, and its mechanical condition. Tests made in the U.S.A in 1947 on six passenger vehicles in good condition driven by operators indicate that normal acceleration is 60 per cent of the maximum possible. The results are shown graphically in Fig 2.2

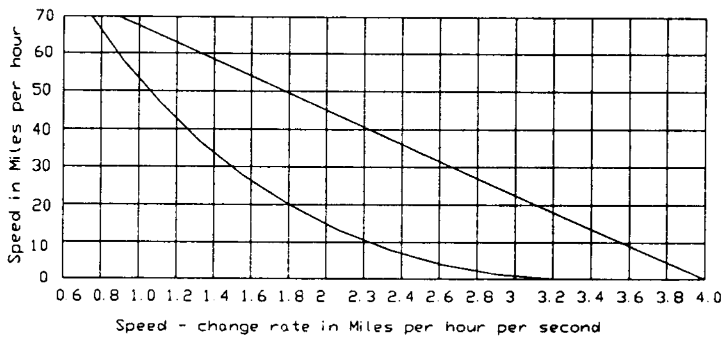


Fig 2.2 Acceleration chart

In the use of the graphs given in Fig 2.2, it is to be assumed that the vehicles will be accelerated at the maximum rate as usually happens in heavy traffic. "It is assumed that the manoeuvre of passing is begun at the speed of the overtaken vehicle and completed at a much higher speed. The rate of acceleration is therefore higher at the beginning of the manoeuvre than at the end". Also, it is to be assumed that passing, once begun, is done in the face of opposing traffic and most drivers accelerates as rapidly as possible, to get back to their lane well before the opposing traffic can meet-their vehicles. The values for maximum acceleration are therefore used in the design. These values are derived from Fig.2.2 are and given in Table 2.2

Table 2.2 Overtaking acceleration for different speeds (Maximum)

Speed V m.p.h	15	20	25	30	40	50
Acceleration *a* ft per sec per sec	4.7	4.3	4.07	3.67	3.01	2.35
Acceleration a_2 in m.p.h per sec	3.2	2.95	2.78	2.5	2.05	1.6

From first principles of dynamics, distance covered = 0.5x acceleration x time^2.

i.e. $2S = 0.5\ at^2$.

or $t = \sqrt{(4S/a)}$ where a is the acceleration in ft per hour per sec.

or $t = \sqrt{(2.73S/a)}$ where a is the acceleration in miles per hour per sec.

The above formulae and the two tables given above supply all the elements for the calculation of the time "t" taken by the overtaking vehicle to cover the distance 2S. Assuming that the overtaken vehicle has been moving at the same uniform speed as before, it would have covered the distance "b" which is therefore given by the equation

$b = 1.47\ V_b \times t.$ -------------------------------- Eq 2.3

Calculations show that distance "b" is the largest factor that enters into the total distance so that, in effect, the speed of the slow moving vehicle is the greatest influencing factor. If the slow moving vehicle is moving at much less than the design speed, the total overtaking distance would be too large for economical design of road alignment. Table 2.3 gives the overtaking distance for design speeds of 25 to 50 m.p.h. and speed difference of 10 m.p.h. between the two vehicles.

Lower speeds than 25 m.p.h. have not been included in the table as conditions for overtaking may not generally arise and the road with such low design speeds is not important enough to warrant high standards of construction necessary to permit such overtaking.

Table 2.3 has been worked out for a speed difference of 10 miles per hour.

There is no hard and fast rule as to why this figure should be adopted, but at design speeds of 30 miles and over, the driver of the overtaking vehicle will, as previously explained, try to complete the operation in the shortest time possible, often with a difference in speed of over 10 miles per hour. Also it is to be conceded that ±5 m.p.h lies within the range of instrumental error or the reaction lag of the transmission operating the speedometer. It would be desirable to concede that a vehicle travelling at 10 m.p.h less than design speed of the road deserves to be overtaken by one travelling at the design speed. On this consideration, and on considerations of economy, in the prescription of the standards a speed difference of 10 m.p.h has been assumed.

Table 2.3 Minimum Overtaking Sight Distance

V.	25	30	35	40	50
V-m.	15	20	25	30	40
S = V - M + 20	35	40	45	50	60
a_2	2.78	2.5	2.2	2.05	1.6
t = sqrt $(2.73S/a_2)$	5.8	6.6	7.4	8.0	10.1
$d_1 = 2.94\ (V - m)$	44	59	74	88	118
$d_2 = 2S + 1.47\ (V\text{-}m)t.$	198	274	358	457	594
$d_3 = 1.47\ Vt.$	213	291	376	476	742
$d = d_1 + d_2 + d_3$	455	624	808	1021	1454
Overtaking sight distance	450	600	800	1000	1450

m = Speed difference in miles per hour between the overtaken and the overtaking vehicle.

d_1 = Distance travelled during perception time of 2 sec.

d_2 = Distance required for overtaking manoeuvre.

d_3 = Distance covered by vehicle travelling in the opposite lane during the overtaking manoeuvre.

2.5.4 Positioning of Overtaking Zones

Overtaking zones are described as lengths of a highway where it would be safe for one vehicle travelling 10 miles an hour faster than the another vehicle going in the same direction to pass the second vehicle. The sight distance at every point in each of these zones must be at least equal to the minimum overtaking distance which is $d_1 + d_2$ if there is no opposing traffic and $d_1 + d_2 + d_3$ if there is opposing traffic. The zone itself must be longer than these overtaking distances so as to allow more than one vehicle to overtake a slow moving vehicle and at every point in the zone. The driver must have a clear view of the road unobstructed by "blind" corners or bends or blind summit curves.

It follows that the whole of a length where vision is unrestricted and where the road is wide enough to permit of vehicles passing, cannot be marked as a safe passing zone because the sight distance near the ends of this zone will not be sufficient. The zone must therefore be restricted to the total length where there is sufficient room to pass minus a length equal to the sight distance on either side i.e. minus $(d_1 + d_2)$ where there is no opposing traffic and minus $(d_1 + d_2 + d_3)$ where there is opposing traffic. it should be noted that the marking signpost will be $(d_1 + d_2)$ or $(d_1 + d_2 + d_3)$ away from the end of the wide length at other end(Fig 2.3)

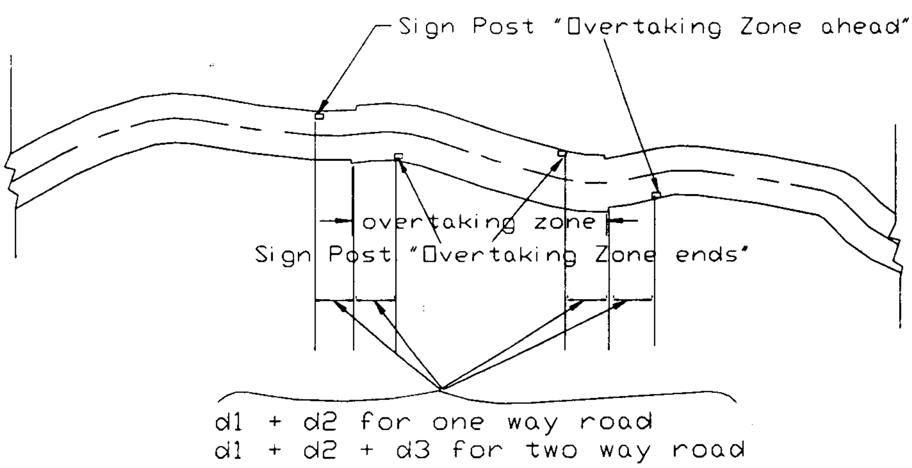


Fig 2.3 Position of overtaking zone

In single-lane highway the berms have to be used for passing. In dry weather or under favourable conditions, the sight distance may be taken as the same as for two-lane highways but these roads are unsafe for overtaking at design speed in wet weather or under unfavourable conditions. If the highway is to be safe for the design speed of its class, overtaking zones fully surfaced must be provided. The minimum length of each of such zones would be, theoretically 2 ($d1 + d_2$) when there is no opposing traffic and 2 ($d1 + d_2 + d_3$) when there is opposing traffic. In practice the length of the zone should be $3(d_1 + d_2)$ or $3(d_1 + d_2 + d_3)$ to allow for comfortable overtaking of one vehicle by another travelling 10 miles faster but where possible the factor should be increased to 4 even 5 in a busy road (For d_1 , d_2 and d_3 see Fig 2.1).

Taking a factor of 3, the length of the surfaced overtaking zone on a National Highway should be, 3x1450 or 4350ft i.e. more than three quarters of a mile. It will be seen from this that no single-lane road can be considered as upto National Highway Standard in wet weather or unfavourable conditions unless it is provided with overtaking zones over a mile long at frequent intervals. In practice vehicles using these roads cannot safely travel in all weathers at what have been fixed as the ultimate design speeds.

Overtaking zones also cannot be fixed in the office merely by looking at plans as the sight distances can only be determined on the spot after taking a note of such obstructions at trees, mounds, huts etc. which interfere with sight as effectively as blind corners, sharp summits, and similar design features. In marking overtaking zones on a road, therefore, common sense must be the first consideration, calculations and formulae being regarded very much as of secondary importance.

2.6. NEED FOR THE STUDY

The present literature is not enough to explain the overtaking operation of vehicles as seen on Indian roads due to the slow and fast moving vehicles. Any micro simulation model without considering the overtaking operation at micro level, will not present the true picture of the real traffic on our roads. Thus, there is a need for building a simulation model for bidirectional-mixed traffic flow considering due emphasis on overtaking behaviour of vehicles.

2.7 SUMMARY

The literature related to the simulation of homogeneous and mixed traffic environment are briefly reviewed in this chapter. Simulation studies conducted on the mid-blocks are emphasised and the methodology adopted for the calculation of Overtaking Sight Distance by the Indian Roads Congress (IRC) under the overtaking operation is also explained.

CHAPTER - 3

DISTANCE AND SPEED MEASUREMENT TECHNIQUES

3.1 GENERAL

Today, with the advent of modern computers and the development in the instrumentation industry, sophisticated equipments are readily available in the market to collect any type of traffic data from the road. It has the power to observe, store and analyse or even to print the results of the field observations. Certain studies like the study of overtaking behaviour, needs spatial data like the speed, the acceleration, the lateral and the longitudinal positions of vehicles on the entire stretch of overtaking zone. The spatial observation systems are very costly. Those are not affordable for studies which are of academic interest. Two simple and least expensive techniques for traffic data collection have been developed and briefly presented in this chapter.

Many of the Traffic Engineering studies specifically related to hypotheses formulation and testing of theories of traffic flow, vehicular overtaking behavioural studies and development of safe passing sight distance, etc, need spatial data. The first part of this chapter describes, a procedure developed for vehicular detection and computerised data retrieval for traction of vehicles in mid blocks using moving camera method.

An accurate and automatic speed recording system is presented in the second part. It is a direct reading mechanism using a computer, based on the signals received from the two probes placed at a fixed distance apart on the highway section.

3.2 TRACING THE PATH FOLLOWED BY VEHICLES IN MIDBLOCKS USING MOVING CAMERA METHOD

3.2.1 INTRODUCTION

Many instrumental methods have been developed for the collection of data like the speeds of vehicles, the traffic volumes, the head ways, etc., all at chosen locations. Since all those measurements are location specific, they can hardly be used to study the vehicle acceleration and deceleration characteristics, like the linear and the lateral positioning of vehicles. There is a need for development of simple methods for tracing the path followed by vehicles in relation to time over a space or stretch of roadway. A simple technique has been developed for achieving this objective. However, it is felt that the fuller utility of the proposed technique could be realised only when the image processing techniques are possible to be coupled with the method developed in this study.

3.2.2 PRINCIPLE USED IN THE CALCULATION OF DISTANCE USING IMAGE SIZE

Image size (width and height in pixels) of an object on a computer screen, which is viewed from a pre-recorded video tape through video card, depends on the distance of the object from the camera and its focal length. Consider the image of an object recorded on the video tape at a constant zoom position as shown in Fig 3.1. In this case the size of the image of the object depends on the distance of the object from the camera.

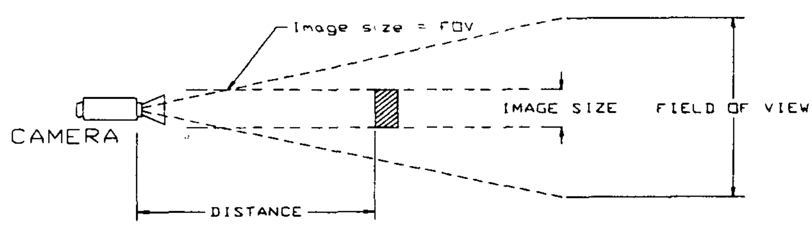


Fig 3.1 : Field of view and image size

In other words, the actual distance from a video camera to an object depends on the length of the image in pixels of unit length of that object, which is displayed on a computer monitor from its video tape at constant focal distance. This relation can be easily established by the calibration experiments as explained in section 3.2.3.6.

By analysing a video tape for a small interval of time, which has recorded images of vehicles moving through the mid-block at constant speed, the distances of vehicles from the video camera can be calculated as described below in successive time intervals and hence it is possible to calculate their instantaneous speed.

A and B are the positions of the camera at t-1 and t seconds and C and D are the positions of vehicle at t-1 and t respectively..

Let the speed of the vehicle on which the camera intalled be Sc, distance from the camera to the object in t th frame be Dt, distance from the camera to the object in t-1 th frame be D(t-1) and time interval be dt.

Then the speed of the vehicle, Sv can be correlated as:

Speed = distance travelled / time = Distance / dt

When vehicles are moving in the same direction of the camera as shown in Fig 3.2(a)

$$Sv = [Dt + Sc.dt - D(t-1)]/dt$$

ie. $$\mathbf{Sv = [Dt - D(t-1)]/dt + Sc.} \qquad \text{Eq.3.1(a)}$$

When vehicles are moving in the opposite direction of the camera as shown in Fig.3.2(b)

$$Sv = [D(t-1) - Dt - Sc.dt]/dt$$

ie. $$\mathbf{Sv = [D(t-1) - Dt]/dt - Sc.} \qquad \text{Eq.3.1(b)}$$

Since the camera is directed along the road way, the view generated will be the cross section of the road as shown in Fig 3.3. So the lateral placement of the vehicles can be calculated by simple ratio of actual width of a vehicle to the width measured from the computer monitor in pixels as:

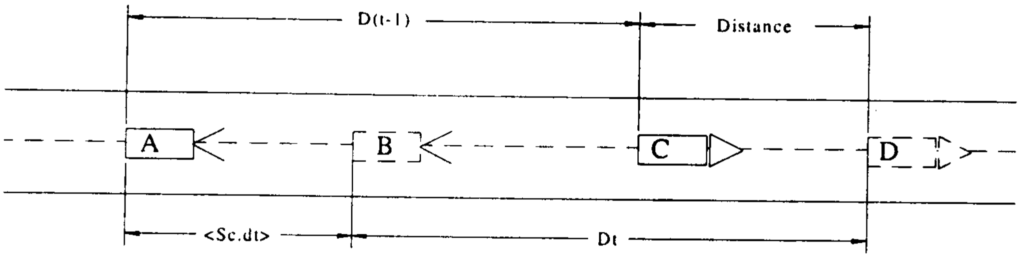


Fig.3.2(a):Positions of vehicle and camera at t and t-1 seconds moving in the same direction

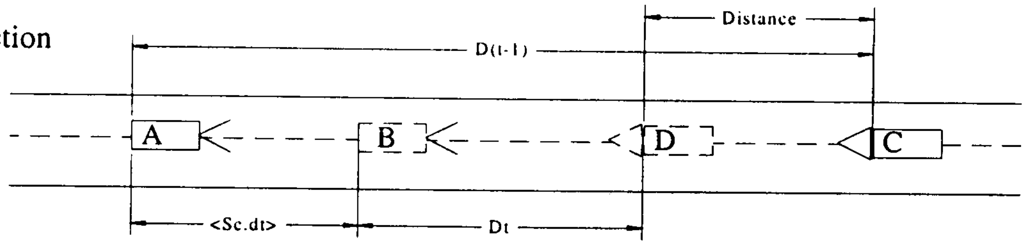


Fig.3.2(b)Positions of vehicle and camera at t and t-1 seconds moving in the opposite directions.

$$L / l = W / w = R / r \qquad \text{Eq. 3.2.}$$

Where :

L - actual left clearance

l - measured left clearance

R - actual right clearance

r - measured right clearance

W - actual width of vehicle

w - measured width of vehicle

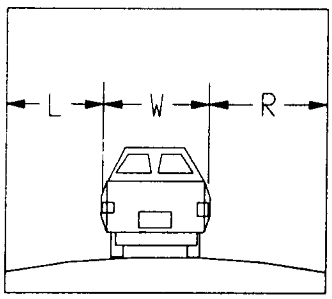


Fig 3.3 : Cross sectional view of the road

Therefore :

$$L = (W / w) \times l \qquad \text{Eq.3.3}$$

$$R = (W / w) \times r \qquad \text{Eq.3.4}$$

But (W / w) is the width factor (K).

ie. $$L = K \times l \qquad \text{Eq.3.5}$$

$$R = K \times r \qquad \text{Eq.3.6}$$

Width factor K varies with the distance from the camera.

3.2.3 CALIBRATION OF VIDEO CAMERA

The calibration of a video camera is performed to find out the relation between the distance from the camera to an object and the width factor. Width factor (K) is defined as the ratio of actual size (in any direction) of an object in metres and its corresponding size measured from the computer monitor in pixels.

3.2.3.1 IDENTIFICATION OF THE VIDEO CAMERA AND ZOOM

In this study, calibration experiments were conducted on Panasonic M 900 camera in which the different zooms are shown in the display as 1, 2, 3, etc.

3.2.3.2 DATA COLLECTION FOR CAMERA CALIBRATION

The aim is to record using the video camera, the known size of objects at different distances and at different zooms. Experiments were conducted on a level ground by holding two measuring staffs of known length (2.8m); one horizontally and the other vertically, as shown in Fig.3.4, at 10 metre intervals from the video camera.

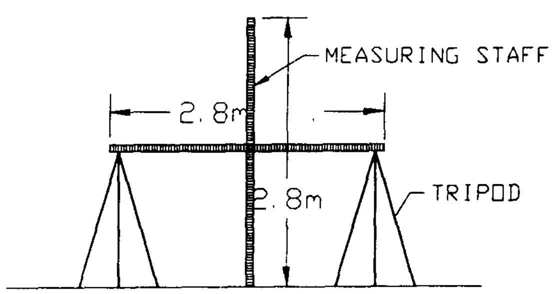


Fig 3.4: Horizontal and vertical measuring staff assembly for calibration.

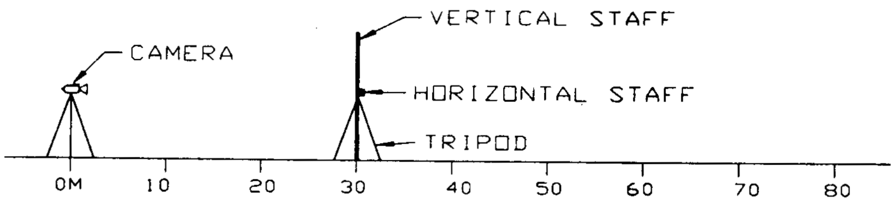


Fig 3.5: Camera and measuring staff setup.

The view of the staff set up was recorded for about 2 seconds by setting the zoom to 1 and this was repeated for various distances of 20m, 30m, etc,. up to 80m, as shown in Fig.3.5. These experiments were repeated for all other possible zooms of 2, 3 and 4 for the video camera selected. Here in this study 4 zooms were selected for Panasonic M900 video camera.

3.2.3.3 DATA RETRIEVAL SYSTEM

For the retrieval of the recorded data a powerful PC with frame grabber or a video card is necessary. V.C.R or a video camera can be connected directly to this card. Required software to display the video tape and to record the current screen are to be installed in the PC (ImageScan and HyperCam are used in this study). The data retrieval system is shown schematically in Fig.3.6.

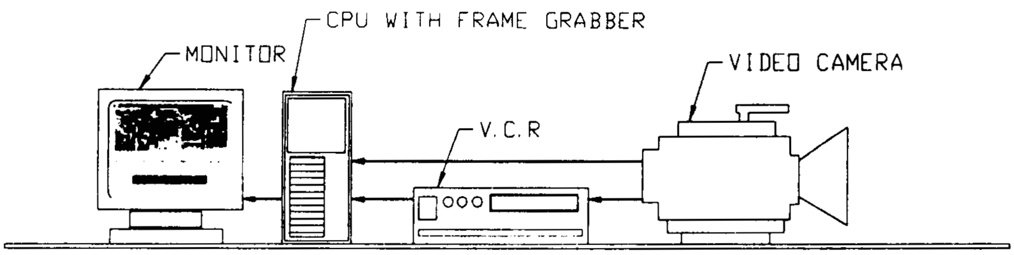


Fig 3.6: Data retrieval system

3.2.3.4 FILE FORMAT AND ITS SPEED

Stored bitmap files can be separate for each frame or all the frames can be in one single file. The important factor in data grabbing is the interval between frames; higher interval will give lesser data and hence less calculations and vice versa. To study the vehicle movements, speeds and positions at micro second intervals are not required. In this study, the standard AVI (Audio Video Interleave) file is used with 2 frames per second interval. The sample frame of an AVI file is shown in Fig.3.7.

Fig 3.7: Sample Frame of an AVI file.

3.2.3.5 DATA EXTRACTION

From the recorded AVI file, length of the staff was measured on the computer monitor in pixels using HyperCam software, by playing the AVI file frame by frame. The corresponding width factors have been calculated by dividing this value with the length of the measuring staff in metres (2.8m), as shown in the Table 3.1.

Distance form the camera in metres and the corresponding width factor in pixels/metre (K) were plotted on X and Y axes respectively as shown in Fig.3.8A. It was found that the relation was linear, on Logarithmic scale and the slopes of the lines were 45 degree as shown in Fig.3.8B. If (x1, y1) and (x2, y2) are the two known points on a straight line, then: $(x-x1)/(x1-x2) = (y-y1)/(y1-y2)$ —— Eq.3.7

Table 3.1: Width factors at different distances for different zooms.

Camera : Panasonic M900. Length of staff (2.8 m)								
Distance from	Zoom=1		Zoom=2		Zoom=3		Zoom=4	
the camera(m)	Pixel	Pixel/m	Pixel	Pixel/m	Pixel	Pixel/m	Pixel	Pixel/m
10	219	78.21	327.5	116.96	530	189.29	-	-
20	107.5	38.39	165	58.93	273	97.5	375.5	34.11
30	73	26.07	110	39.29	182	65	251.5	89.82
40	54	19.28	83	29.64	134.5	47.86	189	67.5
50	43	15.36	65	23.21	108	38.57	147	52.5
60	36	12.86	54	19.29	87	31.07	122	43.57
70	30	10.71	46	16.43	77	27.5	104	37.14
80	27	9.64	40	14.29	67	23.93	-	-

Let the y-intercept at X = 10 be equal to C. Then (10,C) and (C,10) are the two known points on the line. Therefore:

$(\log(x)-\log 10)/(\log 10-\log(C)) = (\log(y)-\log(C))/(\log(C)-\log 10)$ ——— Eq.3.8

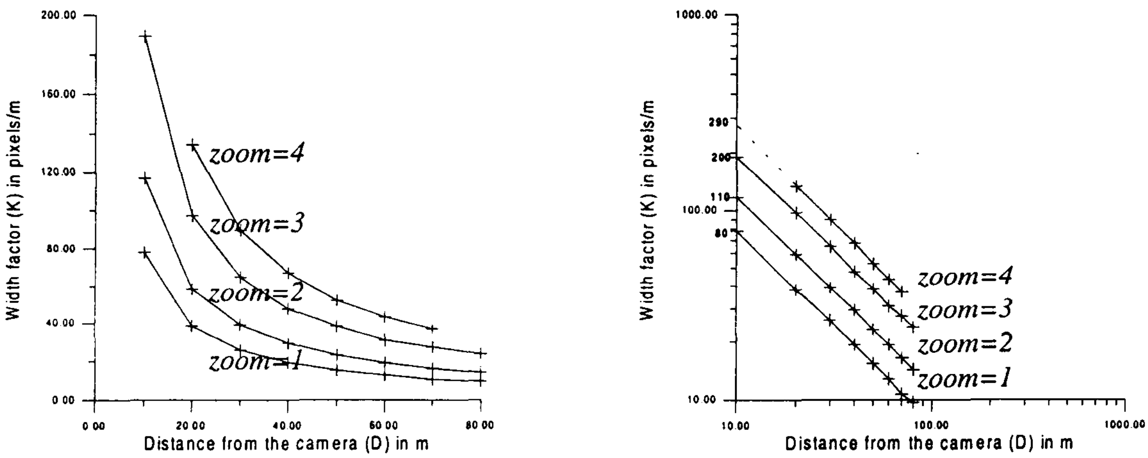
$\log(x)-\log 10 = \log(C)-\log(y)$ ——— Eq.3.9

$\log(x) + \log(y) = \log(C) + \log 10$ ——— Eq.3.10

$x.y = 10C$ ——— Eq.3.11

$x = 10C/y$ ——— Eq.3.12

ie. $D = 10C/K$ ——— Eq.3.13



A) Linear scale B) Logarithmic scale

Fig 3.8. Relation between the distance from the camera and the width factor

3.2.3.6 RELATIONS BETWEEN DISTANCE (D) AND WIDTH FACTOR (K) FOR DIFFERENT ZOOMS

Substituting y intercepts in Eq.3.13, the following relations are obtained

For zoom = 1 : D = 800 / K ———————— Eq.3.14

For zoom = 2 : D = 1100 / K ———————— Eq.3.15

For zoom = 3 : D = 2000 / K ———————— Eq.3.16

For zoom = 4 : D = 2900 / K ———————— Eq.3.17

Where D is the actual distance from the video camera to an object and K is its width factor measured from the computer monitor.

3.2.4 METHODS FOR ANALYSIS OF SPEEDS OF VEHICLES FROM VIDEO TAPES

Instantaneous speed of a vehicle Sv = Sc + (Dt - D(t-1))/dt.

Where Sc - the speed of the vehicle on which the camera is fitted.

Dt - the distance from the camera to the vehicle in t th frame.

D(t-1) - the distance from the camera to the vehicle in the (t-1)th frame.

dt - the time interval between frames.

Two methods are proposed to analyse the video for calculation of speeds of vehicles on the traffic stream; 1) Manual method and 2) Automatic method. The flow chart for these methods are shown in Figs. 3.9 and 3.10 for manual and automatic methods respectively.

3.2.5 CALCULATION OF LATERAL PLACEMENT OF VEHICLES.

To trace the path followed by a vehicle in highway, in addition to the instantaneous speed, the lateral position of vehicles (or lateral speed) are also required. Lateral position of the vehicle can be calculated with the assumption that the width factor (K) is constant for a fixed distance from the camera. The actual left and right clearances are easily calculated from the relation W / w = L / l = R / r.

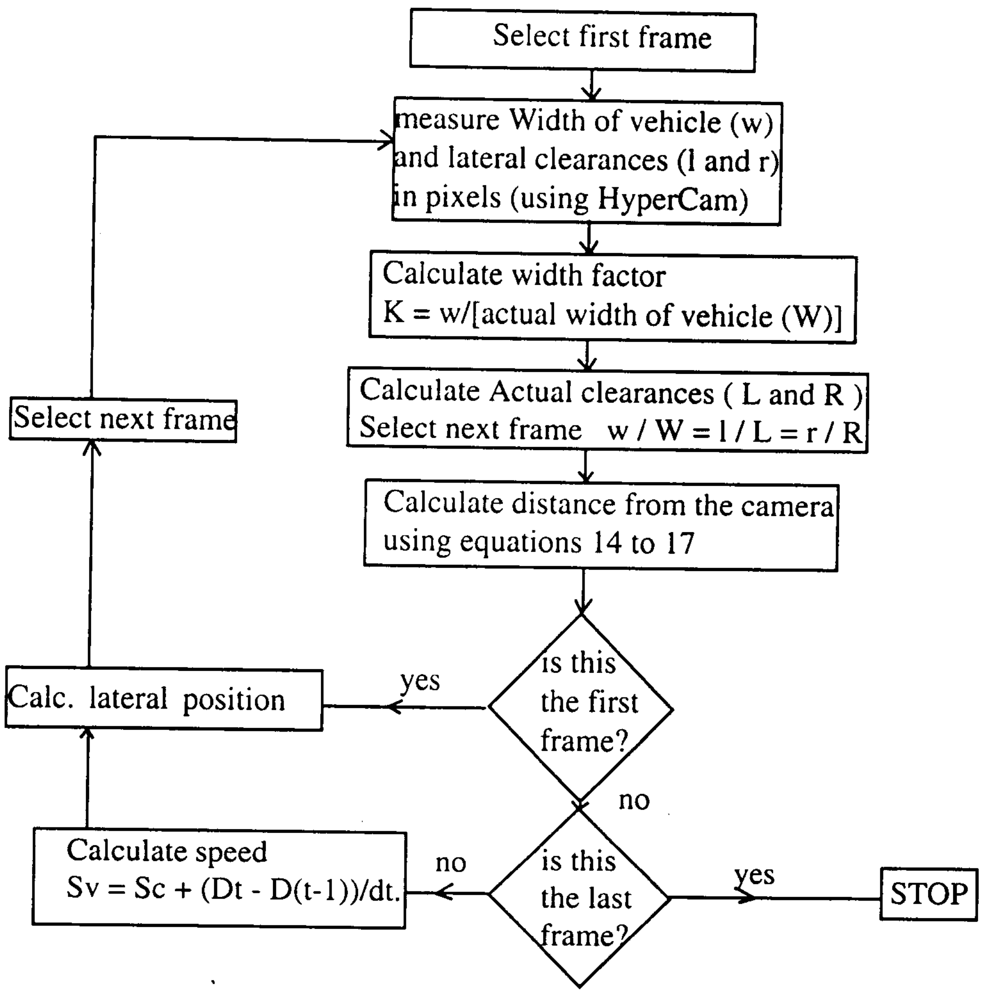


Fig 3.9. Schematic steps in video analysis using manual method.

(see Fig. 3) and the width of road B = L + W + R. Analysing frame by frame the lateral placement of vehicles can be easily traced by this technique. Here also the manual and automatic methods are proposed.

3.2.6 STUDY RESULTS

3.2.6.1 DATA COLLECTION

The data shown in Table 3.2 in pixels were collected from a sample survey conducted on National Highway No.17 at about 5 km away from University of Calicut towards Ernakulam. Data retrieval and analysis were made using Manual method.

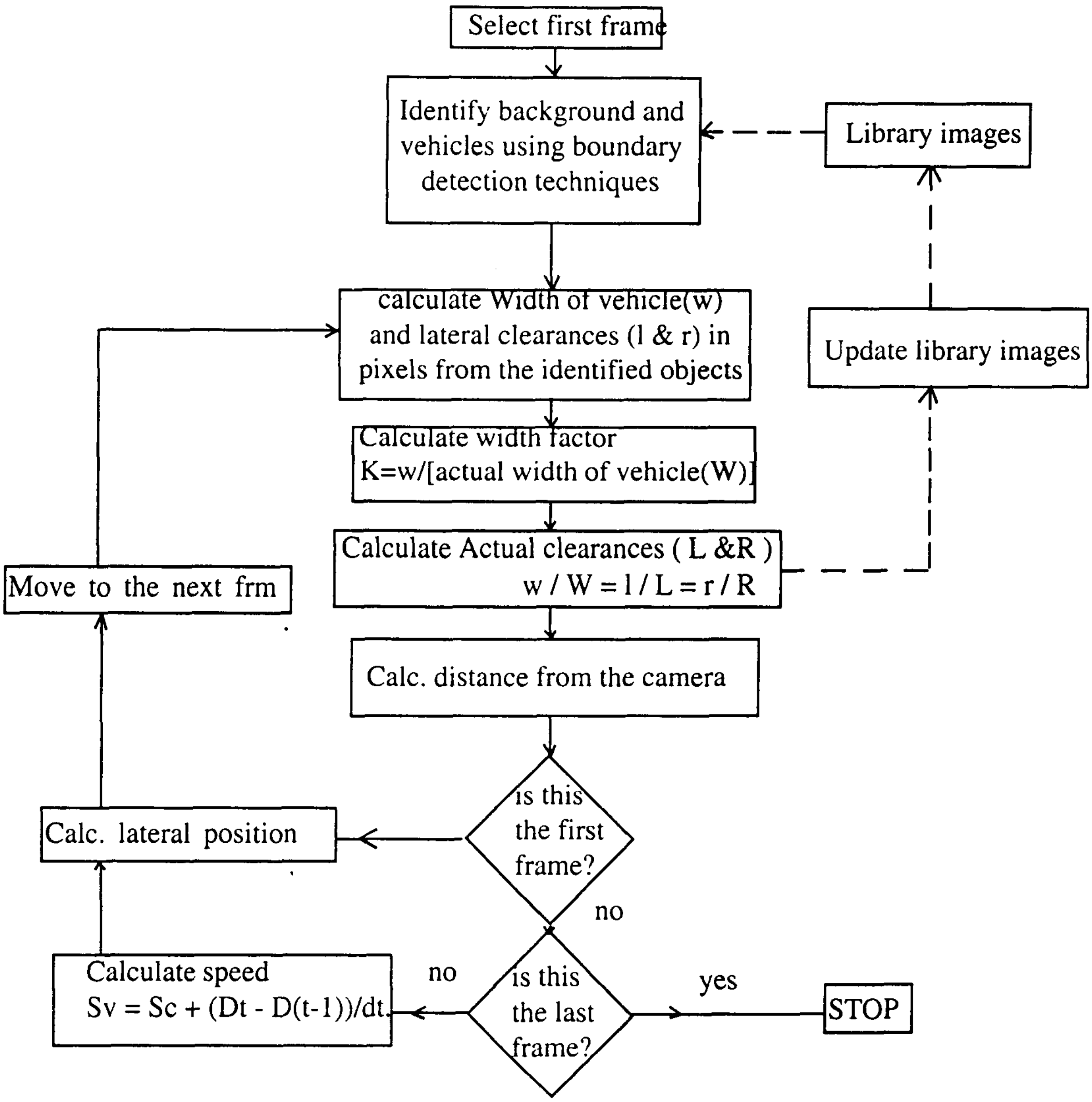


Fig 3.10. Schematic steps in video analysis using automatic procedure.

3.2.6.2 RESULTS OF THE ANALYSIS

Table 3.3 presents the results of the analysis using manual method. The position and speeds of overtaking and overtaken vehicles calculated using the equation system established in articles 3.2.4 and 3.2.5. Positioning of these vehicles at 1 sec time interval are pictorially presented in Fig. 3.11.

Table 3.2: Values of left and right clearances and width of vehicle in pixels. (See fig.3.3)

	Overtaking Vehicle			*Overtaken Vehicle*		
Time(sec)	L	W	R	L	W	R
0.0	37	42	56	0	0	0
0.5	36	40	57	0	0	0
1.0	33	38	57	0	0	0
1.5	30	39	60	0	0	0
2.0	28	39	60	0	0	0
2.5	30	38	62	0	0	0
3.0	31	39	55	0	0	0
3.5	38	38	48	0	0	0
4.0	50	36	38	15	27	43
4.5	52	34	33	13	26	49
5.0	60	32	25	14	25	53
5.5	68	33	24	13	25	51
6.0	74	32	20	14	26	52
6.5	78	32	19	13	27	50
7.0	78	32	19	14	26	52
7.5	79	32	18	14	26	51
8.0	78	31	18	14	26	51
8.5	76	30	17	13	26	51
9.0	74	29	16	13	26	54
9.5	72	28	16	14	27	60
10.0	60	26	17	13	26	62
10.5	58	25	16	12	26	62
11.0	57	24	15	13	25	60
11.5	57	24	16	13	25	58
12.0	55	23	16	12	25	57
12.5	51	22	19	12	25	58
13.0	41	21	23	12	25	62
13.5	35	21	24	13	25	61
14.0	32	20	22	13	24	56
14.5	25	20	22	15	25	55
15.0	23	21	22	16	25	51
15.5	21	21	22	16	25	50
16.0	22	21	22	19	25	48

Table 3.3: Results of analysis.

Time	Overtaking vehicle		Overtaken vehicle	
	Speed	L.position	Speed	L.position
0.0	60.40	0.84	-	-
0.5	60.85	0.91	-	-
1.5	58.40	1.03	-	-
2.0	56.05	1.05	-	-
2.5	55.20	0.90	-	-
3.0	58.25	0.67	-	-
3.5	62.20	0.28	-	-
4.0	63.24	0.14	63.15	1.47
4.5	64.00	-0.21	62.56	1.59
6.5	61.60	-0.70	60.95	1.52
7.0	59.20	-0.74	57.75	1.50
7.5	58.35	-0.76	53.35	1.50
8.0	58.80	-0.78	50.95	1.52
8.5	59.81	-0.80	50.55	1.60
10.0	62.12	-0.59	51.15	1.85
11.5	63.57	-0.60	51.56	1.76
12.0	65.36	-0.45	51.16	1.79
12.5	66.77	-0.06	50.76	1.90

(speeds in km/h and lateral position in metres +ve to the left of centre line and -ve to the right of centre line)

3.2.7 VERIFICATION

Experiments were also conducted to validate the equations developed (Eq. nos. 3.14 to 3.17). It was observed that the maximum error in the distance calculated was approximately 5 percent. Even though the error is quite high, we are interested only in the difference in distances of the camera and the vehicle in successive frames, therefore that error will only be very marginal.

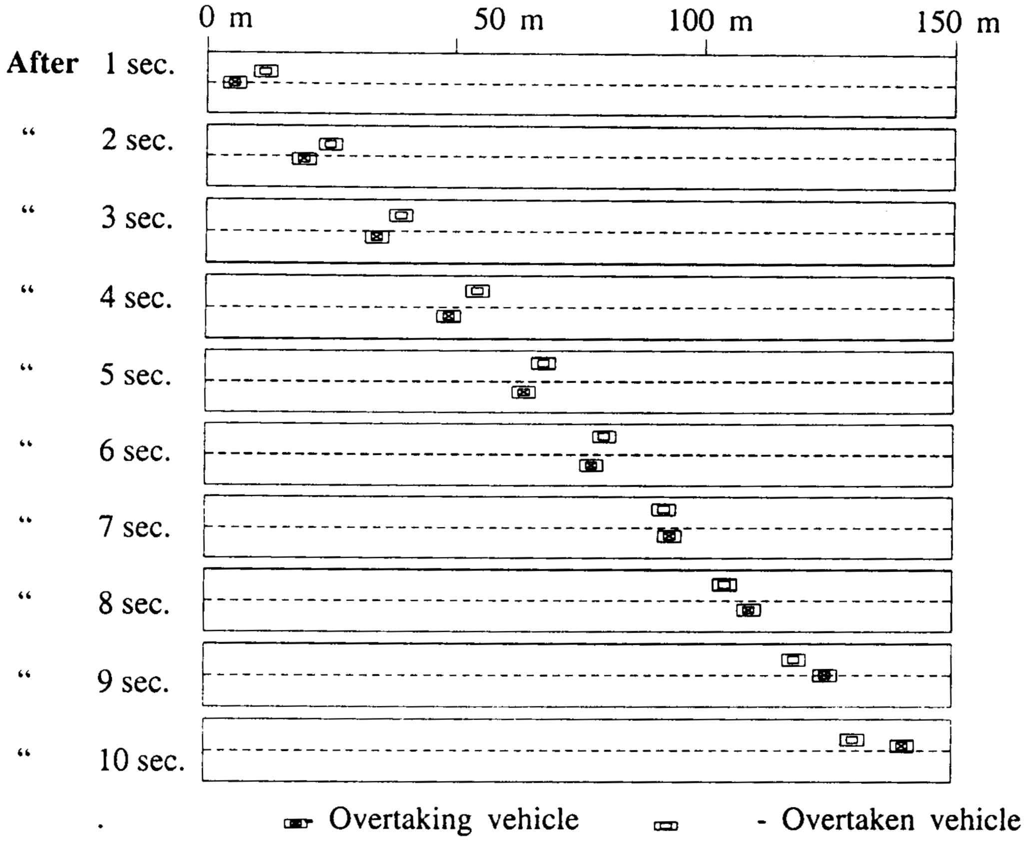


Fig. 3.11. Instantaneous positioning of two vehicles under overtaking by the proposed method

3.2.8 CONCLUSION

With the help of digital computers and softwares, the proposed moving camera method of data collection shows a promise, in traffic engineering to transport the real traffic system from the site to the laboratory. Experiments conducted using Panasonic M900 camera have shown that the manual method developed in this study could turn out to be a cost effective method for analysing traffic engineering data collected using video-graphy.

3.2.9 LIMITATION

Manual method of analysing data from video film is very much time consuming and laborious. Only when high level automatic image processing analysing techniques are developed, the time involved in data extraction from video films for traffic engineering could be reduced.

3.3 ACCURATE SPEED MEASUREMENTS USING DIRECT READ METHOD

3.3.1 INTRODUCTION

Police men generally use Infra red speed measuring equipments to check the overspeeding of vehicles. The speed recording equipment has to be fixed inside the vehicle, to get the instantaneous speeds of a vehicle during an interval of time. To get the speeds of all vehicles at a section of road during a time interval, the above two methods cannot be used. The simplest method of speed calculation in such a case is by dividing the length of a fixed stretch by the time required to travel through the stretch. The time required to travel is calculated by subtracting the entry time to the stretch from the exit time from the stretch. The entry time and the exit time can be observed either manually with a stop watch by eye judgement or with some vehicle detection instruments. This article presents a simplest, an easiest and a cheapest method of vehicle detection at the entry and exit sections to calculate the speeds of vehicle on a road during an interval of time.

3.3.2 PRINCIPLE

Two active probes are fixed at the entry and exit sections at s distance apart. Whenever a vehicle crosses at the entry section, the switch, which is connected at the end of the probe will be activated. The computer will detect its current system time $t1$ at the time of activation of the switch, which is connected through the printer port of the computer. When the vehicle crosses the exit section the same process will repeat and the exit time $t2$ will be recorded.

Therefore the speed of the vehicle can be calculated as:

$$v = \text{distance travelled / time required}$$

i.e. $$v = s / (t2 - t1)$$

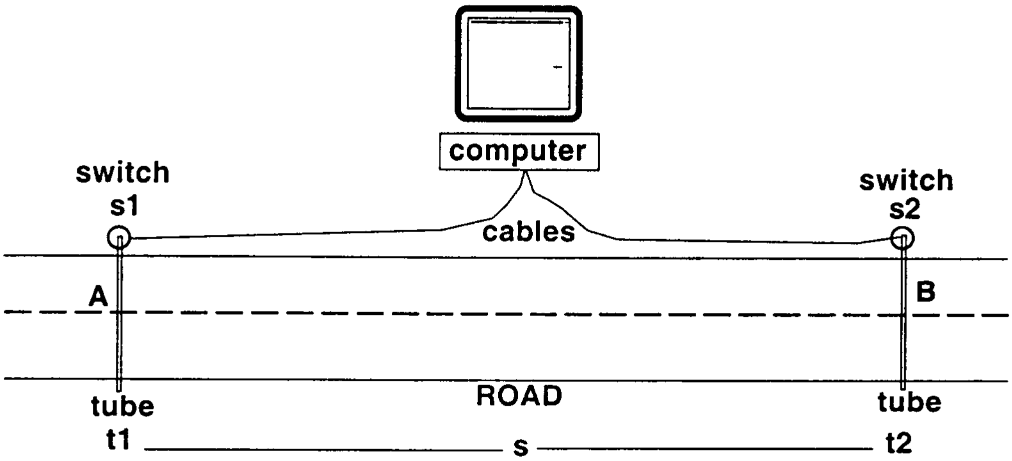


Fig 3.12 Field setup

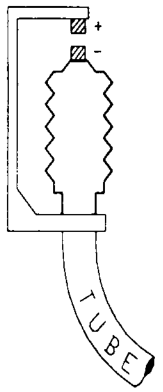


Fig 3.13 Pressure activation switch

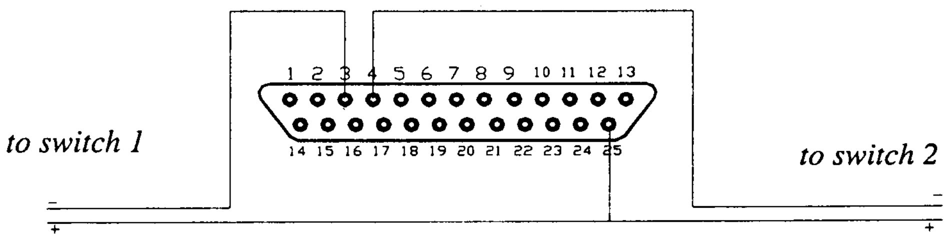


Fig 3.14 Printer port connection information

3.3.3 PERIPHERALS

A computer with the program listed in the Appendix-3.1, is the observation, calculation and the recording system of the device. The additional peripherals needed are presented in Table 3.4.

Table 3.4 List of peripherals

Sl.N	Item	Quantity
1	Flexible tube of 10mm dia and 10m length	2 nos.
2	Electric insulated cable	50 m.
3	Parallel port male connecter	1 no.
4	Pressure activation switch	2 nos.

3.3.4 FIELD SETUP

The one end of the tube is closed and at the other end the pressure activation switch is fitted. The tube is completely filled with water without any air bubbles. Whenever a vehicle crosses over the tube, due to the high pressure of wheels, the pressure in the tube will increase and the switch (Fig 3.13) will close. The computer continuously checks the circuit and whenever the circuit is closed, the system will read the current time and start checking for the other tube. These two switches are connected with the computer through printer (parallel port) port. The connectivity informations are presented in Fig.3.14 The 3rd and 4th connections among the available 25 connections are used for the checking of two switches and the 25th connection is used to supply voltage to the switches, which will have +5volts always.

3.3.5 COMPUTER PROGRAM

The working of the system is briefly presented in the flow diagram (See Fig 3.15). It is very clear from the diagram that the direction of the vehicle can also automatically recorded by the program. The computer program is encoded in C language and the program listing is presented in APPENDIX-3.1.

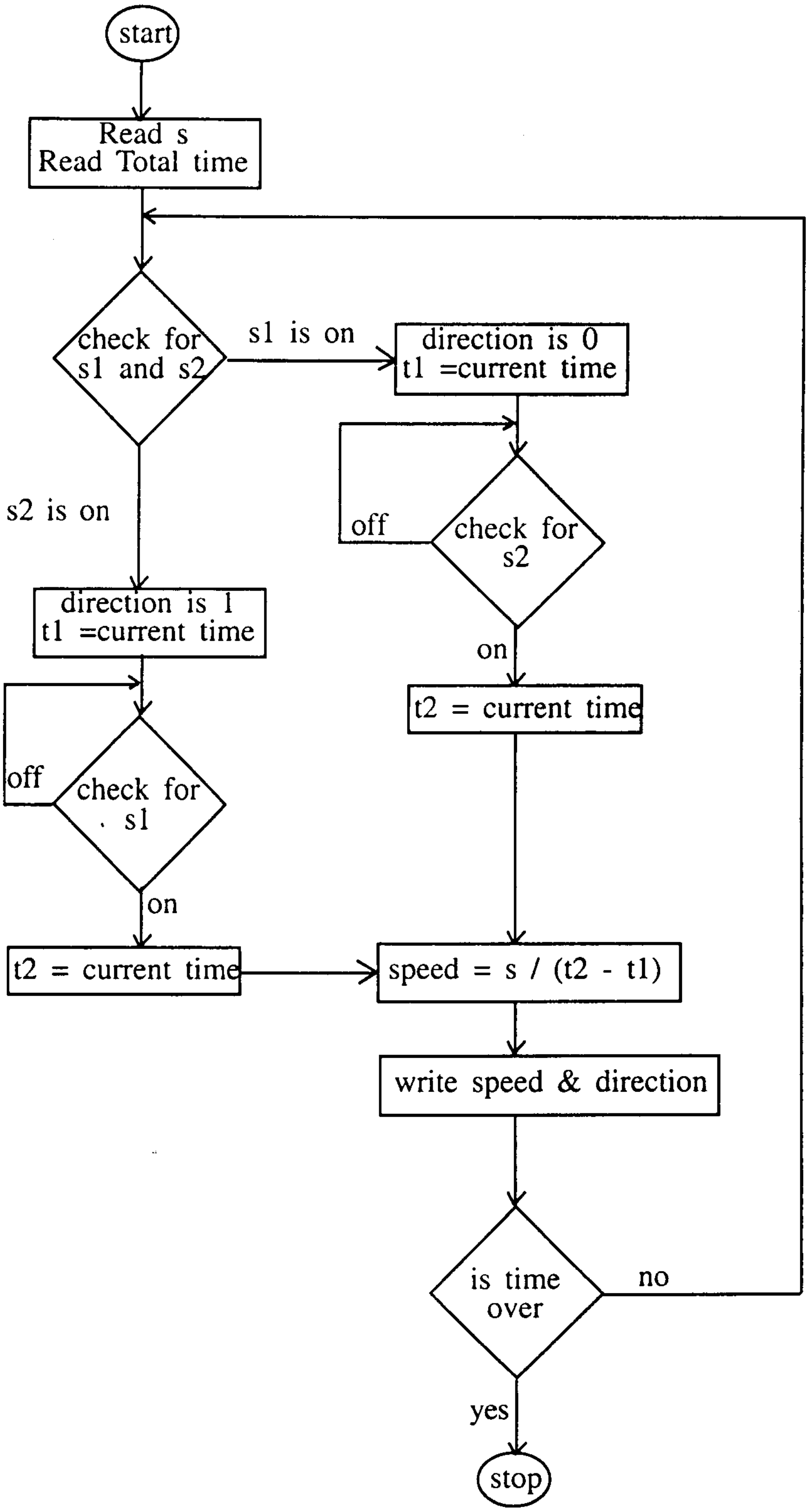


Fig 3.15 Flow chart for detecting entry and exit time of vehicles

The proposed methodology has no way to find the type of vehicle automatically, which is coming to the test stretch. In order to incorporate the type of vehicle also, the C program has been written to get a key from the user (C for Car, B for Bus, etc.,) so as to identify the type of the next vehicle coming to the test section.

3.4 SUMMARY AND CONCLUSION

By the use of simple instrumentation set up proposed in this study, it is possible to measure the distances of the moving vehicles from a chosen reference, the speeds of the moving vehicles and the lateral placement of the vehicles. While, the instrumentation set up is quite cheap and cost-effective, the potential of a laptop computer is fully exploited for vehicle detection and study of lateral placements using the number of pixels the vehicle images occupy on the computer monitor. This procedure for vehicle detection and placement study avoids costly requirement of pavement markings and uses the potential of modern computer thereby reducing the manpower needed for conduct of survey.

APPENDIX - 3.1

VEHICLE DETECTION PROGRAM

This program listing (PORT.CPP) is to read the impact of vehicle wheels from the probes on the road so as to calculate the speed of the vehicle automatically on a PC connected to the probes through the printer port.

```
//————————PORT.CPP————————————————————

#include <stdio.h>
#include <ctype.h>
#include <conio.h>
#include <process.h>
#include <stdlib.h>
#include <string.h
#include <dos.h>
#define Port 0x3bd

FILE *fpout;

main()
{
int i,count,in1=55,in2=247,vtype,byte1,byte2;
int test,dir,vno[12],total_no;
char file_name[12],key,vehicle[12],temp_str[25],direction[10];
struct time time_in,time_out;
float time1,time2,time,distance,speed,temp_float;
char temp_string[100];
clrscr();

print("\nEnter Distance between stations:");
scanf("%f",&distance);

printf("\nEnter output file name:");
scanf("%s",&file_name);

clrscr();
if((fpout=fopen(file_name,"w"))==NULL)
        {printf("\n\aError writing file");
        exit(0);
        }
outportb(0x3bc,1);
```

```
textbackground(BLUE);
window(0,0,80,25);
for(i=1;i<=25;i++)
cprintf("                                                                    ");
textcolor(YELLOW);
gotoxy(3,1);cprintf("————————————");
gotoxy(35,2);cprintf("Speed Tester");
gotoxy(3,3);cprintf("—————————");
textcolor(GREEN);
gotoxy(3,7);cprintf("|—————————|");
gotoxy(3,8);cprintf("|Sl No:  Vehicle ....Speed Tester");
gotoxy(3,9);cprintf("|——|");
gotoxy(3,5);textcolor(YELLOW+BLINK);cprintf("Press");
textcolor(WHITE);cprintf(" - Vehicle Code(B/C/A/T/M/V/J/L/1/2 or Q to quit) O/
P:%s",file_name);
gotoxy(4,23);cprintf("————————");
gotoxy(4,24);cprintf("By P.Abdul Nazer....");
for(i=1;i<=10;i++)vno[i]=0;
count=1;

do
{
 total_no=0;
 for(i=1;i<=10;i++)total_no=total_no+vno[i];
 test=0;
 key=getch();
 strcpy(vehicle,"    ");
 if(key=='q'||key=='Q')goto end;
 else if(key=='c'||key=='C'){vtype=2;strcpy(vehicle,"Car");}
      if(key=='t'||key=='T'){vtype=4;strcpy(vehicle,"T/W");}
      if(key=='a'||key=='A'){vtype=3;strcpy(vehicle,"Auto");}
      if(key=='l'||key=='L'){vtype=8;strcpy(vehicle,"Lorry");}
      if(key=='m'||key=='M'){vtype=5;strcpy(vehicle,"Mini.Lorry");}
      if(key=='v'||key=='V'){vtype=6;strcpy(vehicle,"Van/M.Bus");}
      if(key=='b'||key=='B'){vtype=1;strcpy(vehicle,"Bus");}
      if(key=='j'||key=='J'){vtype=7;strcpy(vehicle,"Jeep");}
      if(key=='1'){vtype=9;strcpy(vehicle,"Ex-1");}
      if(key=='2'){vtype=10;strcpy(vehicle,"Ex-2");}
      else
        {
        textcolor(YELLOW+BLINK);gotoxy(23,16);cprintf("Invalid       Key
Presed");sound(300);delay(1000);
        nosound();gotoxy(23,16);textcolor(BLUE);cprintf("                    ");
        }
```

```
gotoxy(13,16);textcolor(YELLOW+BLINK);cprintf("    %s",vehicle);
if(key=='c'||'C'||'t'||'T'||'a'||'A'||'l'||'L'||'m'||'M'||'v'||'V'||'b'||'B'||'j'||'J'||'1'||'2')

do
  {
  byte1=inportb(Port);
  if(byte1==in1||byte1==in2)
  {
  if(byte1==in1){dir=1;srcpy(direction,"UP");
  if(byte1==in2){dir=2;srcpy(direction,"DOWN");
  gettime(&time_in);
  sound(1000);
  time1=time_in.ti_min+time_in.ti_sec/60.0+time_in.ti_hund/6000.0;
  gotoxy(24,16);

  cprintf("%d:%d:%d.%d(%s)", time_in.ti_hour,time_in.ti_min,time_in.ti_sec,
          time_in.ti_hund,direction);
  textcolor(GREEN);

do
    {
    byte2=inportb(Port);
    if((byte1==in1&&byte2==in2) ||(byte1==in2&&byte2==in1))
      {
      gettime(&time_out);
      nosound();
      test=1;
      time2=time_out.ti_min+time_out.ti_sec/60.0+time_out.ti_hund/6000.0;
      speed=distance/1000/(time2-time1)*60;
       fprintf(fpout"\n%d
  cprintf(" %d:%d:%d.%d",time_out.ti_hour,
time_out.ti_min,time_out.ti_sec,time_in.ti_hund);
       }
      if(test==1)break;
    }while(1);
  }
 if(test==1)break;
}while(1);
}while(1);
end:
flose(fpout);
clrscr();
}//————————————————————————————————EOF PORT.CPP——————————
```

CHAPTER - 4

MIXED TRAFFIC BEHAVIOUR

4.1 GENERAL

The traffic observed on Indian roads is of mixed type, generally referred as heterogeneous in character. It includes both fast and slow moving vehicles, with varied vehicular characteristics playing on the same road. Considerable variations are observed even in fast moving heavy duty vehicles like the trucks, the buses and also in the light duty vehicles like the cars, the scooters, the autos etc. Moreover, the traffic composition of fast and slow moving vehicles also vary significantly in different environments. Due to the heterogeneity, the head way, the lateral positioning, etc., also vary widely. The behaviour of the speed, the head way and the lateral positions are studied and briefly presented in the following sections.

4.2 STUDY STRETCH AND TYPES OF VEHICLES

The present research work focuses on the development of simulation model for mixed traffic flow in bi-directional condition at mid blocks only. Merging, diverging and crossing manoeuvres that are quite prevalent on road intersections are outside the scope of the study. The effect of curves on the traffic flow is outside the scope of the study. Similarly the effect of the pedestrian and the cycles are also outside the scope of the study.

Studies have been conducted at different locations on the National Highway 17 and 47 in Kerala. Most of the studies have been conducted on NH 47 between Trichur and Palakkad and some locations on NH 17 between the Calicut University and Kuttippuram. All the roads selected are of two way two lane traffic. There are eight types of vehicles identified, viz. Car, Bus, Auto, Truck, Two Wheeler, Mini Bus, Mini Truck and Jeep, their average length and width observed from the field are presented in Table 4.1.

Table 4.1 Dimensions of the type of vehicles observed in the study

Code No	Type	Length in m.	Width in m.
1.	Car	3.8	1.5
2.	Bus	9.0	2.3
3.	Auto.	2.5	1.2
4.	Truck	6.8	2.3
5.	T/W.	1.9	0.7
6.	Mini. Bus	6.0	1.8
7.	Mini. Truck	5.2	1.9
8.	Jeep	3.7	1.6

4.3 SPEED STUDIES

One of the fundamental measurements of traffic performance on the road is the speed of vehicles. It forms one of the basic input parameter to any simulation study. Various forms of speed such as the desired speed, the design speed and the actual speed are to be understood clearly to form the input to the simulation model.

Under unimpeded vehicular movement, most of the drivers tend to drive their vehicles at the desired speed. The desired speed is subjective in nature and they do vary with the individual drivers. The desired speed is associated with the design speed or the speed limits imposed on a road system. The variations in desired speed are generally considered as normally distributed. Exhaustive free speed data analysis of various modes of Indian vehicles was carried out on National Highways by the Central Road Research Institute, New Delhi(1982) as part of the Road User Cost Study project sponsored by the World Bank and Government of India. The speeds of various modes were observed to follow normal distribution in that study. Observations made using simulation studies (Marwah(1976) and Ramanayya(1977)) for mixed traffic conditions also supported that the speed phenomenon was better explained by normal distribution, but it needed mode wise consideration.

The assigned speed is also a function of the condition of the road. The grades and the sharp curves may not permit the desired speeds. However, the driver tries to attain the desired speeds with respect to the geometrical conditions and upon the opportunities available. Similarly, actual speed is also another form of attribute that a vehicle attains at any point of time in simulation process. It varies for a mode throughout the simulation period depending on the traffic conditions. The speed summary statistics of different types of vehicles that were observed in the study are presented in Table 4.2

Table 4.2 Desired speeds of different types of vehicles

Code No.	Type of vehicle	Mean Speed(Km/h)	Std.Dev.	Sample size
1.	Car	56.73	6.32	243
2.	Bus	51.32	5.54	189
3.	Auto.	43.65	4.41	124
4.	Truck	40.97	7.42	154
5.	T/W.	46.09	9.26	167
6.	Mini. Bus	47.13	7.61	104
7.	Mini. Truck	42.75	9.14	136
8.	Jeep	52.03	8.46	186

4.4 LATERAL POSITIONING

Studies have been conducted on the positioning of vehicles across the road for different types of vehicles. Sample views of the free flowing vehicles are presented in Fig 4.1. It is clear from the figure that the lateral positions(L_f) of different vehicles are different in the free flowing situation. In addition to this, it has been observed that the lateral placement of a free flowing vehicle varies with its speed. Lateral positions of three different free flowing cars are presented in Fig 4.2. The speeds of vehicles shown in the Figs 4.2(a), 4.2(b) and 4.2(c) are 43kmph, 57kmph and 65kmph, respectively. It is clear from these figures that the vehicle have a tendency to move towards the centre line of the road as its speed increases. When a vehicle is coming from the opposite direction, the lateral positions(L_o) of the vehicle is observed changing with respect to its speed. Sample views are presented in Fig 4.3. Similarly when a vehicle is passing from the same direction, the lateral positions(L_p) of the vehicle is observed changing with respect to its speed. Sample views are presented in the Fig 4.4. These lateral distances from the left edge of the road to the centre of the vehicle L can be presented as:

$$L = A \times Speed^2 + B \times Speed + C \text{ ---------------------------------- } 4.1$$

L_f : Distance from the left edge of the road to the centre of the vehicle, when the vehicle is free flowing.

L_o : Distance from the left edge of the road to the centre of the vehicle, when there is an opposing vehicle in the opposing lane.

L_p : Distance from the left edge of the road to the centre of the vehicle, when one vehicle is overtaking another in the same direction while passing. The constants A, B and C of lateral distances for different types of vehicles are presented in Table 4.3.

4.5 HEADWAY DISTRIBUTION

The road traffic headway distribution can be studied as either in space or as distribution in time and are termed as space and time headway distributions. The space headway is defined as the distance from a selected point on the lead vehicle to the identical point on the following vehicle. Usually the front edges are selected since they are easily detected in automatic detection system. It is thus seen that the space headway includes the length of the lead vehicles and the gap length between the lead and following vehicle. The time headway is defined as the time elapsed between the arrival of successive pairs of vehicles. In this case also the time between the passage of identical points on two consecutive vehicles is considered. In practice the leading edges of vehicles are used for both manual and automatic detection.

Fig 4.1(a)
Lateral position of a free flowing auto.

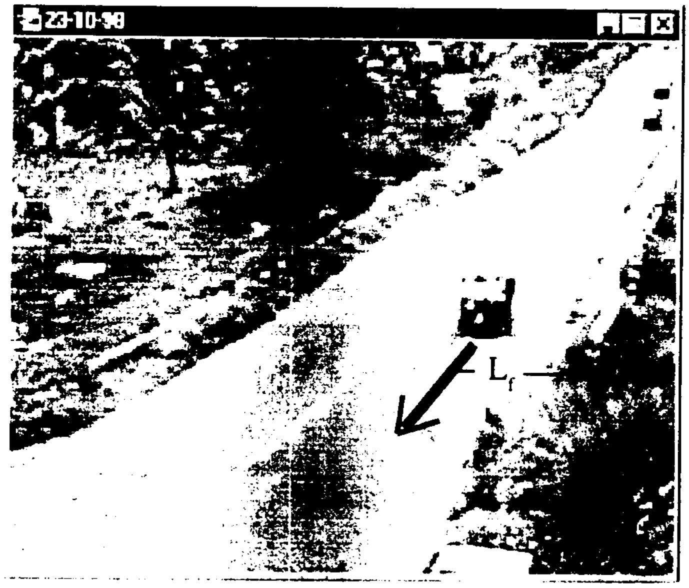


Fig 4.1(b)
Lateral position of a free flowing car.

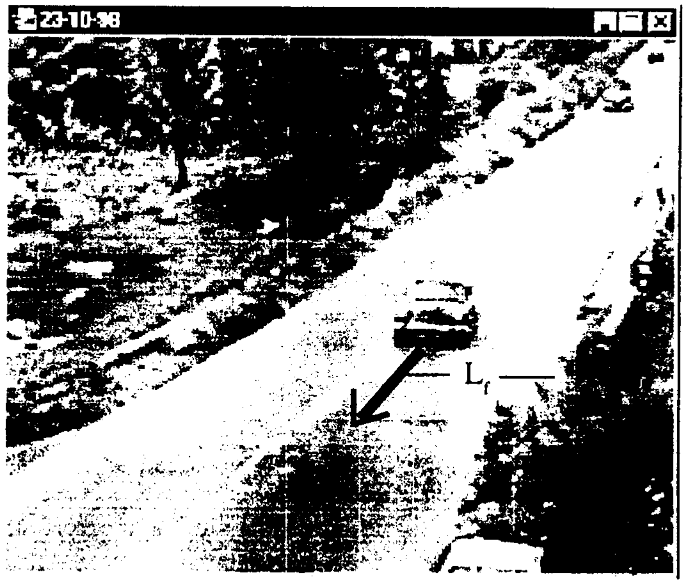


Fig 4.1(c)
Lateral position of a free flowing truck.

Fig 4.2(a) Lateral Position of a Car Speed = 43 kmph

Fig 4.2(b) Lateral Position of a Car Speed = 57 kmph

Fig 4.2(c) Lateral Position of a Car Speed = 65 kmph

Fig 4.3(a). Lateral positions of opposing vehicles (Car and jeep)

Fig 4.3(b). Lateral positions of opposing vehicles (Truck and Jeep)

Fig 4.4(a). Lateral positions of passing vehicles (Jeep and Jeep)

Fig 4.4(b) Lateral positions of passing vehicles (Bus and Auto)

Table 4.3 Lateral distances L_f, L_p and L_o for different types of vehicles

$$L = A \times Speed^2 + B \times Speed + C$$

No.	Veh. Type	L	A	B	C
1.	Car	L_f	- 0.0003	0.0517	- 0.7773
		L_p	- 0.0004	0.0561	- 1.0151
		L_o	- 0.0002	0.0352	- 0.5961
2.	Bus	L_f	- 0.0007	0.0777	- 0.9858
		L_p	- 0.0008	0.0743	- 0.7920
		L_o	- 0.0002	0.0252	- 0.4061
3.	Auto	L_f	- 0.0004	0.0352	- 1.2390
		L_p	- 0.0004	0.0301	- 0.9871
		L_o	- 0.0002	0.0290	- 1.1923
4.	Truck	L_f	- 0.0005	0.0610	- 0.8731
		L_p	- 0.0004	0.0471	- 0.9291
		L_o	- 0.0004	0.0487	- 1.0231
5.	T/W	L_f	- 0.0001	0.0910	- 1.8230
		L_p	- 0.0001	0.0628	- 1.6521
		L_o	- 0.0001	0.0687	- 1.2342
6.	M.Bus	L_f	- 0.0005	0.0543	- 0.9254
		L_p	- 0.0006	0.0498	- 0.8923
		L_o	- 0.0004	0.0501	- 0.6521
7.	M.Truck	L_f	- 0.0008	0.0767	- 1.1242
		L_p	- 0.0004	0.0452	- 0.7625
		L_o	- 0.0005	0.0531	- 0.9435
8.	Jeep	L_f	- 0.0007	0.0875	- 0.8414
		L_p	- 0.0008	0.0476	- 1.1930
		L_o	- 0.0003	0.0554	- 0.9835

The time headway distribution varies considerably with respect to the flow levels. These headway distributions can be approximated through the use of various mathematical forms. At low traffic volume there is very little interaction between the vehicles and the headways appear to be randomly distributed. In the early years of simulation modelling, Poisson distribution was used for modelling the vehicular arrivals, which was later changed to a negative exponential distribution to suite the continuous data.

The mixed traffic on Indian roads generally consists of both slow and fast modes, moving on the same road network. Vehicular characteristics vary considerably from mode to mode in terms of speed, acceleration and deceleration capabilities, size, road occupation etc. Moreover, distinct lane discipline does not exist. Under the circumstances, realization of headway distribution in correct perspective is quite essential.

Many researchers have observed different distributions for different traffic situations. None of them have suggested a single distribution for a rural two way highway under all flow ranges. Kuncheria (1995) has observed the following headway distributions for different flow levels of the mixed traffic environment:

(1) < 500vph - exponential

(2) 500 - 2000 vph - shifted exponential

(3) 2000 - 3000 vph - Erlang and composite models

But today with the abrupt increase in the speeds of modern computers and in the simulation point of view, we have the power to allow vehicles to move a long distance before the vehicles enter in to the actual simulation study stretch. This zone is known as warm up zone. In this study a warm up length 1Km is taken on the

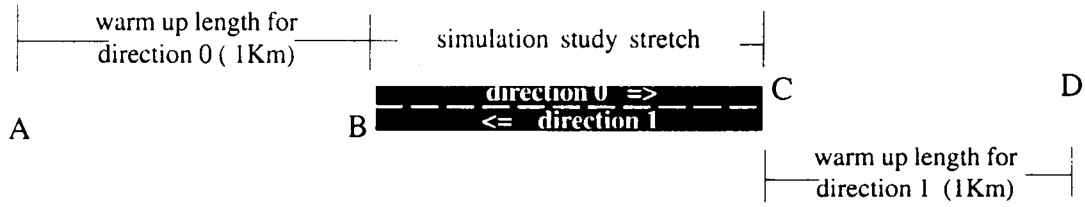


Fig 4.5 Warm up zones on either side of the simulation study stretch

either side of the simulation study stretch as shown in Fig 4.5. Vehicles enter at 'B' in the direction 0 (left to right), which has already gone through the warm up zone (1Km) will have its headway adjusted to the real situation as at 'B', irrespective of the headway distribution adopted at the vehicle generation point at 'A'. Similarly, a warm up zone length 1Km is also adopted in the other direction (direction 1), in which the vehicle enters the simulation stretch at 'C' and the vehicle generation point is at 'D'. At the vehicle generation points 'A' and 'D', the headway distributions suggested by Kuncheria (1995), for different flow levels, are adopted.

4.6 DENSITY OF MIXED TRAFFIC STREAM FROM THE SPEEDS OF INDIVIDUAL VEHICLES

(Abdul Nazer, P, (2001), Traffic Engineering & Control, pp. 308-310, U.K.)

The major three characteristics of a traffic stream are the speed, the flow and the density. The fluid flow relation between these three parameters will hold considerably good only in a homogenous flow, where, the speed variations among the vehicles are less and thus it will not be valid in a mixed traffic environment due to the wide range of vehicular characteristics. These three characteristics can be observed from the field independently. Due to the high variations in the stochastic nature of the headway, density is always troublesome to observe from the field, compared to the other two. This section describes a methodology developed to find the density parameter from the speeds of individual vehicles. This theory has been developed on the assumption that every vehicle has some amount of contribution towards the stream density and that amount of contribution can be worked out by its speed. The developed equation has been validated with different cases of field observation and by the simulated data by "AutoTRAFFIC".

4.6.1 Mixed traffic flow

In a mixed traffic flow due to the wide range of fast and slow moving vehicles, the ideal fluid flow equation is not valid, ie. $Q \neq K.U$, so the third parameter can not be calculated by knowing the other two. In such a situation the density of the stream can be calculated from the speeds of individual vehicles which is described in the following sections.

4.6.2 Principle

This theory has been developed on the assumption that each vehicle will have a contribution towards its stream density. Thus the stream density can be written as:

$$K = \kappa_1 + \kappa_2 + \kappa_3 + \ldots\ldots \kappa_Q \qquad \text{------------------------------} \quad 4.2$$

where: κ_1, κ_2, κ_3, ... κ_Q are the contributions of densities of 1st, 2nd, 3rd,....

Qth vehicle respectively and Q is the number of vehicles observed during one hour.

4.6.3 Unit Flow and its properties

When the flow is one vehicle per hour, such a flow is termed as unit flow stream. Thus

The flow, Q = 1 vehicle/hr.

The stream speed, $U = U_1/1 = U_1$, ie. the speed of the vehicle itself

The mean distance head way is the distance between two successive vehicles. But the time headway is one hour. Therefore the distance headway is the distance travelled by the vehicle during one hour.

Thus:

$D = U \times 1.$ Where D is the distance headway in km.

ie. D = U, for example: if the speed of the vehicle is 60kmph. then the distance between two successive vehicles will be 60km in a unit flow stream.

But, density = 1 / distance headway.

Therefore density, K = 1 / D = 1 / U

$$K = \frac{1}{U} \qquad \text{------------------------------} \qquad 4.3$$

4.6.4 Stream Density

A mixed traffic stream with flow Q can be considered as Q number of unit flow streams. Thus the equation 4.2 can be rewritten as:

$$K = 1/U_1 + 1/U_2 + 1/U_3 + \ldots\ldots + 1/U_Q \qquad \text{-----------------} \qquad 4.4$$

ie. $$K = \sum_{i=1}^{Q} \frac{1}{U_i} \qquad \text{------------------------------} \qquad 4.5$$

Q is the number of vehicles observed during one hour. If n is the number of vehicles observed during the time T, the above equation can be re written as:

$$K = \frac{1}{T} \sum_{i=1}^{n} \frac{1}{U_i} \quad \text{------------------------------4.6}$$

Therefore, the density (K) of a mixed traffic stream is given by the equation 4.6 in which U_i is the speed of i th vehicle, n is the number of vehicles observed crossing at a section of the road during the time T.

4.6.5 Check for ideal condition

In an ideal homogeneous condition , $U = U_1 = U_2 = U_3$, ... U_n

Thus the above equation:

$$K = \frac{1}{T} \sum_{i=1}^{n} \frac{1}{U}$$

$$K = \frac{1}{T} \times \frac{n}{U} \quad \text{------------------------------4.7}$$

But n / T = Q.

Therefore: K = Q / U ------------------------------4.8

4.6.6 Comparison with direct observation

Fig 4.6 shows the observed average density for a particular stream upto 30 minutes. It is a cumulative of average densities measured at every 10sec. At initial stages, due to the less number of observations, the plot is highly fluctuating and after some time it is converging to 17.5vehicles/km. This is the actual direct measurements from the field. Now let us see the density with the new equation. It is presented in Fig 4.7. Whenever a new vehicle is observed at a section for measuring speed, the value of K is recalculated with the equation 4.7 and plotted. It is clearly observed in the figure that the value of K is converging to the same value which is measured from the field and presented in Fig 4.6.

The observed and calculated densities are presented in Fig 4.8 for some other stream.

4.6.7 Omitting the time factor

In the equation 4.6, n is the number of vehicles observed during the time T. So all of the n vehicles speeds have to be observed from the field without missing any during the time T. Therefore, it will be practically useful if the time factor T in the equation is removed. Flow is nothing but the number of vehicles observed during one hour. i.e:

$$Q = n / T$$

$$\text{i.e} \quad T = n / Q \quad \text{------------------------------ } 4.9$$

Substitute in equation 7.5

$$K = \frac{Q}{n} \sum_{i=1}^{n} \frac{1}{U_i} \quad \text{------------------------ } 4.10$$

4.6.8 Sample size

In the above equation 4.10, as the value of n increases the calculated density using the equation will converge to actual value of the density. When the value of n is very less (5 or 6 vehicles), then the calculated value of K is observed deviating far from the actual value in the heterogeneous traffic conditions. A number of observations have been conducted for various flow levels and a sample size 50 is observed enough to calculate K even in the worst heterogeneous flow levels. Thus the equation 4.10 can be rewritten as:

$$K = \frac{Q}{50} \sum_{i=1}^{50} \frac{1}{U_i} \quad \text{------------------------ } 4.11$$

This can be summarised as: If the flow of any traffic stream is known with speeds

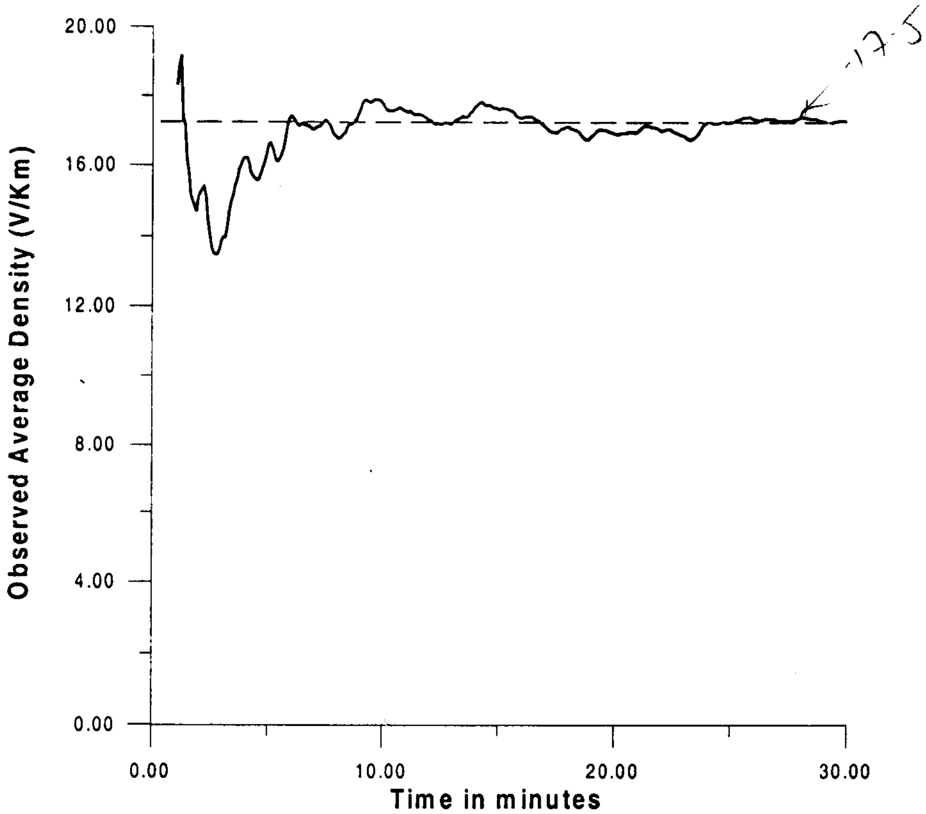


Fig. 4.6 Observed average density

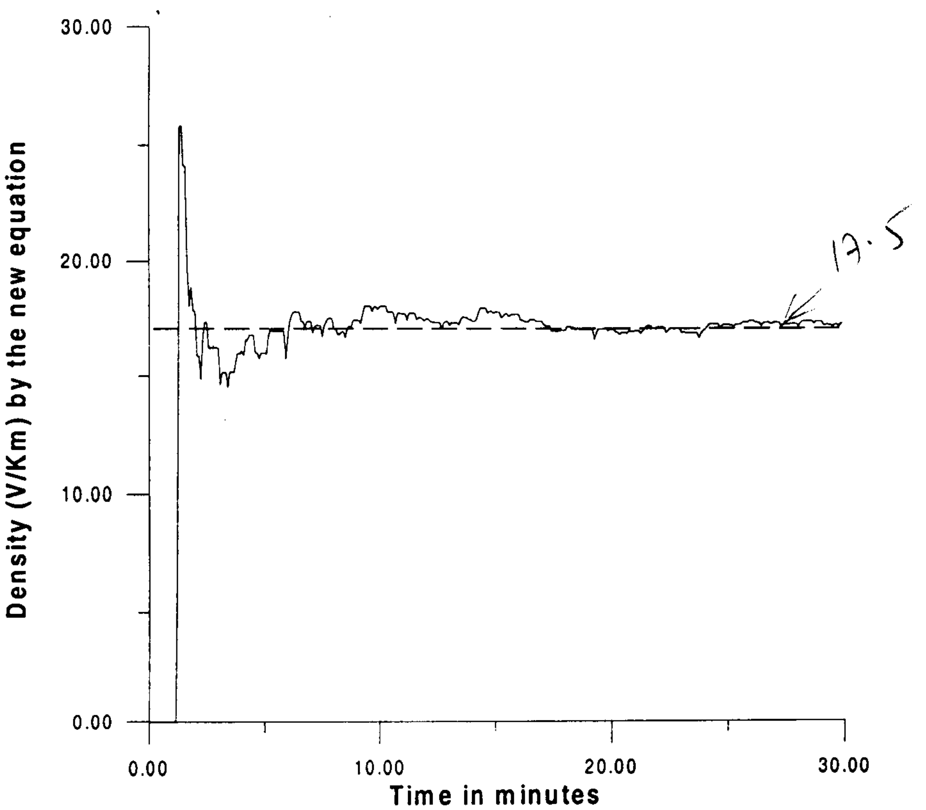


Fig. 4.7 Calculated density

of at least 50 vehicles in it, which are selected either continuously or randomly, then the density of the stream (the average number of vehicles occupied per unit length of the road) can be directly calculated using the equation 4.11.

4.6.9 Validation

Densities have been observed and calculated using the above equations for different mix of vehicle classes at different flow levels. It is observed that the calculated value of density is exactly matching with the observed values from the field. One such example is described below:

Table 4.4 shows the actual density observed at every 10 seconds intervals of time. 30 observations were recorded during 5 minutes duration. The third column is the observed value and the fourth column indicate the average of the density observed. The average density of these 30 observations is 26.38 vehicles/km in which the density observations are ranging from a minimum value 13 to a maximum of 40 vehicles/km. Speeds of continuous 50 vehicles and the density calculations are presented in Table 4.5, in which the columns 2, 3 and 4 indicates the time of arrival, speed and the type of the vehicle respectively. The calculated density using the equation 4.6 (with the time factor) is presented in column 5 and using equation 4.10 (without the time factor) is presented in column 6. The flow of the stream was 1235 vehicles/hour(Q) is used in the equation 4.10. At the end of 50th calculation the density calculated by the equation 4.6 is 26.37 vehicles/km and that by the equation 4.10 is 26.26 vehicles/km, which are very near to the observed average value of 26.38 vehicles/km.

The proposed equation is a very simple and accurate method to calculate the density of a mixed traffic stream from the speeds of individual vehicles. So, in the case of traffic studies, where the speeds of individual vehicles (at least 50) are known for some sample of time, then there is no need to conduct any more field observations to find the density of the stream. This is valid in homogeneous and heterogeneous traffic at any flow levels.

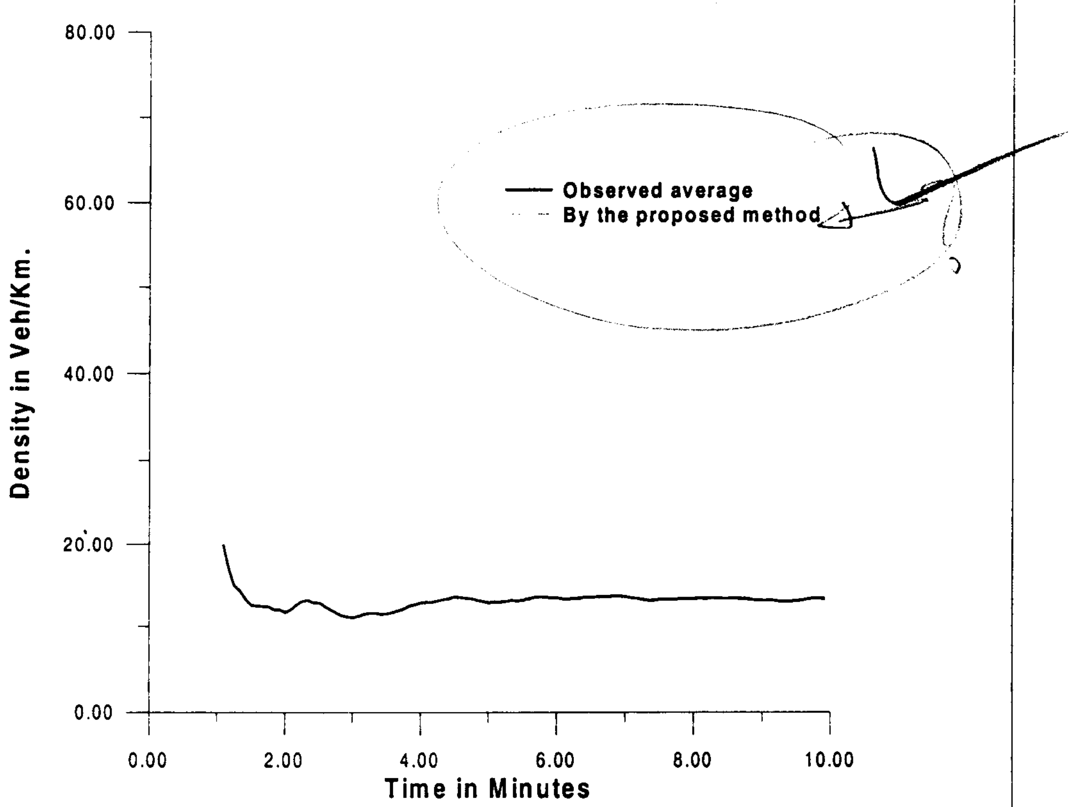


Fig 4.8 Observed and Calculated Densities.

Ti Ki

moving av.

Table 4.4 Observed density

Observation No.	Time (end of)sec.	Density observed.	Average Density.
1	10.00	26.67	26.67
2	20.00	33.33	30.00
3	30.00	20.00	26.67
4	40.00	13.33	23.33
5	50.00	33.33	25.33
6	60.00	26.67	25.56
7	70.00	26.67	25.71
8	80.00	40.00	27.50
9	90.00	26.67	27.41
10	100.00	13.33	26.00
11	110.00	20.00	25.45
12	120.00	33.33	26.11
13	130.00	33.33	26.67
14	140.00	20.00	26.19
15	150.00	40.00	27.11
16	160.00	26.67	27.08
17	170.00	20.00	26.67
18	180.00	33.33	27.04
19	190.00	26.67	27.02
20	200.00	20.00	26.67
21	210.00	26.67	26.67
22	220.00	26.67	26.67
23	230.00	23.33	26.52
24	240.00	33.33	26.81
25	250.00	26.67	26.80
26	260.00	33.33	27.05
27	270.00	16.67	26.67
28	280.00	26.67	26.67
29	290.00	23.33	26.55
30	300.00	21.33	26.38

Table 4.5 Calculated density

(n) No.	(T) Time in sec.	(U_i) Speed in Km/h	Vehicle class	Density, in vehicles/Km, (K) $\frac{1}{T}\sum_{i=1}^{n}\frac{1}{U_i}$	$\frac{Q}{n}\sum_{i=1}^{n}\frac{1}{U_i}$
1	0.00	51.42	Car	0.00	0.00
2	4.00	49.09	Bus	18.33	12.59
3	8.00	54.00	Car	17.50	16.02
4	15.00	34.83	Auto	16.22	20.89
5	16.00	43.20	T/W	20.42	22.43
6	17.00	45.00	Bus	23.92	23.27
7	21.00	41.53	Bus	23.49	24.20
8	22.00	43.20	Truck	26.21	24.75
9	29.00	46.95	Car	22.53	24.93
10	42.00	46.95	Car	17.38	25.07
11	43.00	34.83	Auto	19.38	26.01
12	46.00	43.20	Auto	19.93	26.23
13	47.00	46.95	T/W	21.14	26.24
14	56.00	36.00	T/W	19.53	26.82
15	57.00	45.00	Car	20.59	26.86
16	58.00	56.84	Car	21.32	26.54
17	59.00	46.95	Bus	22.26	26.53
18	63.00	67.50	Jeep	21.69	26.07
19	66.00	40.00	Bus	22.07	26.32
20	68.00	41.53	Bus	22.70	26.50
21	74.00	60.00	Car	21.67	26.22
22	75.00	38.57	Auto	22.62	26.48
23	76.00	40.00	Auto	23.51	26.67
24	78.00	43.20	Truck	23.98	26.75
25	79.00	49.09	Bus	24.60	26.69
26	81.00	54.00	Car	24.82	26.54
27	84.00	38.57	Truck	25.04	26.75
28	88.00	43.20	Jeep	24.85	26.81
29	89.00	45.00	Jeep	25.47	26.84
30	90.00	45.00	Bus	26.08	26.86
31	99.00	41.53	Jeep	24.58	26.95
32	104.00	54.00	T/W	24.04	26.82
33	106.00	41.53	T/W	24.40	26.91
34	108.00	46.95	Jeep	24.66	26.90
35	109.00	63.52	Car	24.96	26.68
36	110.00	63.52	Car	25.24	26.48
37	114.00	51.42	Truck	24.97	26.42
38	116.00	40.00	Truck	25.32	26.53
39	117.00	56.84	Bus	25.64	26.41
40	118.00	56.84	Jeep	25.96	26.30
41	121.00	54.00	Bus	25.87	26.21
42	122.00	56.84	Jeep	26.18	26.11
43	127.00	54.00	Jeep	25.67	26.03
44	129.00	43.20	Car	25.92	26.09
45	131.00	43.20	Car	26.16	26.15
46	133.00	46.95	Jeep	26.34	26.15
47	138.00	56.84	Car	25.85	26.06
48	141.00	54.00	Bus	25.77	25.99
49	143.00	31.00	Auto	26.22	26.27
50	145.00	48.53	T/W	26.37	26.26

4.7 SUMMARY AND CONCLUSION

Simulation models do need many input data in the form of dimensions of the various types of vehicles, initial speeds of vehicles, lateral positioning of the vehicles on the roadway sections, the gap or the headway between vehicles and the density of vehicle on the chosen roadway stretch. This chapter has described the procedure adopted for assigning the above values to the vehicles in the traffic stream. A warm up length of 1km on either side of the simulation study stretch has been suggested for the vehicles to overcome the irregularities in the initial assignment, The assigned vehicular speeds were assumed to be normally distributed and headways according to the various distributions suggested by earlier researchers in this field. Equation system has been developed for lateral placement of vehicles in the free flowing and with vehicles passing in the same and opposing directions. Similarly, the equation system has been developed for the determination of density of the traffic stream using the time mean speed data of vehicles. It has been established in this study that when the duration of observation of vehicles on the study stretch increases, there will only be marginal difference between the observed and the predicted densities. This method of prediction of density of traffic stream has considerable advantage over the conventional methods of obtaining density, which suffer from limitations of field of view of video camera used and limitations of synchronization of vehicle observations at inlet and out let sections. These initial data will be used for manoeuvring the vehicles on the simulation study stretches. Next and subsequent chapters explain the process of manoeuvering of these vehicles on the chosen simulation study stretch.

CHAPTER - 5

A STUDY OF OVERTAKING CHARACTERISTICS OF VEHICLES IN MIXED MODE ENVIRONMENT

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Sudip Roy 11TK9Pt.

5.1 GENERAL

This chapter presents a study of overtaking behaviour of vehicles in two way mixed traffic flow environment at highway mid blocks, based on the observations made at different sections of the National Highways (NH 17 and NH 47) in Kerala. Five different types of overtaking operations have been observed, viz., Free Passing, Normal Overtaking, Forced Overtaking, Parallel Overtaking and Stream Lined Overtaking. The conditions for the above situations have been established and mathematical models have been developed. All possible overtaking operations ranging from overtaking of a single vehicle to a bunch of vehicles travelling at nearly identical speeds have been observed. Even during overtaking operation, conditions forcing the vehicle to abandon the overtaking have also been established in the study. A dynamic sine function has been incorporated to handle the irregularities of the lane changing operation in the overtaking manoeuvres. The developed theories and the mathematical models established are expected to be useful for micro level simulation of mixed traffic flow environment.

5.2. METHODOLOGY PROPOSED BY INDIAN ROADS CONGRESS

Overtaking behaviour of vehicles are common on Indian roads due to the wide range of fast and slow moving vehicles sharing the same road spaces. For the establishment of traffic stream behaviour, micro level studies of vehicle movements become necessary. In this venture, overtaking behaviour of vehicles plays prime importance in the simulation of mixed traffic flow environment.

Most of the Indian highways comprise of two way mixed traffic flow with practically very little lane discipline and the desired speeds of vehicles also vary considerably. When the fast and slow moving vehicles are all present in the same stream, the spacing between a fast moving follower and a slow moving leader will reduce with respect to time. After some time, when the spacing is less than certain value (desire spacing), the driver of the fast moving vehicle will feel an unsafe movement of the vehicle. In such situations either the fast moving vehicle has to reduce its speed and follow the slow moving leader or it has to pass ahead of the leader vehicle by changing its lane. Such an operation is termed as overtaking operation. The fast moving follower is the overtaking vehicle and the slow moving vehicle is the overtaken vehicle.

IRC has proposed a minimum sight distance by analysing the overtaking phenomena as d1+d2+d3, where, d1 is the distance travelled by the overtaking vehicle (A) before the overtaking operation to reduce its speed, d2 is the distance travelled by the overtaking vehicle from the beginning of the lane shifting to the end of rejoining operation to the original lane and d3 is the distance travelled by the opposing vehicle (C) during the overtaking, as shown in Fig 5.1.

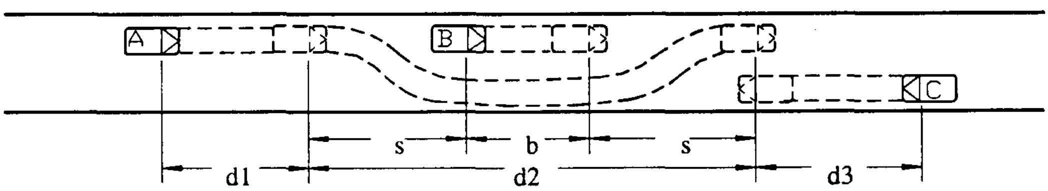


Fig 5.1 Overtaking Operation

Irrespective of the vehicle speed, the time required to cover d1 distance is taken as two seconds. The overtaken vehicle (B) is assumed to travel at constant speed during the overtaking period. In the calculation of the distance d3, the opposing vehicle (C) is also assumed to travel at constant speed. Due to the above three simplifications, the overtaking phenomena (distances - d1, d2, d3, etc., and time of overtaking) is deterministic in nature for a given problem. But in reality, the speed of the overtaken and the speed of opposing vehicle can also vary with time.

Researchers (Ramanayya(1977), Kuncheria(1995), etc.,) have developed simulation models for highway traffic. Both of them have used a similar kind of approach for overtaking operation as proposed by IRC. Thus in the present literature, mathematical models that are available for explaining overtaking operation are those in which the dynamics of the overtaking, the overtaken and the opposing vehicles are all assumed to be preset at the beginning of the overtaking operation itself and are assumed to be faithfully executed. The possibilities for abandoning of the overtaking operation due to unforeseen developments are not considered. Take for example the condition in which vehicle being overtaken, itself starts accelerating.

Therefore, the present literature is not satisfactory to handle the possible variations within the overtaking operation as observed in the real traffic flow. Thus there is a need for further development in this field to cover all types of overtaking operations.

5.3. TYPES OF OVERTAKING OPERATION

A complete overtaking operation can be divided into three stages, viz, the lane changing before overtaking, the acceleration stage and the lane changing stage after overtaking. These are presented in Fig 5.2. The fast moving vehicle, travelling from A1 to A2 is in the lane changing stage before overtaking, is in the acceleration stage from A2 to A3 and is in the lane changing stage from A3 to A4, after overtaking. The corresponding positions of the overtaken vehicle are shown as B1, B2, B3 and B4, respectively.

Basically, five different types of overtaking operations were observed from the field. These are, Free Passing, Normal Overtaking, Forced Overtaking, Parallel Overtaking and Stream Lined Overtaking. These are described in the following sections.

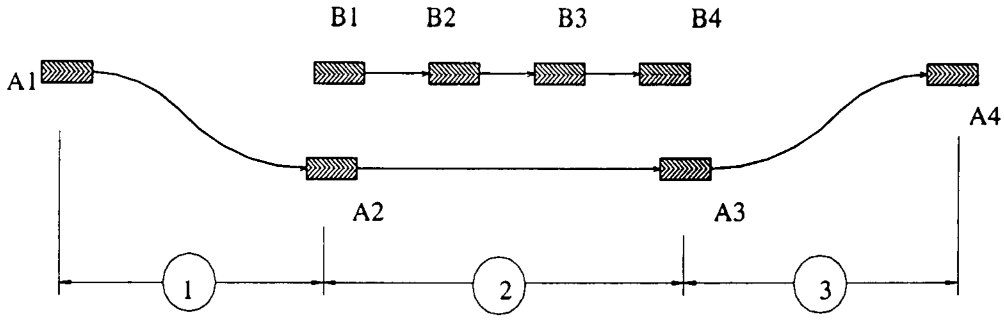


Fig 5.2. Stages of overtaking operation.

5.3.1 FREE PASSING

Whenever a fast moving vehicle approaches a slow moving vehicle in a free flow stream, in some situations, the follower vehicle changes its lane very slowly at a long distance from the leader and after the overtaking operation the vehicle will reach its original lane at a long distance from the overtaken vehicle. Such a type of overtaking operation is known as Free Passing. The relative positions of overtaking and overtaken vehicles during a free passing is presented in Fig 5.3.

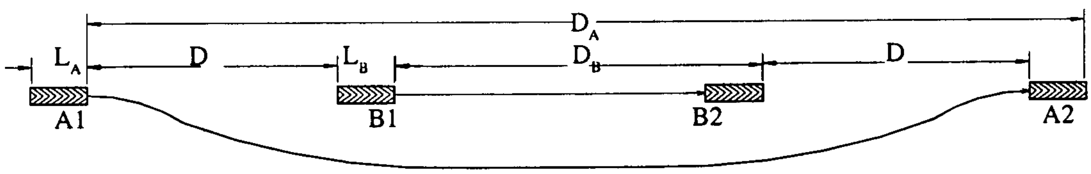


Fig 5.3. Relative positions of vehicles during free passing

During a free passing, the speeds of the overtaking and the overtaken vehicles will not vary much. Free passings are normally observed when there are no vehicles present in nearby locality and if the speed differences between the overtaking and the overtaken vehicles are considerably high. From the empirical studies, the following observations have been made for free passing:

1. The free passing of vehicles have been observed to be generally taking place when the differences between the speeds of the followers and those of the leaders are greater than 8 to 12 kmph.

2. The followers have been observed to decelerate and follow the leaders when the differences in the speeds of the followers and those of the leaders are less than 2 to 4kmph.

3. The followers have been found to decelerate and then overtake when the differences in the speeds of the followers and those of the leaders are between the above two limits.

4. The above two limits have been observed to be varying with the types of the overtaking vehicles and the types of the overtaken vehicles.

Eight different types of vehicles (Car, Bus, Auto, Two wheeler, Truck, Mini Bus, Mini.Truck and Jeep) have been identified on the National Highways of Kerala and the mathematical equation were developed for these eight categories. The percentage of vehicles following(□), overtaking (o) and passing (∇) were calculated for eight different types of overtaking vehicles with respect to eight different types of overtaken vehicles. There can be at the most 192 relations (8 x 8 x 3 types of operation, viz. passing, overtaking and following) with respect to (V_A - V_B), where V_A is the speed of overtaking vehicle and V_B is the speed of overtaken vehicle. A typical plot is presented in Fig 5.4. The data points "squares" (% vehicles following), "circles" (% vehicles overtaking) and "triangles" (% vehicles passing) are percentage of vehicles which are plotted against (V_A - V_B), on the X-axis, these are approximated as a straight line, a part of a circle and a part of a hyperbola respectively, as shown in Fig 5.4.

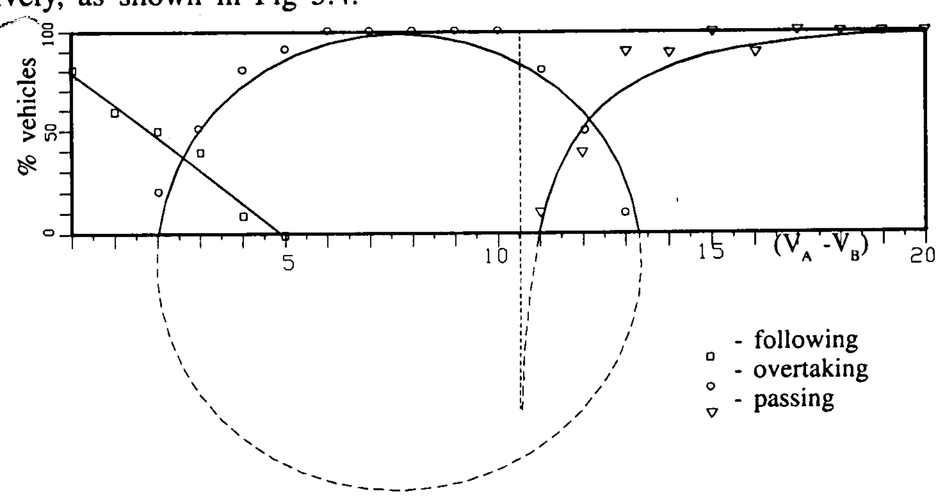


Fig 5.4. Percentage of vehicles following, overtaking and passing

For different types of overtaking and overtaken vehicles, different scatter diagrams were plotted. But, in order to use this large number of plots, especially in computer simulation applications, simplified best fit relationships have to be developed. The best fit relation for the probability of following vehicles (P_F) is a straight line:

$$P_F = \alpha_F - \beta_F(V_A - V_B) \text{ --- Eq.5.1}$$

where, α_F is the y-intercept and β_F is the slope of the line (f1 f2) as shown in Fig 5.5.

The probability of overtaking (P_o) is approximated as a part of a circle, which has a centre belqw x-axis(α_O, $-\beta_O$), as shown in Fig 5.5. By simplifying the equation of the circle, the probability of overtaking can be expressed as:

$$P_o = \sqrt{(1 + \beta_O)^2 - (V_A - V_B - \alpha_O)^2} - \beta_O \text{ ----------- Eq.5.2}$$

The probability of passing (P_P) is assumed as a part of a hyperbola, as shown in the Fig 5.5, whose origin (E) is shifted to (α_P,1) and its shape is described by the parameter βp. By simplifying the equation of the hyperbola, the probability of passing can be:

$$P_P = -\beta_P/(V_A - V_B - \alpha_P) + 1 \text{ -------------------------- Eq.5.3}$$

The values of α_F, β_F, α_O, β_O, α_P and β_P for different types of overtaking and

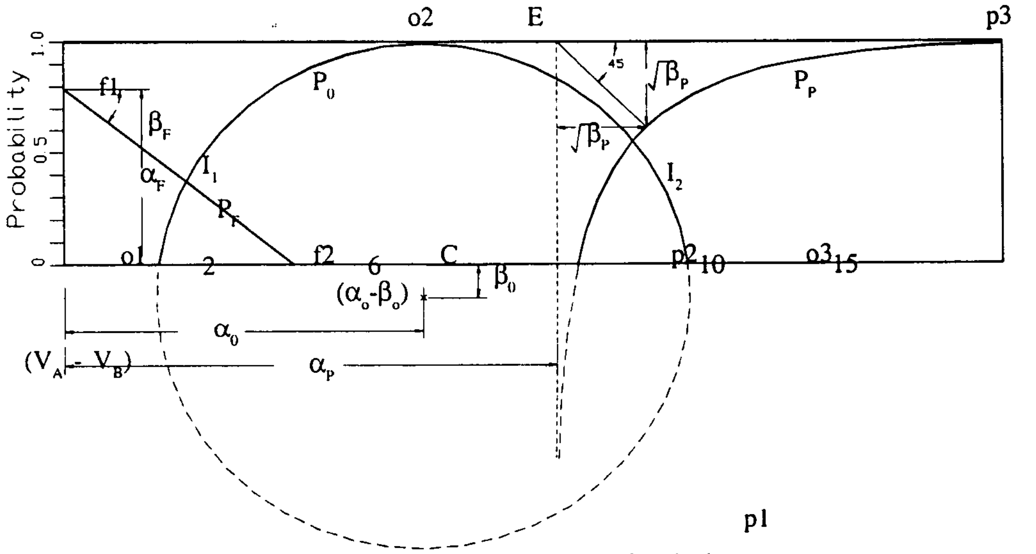


Fig 5.5. Approximation of relations.

overtaken vehicles are presented in Table 5.1.

Fig 5.5 is an average representative plot of the probabilities of following(P_F), overtaking(P_O) and free passing(P_P) of different types of vehicles in which the circle intersects at 2 and 15, line at 6 and hyperbola at 10 on the x-axis. When the value of (V_A-V_B) is less than 6 and greater than the value corresponds to the intersection point of the circle and the line (I_1), according to the above equations P_o will be always greater than P_F and this is against the field observation. Therefore a correction factor has been incorporated here to rectify this problem, as described below:

When the value of (V_A-V_B) is between 2 and 6, a random number R_1 with mean 0.5 is added to P_F, and subtracted by 0.5, similarly 0.5 is added to P_o and subtracted by the same random number R_1 so that to maintain $P_O + P_F = 1.0$

i.e. $P_F = P_F + R_1 - 0.5$

$P_o = P_o + 0.5 - R_1$

where, R_1 = Random(mean 0.5).

For example: if $P_F = 0.55$ and $P_O = 0.45$ are the values calculated for a particular problem at the indefinite region using equations 5.1 and 5.2, then the decision can be for a passing or for the overtaking depending on the value of the random number generated as shown below:

If the value of random number R_1 is 0.4, using the above equations:

$P_F = 0.55 + 0.4 - 0.5 = 0.45$

$P_o = 0.45 + 0.5 - 0.4 = 0.55$

i.e $P_O > P_F$ previously it was $P_O < P_F$

A similar correction has to be applied to the region when the value of (V_A-V_B) is between 10 and 15. Thus:

$P_o = P_o + R_2 - 0.5$

$P_P = P_P + 0.5 - R_2$

where, R_2 = Random(mean 0.5). Thus, by knowing the type and the speed of the leader and those of the approaching vehicle, the likelihood for overtaking phenomena can be estimated. For example, let the leader vehicle be an Auto with a speed of 35kmph(V_B) and approaching vehicle be a car with a speed of 60kmph(V_A). By the equations 5.1, 5.2 and 5.3 and the values of constants from the Table 5.1., we obtain:

$$P_F = \alpha_F - \beta_F(V_A - V_B) = 0.891 - 0.324(60-35) = -7.209$$

$$P_O = \sqrt{(1+\beta_O)^2 - (V_A - V_B - \alpha_O)^2} - \beta_O = \sqrt{(1+2.453)^2 - (60-35-5.235)^2} - 2.453$$

Square root of a -ve value means out of its probability range.

$$P_P = -\beta_P/(V_A - V_B - \alpha_P) + 1 = -2.098 / (60 - 35 - 10.74) + 1 = 0.853$$

Therefore, the expected overtaking manoeuvre of the car is a free passing.

Table 5.1. Values of α_f, β_f, α_o, β_o, α_p and β_p for different types of overtaking and overtaken vehicles

Overtaken vehicle	Following Overtaking Passing	Car		Bus		Auto		Truck		T/w		M.Bus		M.Truck		Jeep	
		α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β
Car	f	1.000	0.143	0.864	0.154	- -	- -	1.000	0.192	1.000	0.432	0.983	0.128	1.000	0.329	0.986	0.143
	o	7.324	5.654	5.346	3.565	- -	- -	6.335	4.674	9.567	5.124	6.938	5.335	5.678	4.553	7.374	6.364
	p	11.54	1.324	9.039	2.032	- -	- -	10.24	2.035	10.34	2.254	12.76	2.456	9.554	2.344	15.55	2.733
Bus	f	1.000	0.136	1.000	0.325	- -	- -	1.000	0.219	1.000	0.532	1.000	0.093	1.000	0.098	1.000	0.098
	o	8.249	6.442	6.456	4.897	- -	- -	7.354	5.235	7.257	5.689	5.334	3.656	7.343	5.235	5.654	4.568
	p	12.98	1.203	11.23	2.049	- -	- -	11.44	1.934	11.25	1.642	11.35	1.945	12.34	2.045	12.45	2.642
Auto	f	0.891	0.324	0.457	0.872	1.000	0.143	1.000	0.143	1.000	0.814	0.993	0.139	1.000	0.653	1.000	0.648
	o	5.235	2.453	4.528	2.976	5.646	3.468	5.235	4.678	8.457	5.689	7.347	5.662	5.377	4.364	7.346	4.684
	p	10.74	2.098	8.324	1.039	10.45	1.034	12.43	1.533	10.34	2.043	12.45	1.355	10.35	1.545	11.53	1.644
Truck	f	0.942	0.132	0.923	0.321	- -	- -	1.000	0.134	0.943	0.742	1.000	0.209	1.000	0.168	1.000	0.276
	o	7.345	6.356	5.398	4.367	- -	- -	6.357	4.577	5.678	4.986	6.246	5.364	6.377	5.388	5.432	4.455
	p	12.09	1.983	10.39	2.302	- -	- -	9.241	1.534	10.52	1.423	10.56	2.456	12.34	2.464	13.45	2.833
T/W	f	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
	o	3.546	2.432	4.567	1.984	4.236	2.953	4.235	3.477	- -	- -	5.361	3.566	5.346	3.457	4.455	3.454
	p	7.935	2.056	6.424	2.534	9.531	1.454	6.346	1.354	5.232	2.445	7.457	1.464	6.756	2.352	10.46	2.633
M.Bus	f	1.000	0.154	1.000	0.432	- -	- -	0.991	0.019	1.000	0.632	0.937	0.198	0.986	0.209	1.000	0.198
	o	5.646	4.364	6.477	4.689	- -	- -	6.468	4.853	7.532	5.098	6.263	5.467	7.275	5.567	7.368	5.568
	p	10.85	1.039	11.46	1.049	- -	- -	12.35	1.572	9.435	2.354	12.43	2.364	12.45	2.356	12.43	2.095
M.Truck	f	0.954	0.239	0.932	0.356	- -	- -	0.918	0.219	1.000	0.625	1.000	0.278	1.000	0.287	1.000	0.329
	o	6.464	5.367	7.236	5.367	- -	- -	6.387	4.678	5.835	3.974	6.273	4.364	6.724	5.257	6.568	5.457
	p	11.43	2.091	12.45	2.341	- -	- -	11.64	2.045	10.43	2.045	11.54	1.094	11.58	2.583	10.44	2.642
Jeep	f	1.000	0.135	0.832	0.398	- -	- -	1.000	0.252	1.000	0.824	1.000	0.284	1.000	0.098	1.000	0.382
	o	7.345	5.235	6.346	3.458	- -	- -	7.368	5.670	7.204	5.739	5.674	4.472	7.368	5.475	7.373	4.568
	p	12.43	2.903	11.09	2.490	- -	- -	10.34	1.353	10.49	1.945	10.45	2.464	12.57	2.947	14.64	2.055

f=Free passing, o=Normal Overtaking and p=Passing

The distance (D) at which the vehicle change its lane for a free passing (see Fig 5.3) is observed by three field methods, viz., Fixed Camera Method, Moving Camera Method and Flow Interruption Method. These three methods are based on the video frame analysis from a pre recorded video tape. In Fixed Camera Method, the video camera will be fixed at a suitable location on the side of the road. Video camera will be fixed on a moving vehicle in the Moving Camera Method. Flow Interruption method is by recording using a fixed video camera, from the side of the road, when a vehicle is parked on the side of the pavement. The sample frames of these methods are shown in Figs 5.7, 5.8 and 5.9 respectively. The distance D, in meters have been observed to be 0.92 times the speed of the overtaking vehicle expressed in kmph as shown in Fig 5.6.

ie. $D = 0.92 \cdot V_A.$ -------------------------------- Eq.5.4

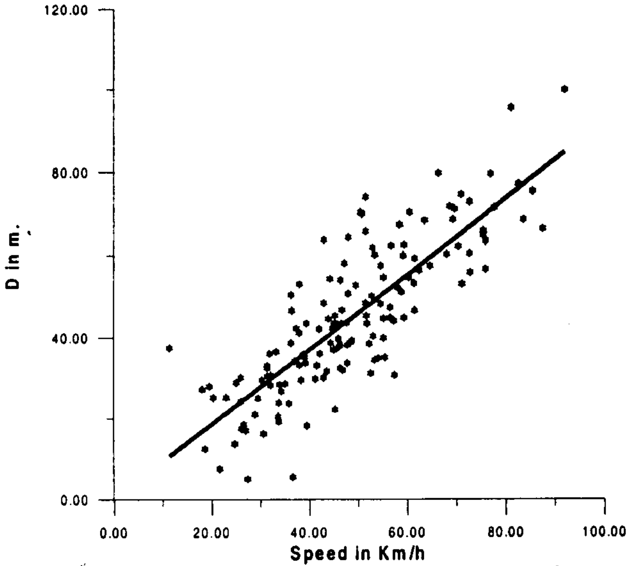


Fig 5.6. D with respect to speed

The relative distance to be travelled by the complete passing operation is given by :

$L_R = D + L_A + L_B + D$ (see Fig 5.3) $\{(D_A - D_B) = D + L_B + D_B + D + L_A - D_B\}$

where, L_A and L_B are the length of the follower and the leader vehicle respectively.

i.e. $L_R = 2.D + L_A + L_B$ ------------------------------------- Eq.5.5

Therefore the duration (T) of passing operation

= relative distance travelled / relative speed

Fig 5.7. Fixed Camera Method

Fig 5.8. Moving Camera Method

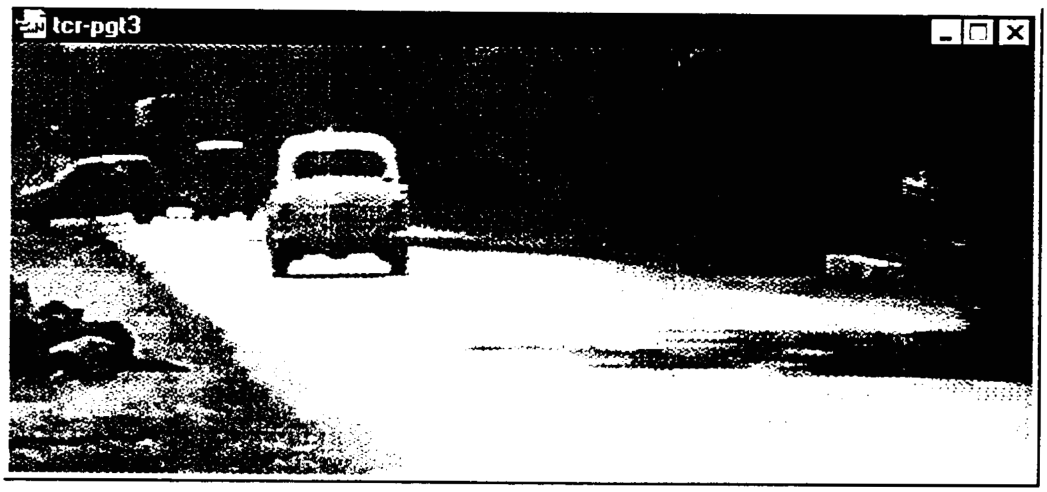


Fig 5.9. Flow interruption method

i.e. $T = L_R / [\ 0.278\ (V_A - V_B\ )\ ]$ ---------------- Eq.5.6

Substituting equation 5.5 in 5.6 : $T = (\ 2.D + L_A + L_B\ ) / [0.278(\ V_A - V_B\ )]$

Substituting equation 4 in the above :

$T = (\ 1.84V_A + L_A + L_B\ )/[0.278(\ V_A - V_B\ )]$ --------- Eq.5.7

Therefore, if the speed and the length of the leader and follower vehicles are known, the time required for a pass can be calculated using equation 5.7.

The length (L) of a complete passing along the length of the road is given by :

L = Speed of the follower vehicle x Time required

i.e. $L = V_A\ (\ 1.84\ V_A + L_A + L_B\ ) / (\ V_A - V_B\ )$------- Eq.5.8

For example :- If the speed of the overtaking vehicle is 40 kmph, that of the overtaken vehicle is 30 kmph and their lengths are 2.5 m each, then the time required for a passing, T = 28 sec (equation 7) and the length of passing operation L = 314 m (equation 8)

5.3.2 NORMAL OVERTAKING

Whenever a fast moving vehicle approaches a slow moving vehicle, the follower will decelerate and follow the leader under certain situations. After sometime, the speed of the follower comes down to the speed of the leader, and the former will proceed with constant spacing. But once an opportunity for a safe overtaking is available, the follower will start changing the lane and accelerate by overtaking to its desired speed. Such an overtaking operation is termed as normal overtaking.

5.3.2.1 NORMAL OVERTAKING DISTANCES

A number of studies have been conducted in this area and it is observed that the overtaking vehicle changes its lane from A_1 at a distance D_1, from the leader to A_2 at a distance D_2 from the leader and after some time the vehicle changes to its original lane from a distance D_3 at A_3 and ends at A_4 at D_4 distance from the overtaken vehicle as presented in Fig 5.10. The distances D_1, D_2, D_3 and D_4 are observed to be functions of speed of the overtaking vehicle and the difference in speeds between the overtaking and overtaken vehicle.

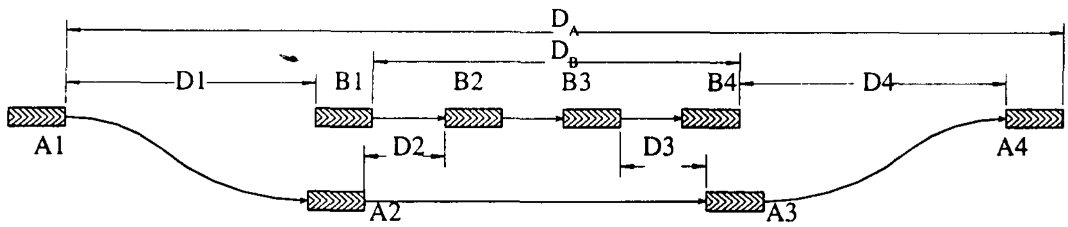


Fig.5.10. Distances in the Normal Overtaking Operation

i.e. $D_i' = a_i V_A + b_i (V_A - V_B) + 1.5$ ---------------- Eq.5.9

where, a_i and b_i are constants, i = 1 to 4. The last term in the above equation is a constant, falling between 1 and 2. Since the value and its variation are less, 1.5 is taken as an average, so as to minimise the size of the table of constants of the equation. Such models have been calibrated for different types of vehicles and the results are tabulated in Table 5.2 for the overtaking vehicles with respect to the overtaken vehicles. IRC method considered the initial speed of overtaking and overtaken vehicles and predefined acceleration, but the present study considered the speed changes thereafter. This is the fundamental difference between the IRC method and the present study.

5.3.2.2 DURATION AND LENGTH OF NORMAL OVERTAKING

The relative distance to be travelled by the overtaking vehicle (see Fig 5.10).

L_R i.e, $D_A - D_B = D_1 + L_A + L_B + D_4$ ---------- Eq.5.10

But $L_R = (V_A - V_B) T + 0.5\, a_a . T^2$.

where, a_a is the acceleration of the overtaking vehicle

Therefore,

$$0.5\, a_a . T^2 + (V_A - V_B) T - L_R = 0$$

$$T = ((V_B - V_A) + \sqrt{[(V_A - V_B)^2 + 2\, a_a L_R]}) / a_a$$

Substituting L_R in the above equation:

$$T = ((V_B - V_A) + \sqrt{[(V_A - V_B)^2 + 2\, a_a(D_1 + L_A + L_B + D_4)]}) / a_a \text{ ----- Eq.5.11}$$

Table 5.2. Values of a_i and b_i for different types of vehicles

Overtaken vehicle		Overtaking vehicle: Car		Bus		Auto		Truck		T/w		M.Bus		M.Truck		Jeep	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Car	D_1	0.495	0.301	0.543	0.265	- -	- -	0.649	0.192	0.422	0.244	0.404	0.390	0.515	0.461	0.496	0.749
	D_2	0.093	0.298	0.134	0.956	- -	- -	0.104	0.294	0.019	0.241	0.104	0.395	0.094	0.238	0.159	0.459
	D_3	0.095	0.288	0.083	0.967	- -	- -	0.195	0.204	0.038	0.479	0.184	0.472	0.073	0.244	0.079	0.352
	D_4	0.686	0.009	0.694	0.194	- -	- -	0.693	0.142	0.429	0.294	0.530	0.294	0.563	0.036	0.599	0.294
Bus	D_1	0.545	0.403	0.523	0.448	- -	- -	0.693	0.299	0.402	0.293	0.530	0.483	0.495	0.301	0.543	0.265
	D_2	0.103	0.248	0.104	0.295	- -	- -	0.259	0.204	0.103	0.204	0.074	0.385	0.105	0.264	0.057	0.195
	D_3	0.094	0.238	0.159	0.459	- -	- -	0.194	0.395	0.294	0.403	0.194	0.403	0.095	0.287	0.088	0.295
	D_4	0.586	0.019	0.593	0.588	- -	- -	0.739	0.359	0.492	0.295	0.693	0.205	0.563	0.036	0.599	0.294
Auto	D_1	0.295	0.240	0.324	0.496	0.353	0.304	0.495	0.294	0.395	0.294	0.402	0.395	0.545	0.403	0.523	0.448
	D_2	0.053	0.297	0.055	0.486	0.037	0.299	0.049	0.490	0.014	0.395	0.193	0.394	0.073	0.244	0.079	0.352
	D_3	0.063	0.278	0.094	0.476	0.073	0.388	0.067	0.395	0.047	0.485	0.093	0.486	0.094	0.238	0.159	0.459
	D_4	0.484	0.019	0.449	0.769	0.492	0.103	0.583	0.284	0.482	0.295	0.583	0.395	0.495	0.301	0.543	0.265
Truck	D_1	0.515	0.461	0.496	0.749	- -	- -	0.593	0.184	0.469	0.092	0.593	0.204	0.573	0.394	0.583	0.842
	D_2	0.083	0.394	0.085	0.584	- -	- -	0.034	0.201	0.039	0.850	0.104	0.948	0.105	0.264	0.057	0.195
	D_3	0.095	0.257	0.047	0.592	- -	- -	0.028	0.329	0.074	0.394	0.159	0.295	0.094	0.238	0.159	0.459
	D_4	0.686	0.009	0.496	0.683	- -	- -	0.629	0.385	0.392	0.203	0.693	0.294	0.515	0.461	0.496	0.749
T/W	D_1	0.193	0.405	0.298	0.154	- -	- -	0.395	0.194	0.249	0.204	0.395	0.591	0.437	70.321	0.393	0.383
	D_2	0.063	0.297	0.057	0.299	- -	- -	0.012	0.385	0.038	0.307	0.084	0.885	0.039	0.304	0.092	0.204
	D_3	0.094	0.228	0.058	0.375	- -	- -	0.047	0.482	0.080	0.284	0.058	0.574	0.094	0.238	0.159	0.459
	D_4	0.282	0.069	0.299	0.684	- -	- -	0.482	0.393	0.204	0.208	0.395	0.295	0.385	0.855	0.398	0.934
M.Bus	D_1	0.394	0.355	0.469	0.183	- -	- -	0.693	0.294	0.493	0.204	0.593	0.293	0.495	0.301	0.543	0.265
	D_2	0.073	0.244	0.079	0.352	- -	- -	0.184	0.273	0.039	0.249	0.024	0.205	0.094	0.238	0.159	0.459
	D_3	0.095	0.287	0.088	0.295	- -	- -	0.138	0.135	0.027	0.204	0.085	0.832	0.073	0.244	0.079	0.352
	D_4	0.586	0.019	0.693	0.285	- -	- -	0.603	0.294	0.395	0.493	0.693	0.835	0.545	0.403	0.523	0.448
M.Truck	D_1	0.477	0.321	0.593	0.383	- -	- -	0.538	0.284	0.395	0.842	0.503	0.253	0.515	0.461	0.496	0.749
	D_2	0.133	0.265	0.067	0.295	- -	- -	0.024	0.369	0.073	0.274	0.028	0.385	0.095	0.287	0.088	0.295
	D	0.105	0.244	0.058	0.394	- -	- -	0.048	0.192	0.058	0.058	0.084	0.573	0.105	0.264	0.057	0.195
	D_4	0.585	0.039	0.692	0.153	- -	- -	0.693	0.294	0.492	0.385	0.542	0.384	0.563	0.036	0.599	0.294
Jeep	D_1	0.523	0.353	0.496	0.204	0.592	0.295	0.693	0.294	0.395	0.842	0.633	0.488	0.477	0.321	0.593	0.383
	D_2	0.124	0.247	0.068	0.285	0.048	0.288	0.098	0.204	0.089	0.293	0.038	0.242	0.094	0.238	0.159	0.459
	D_3	0.105	0.264	0.057	0.195	0.104	0.285	0.184	0.385	0.037	0.385	0.058	0.375	0.095	0.287	0.088	0.295
	D_4	0.563	0.036	0.599	0.294	0.487	0.284	0.698	0.295	0.284	0.205	0.693	0.285	0.495	0.301	0.543	0.265

Thus the overtaking sight distance is the sum of the distance travelled by the vehicle during reaction time, the distance travelled during the overtaking time, T and the distance travelled by the opposing vehicle

Therefore, $S = S_1 + V_A .T + 0.5a_a .T^2 + C$---------------- Eq.5.12

where, S_1 is the distance travelled by the vehicle before overtaking to slow down to the speed of the overtaken vehicle and C is the distance travelled by the opposing vehicle.

5.3.3 FORCED OVERTAKING

It has been observed that the maximum speed during the overtaking operation is almost same as its desired speed in normal overtaking. But in some cases the speed has been observed to be 10 to 15% greater than the free flow speed. Such a kind of overtaking is termed as forced overtaking. There are certain reasons identified to force the vehicles to increase their speed more than their desired speed, due to certain causes described below.

5.3.3.1 FORCED OVERTAKING DUE TO THE ACCELERATION OF THE OVERTAKEN VEHICLE

Sometimes, the leader may accelerate during the overtaking operation, then the follower also has to accelerate more than what is required for a normal operation or he has to abandon the overtaking operation. Consider the initial positions of overtaking vehicle is at A and that of overtaken vehicle is at B, as shown in the Fig 5.11(a). After the lane changing operation, these vehicles will occupy the positions as shown in Fig5.11(b). But, if the overtaken vehicle B also accelerates almost at the same rate as that of the overtaking vehicle during the acceleration zone, then the relative positions of these vehicles will not change much as indicated in Fig5.11(c). In such a situation, the overtaking vehicle has to increase its speed further to complete the overtaking as shown in the Fig 5.11(d) or it has to abandon the overtaking operation as shown in the Fig 5.11(e).

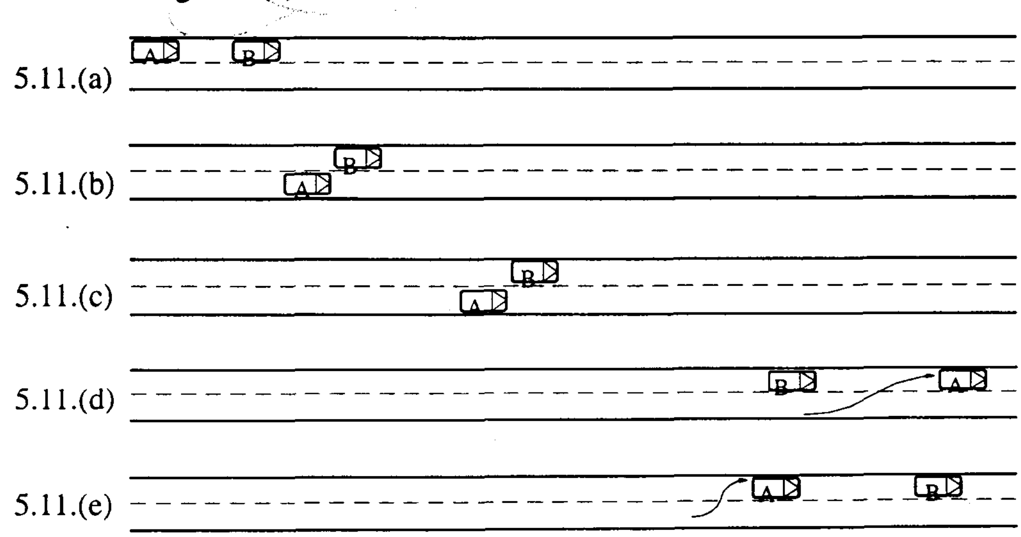


Fig 5.11. Forced overtaking due to the acceleration of the overtaken vehicle

When the overtaking is in progress, with the acceleration of the leader, the difference in the speeds between A and B (dV_{AB}) may decrease and at very low values of dV_{AB}, the time required to complete the overtaking operation will be very high. Usually, drivers will not prefer to overtake under this condition. Therefore, there should be a minimum value of dV_{AB} at its maximum possible speed. The minimum value of dV_{AB} has been observed to be having a slightly increasing trend with the speed of the overtaken vehicle (VB). The equation of the minimum value line (as shown in the Fig.5.12) drawn on the scatter diagram of dV_{AB} v/s V_B is given by :

$dV_{AB\ min} = 0.1125\ V_B + 0.075$ ------------ Eq.5.13

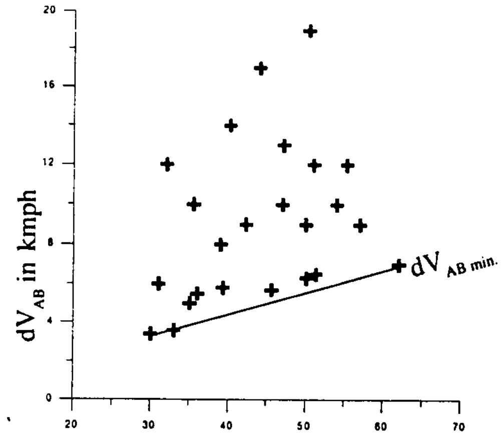


Fig 5.12. V_B v/s dV_{AB}

Thus, the minimum speed of the overtaking vehicle, $V_{A\ min.} = V_B + dV_{AB\ min.}$

i.e. $V_{A\ min.} = 1.1125\ V_B + 0.075$ ---------------------- Eq.5.14

Table 5.3 shows the type of overtaking operation that may take place depending on the values of speed of the overtaking vehicle, in relation to its desired and maximum speed.

Table 5.3. Conditions for forced overtaking operation.

Sl. No.	Conditions	Type of overtaking.
1.	$V_{A\ min} < V_{A\ des}$	Normal overtaking
2.	$V_{A\ des} \leqq V_{A\ min} \leqq V_{A\ max}$	Forced overtaking
3.	$V_{A\ min} > V_{A\ max}$	Not possible.

The value of $V_{A\ max.}$ has been observed to be 1.2 times its desired speed.

i.e. $V_{A\ max.} = 1.2\ V_{A\ des.}$ ---------------------- Eq.5.15

5.3.3.2 FORCED OVERTAKING DUE TO THE ACCELERATION OF THE OPPOSING VEHICLE

Once the normal overtaking is in progress, due to the presence of a vehicle in the opposing lane, it may not be possible to complete the normal overtaking operation. In such situations, either the driver has to abandon the overtaking operation or he is forced to complete the overtaking operation within a distance less than that of the normal overtaking operation.

Consider the initial positions of overtaking vehicle A, overtaken vehicle B and opposing vehicle C as shown in the Fig 5.13(a). After the lane changing operation, these vehicles will occupy the positions as shown in Fig 5.13(b). But, if the distance between the overtaking vehicle and the opposing vehicle is considerably less so as to prevent a smooth overtaking and complete the overtaking operation as shown in Fig 5.13(c) or it has to abandon the overtaking operation as shown in the Fig 5.13(d).

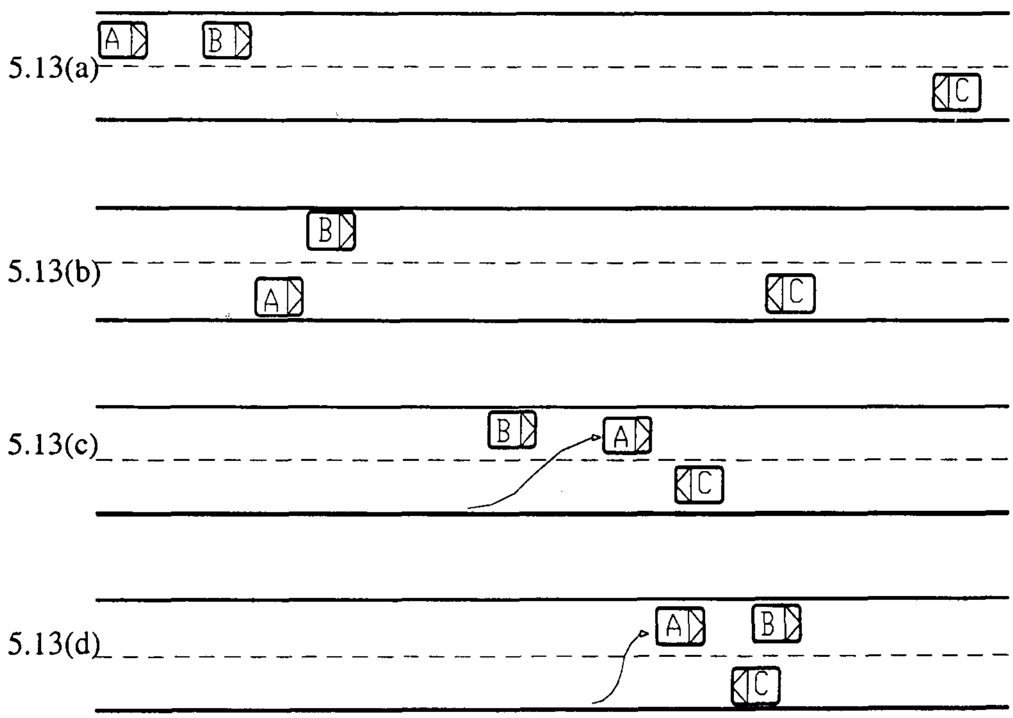


Fig 5.13. Forced overtaking due to the fast moving opposing vehicle.

5.3.4 PARALLEL OVERTAKING

Many times it has been observed from the field that, an overtaking vehicle will be overtaken by a closely following another vehicle. Such an overtaking is termed as parallel overtaking. If the opposing vehicles are far apart, the road widths are sufficient and if the two overtaking vehicles are nearer to one other, this kind of parallel overtaking may take place. There may be at least three vehicles in a parallel overtaking operation, one the overtaken vehicle and the other two or more the overtaking vehicles.

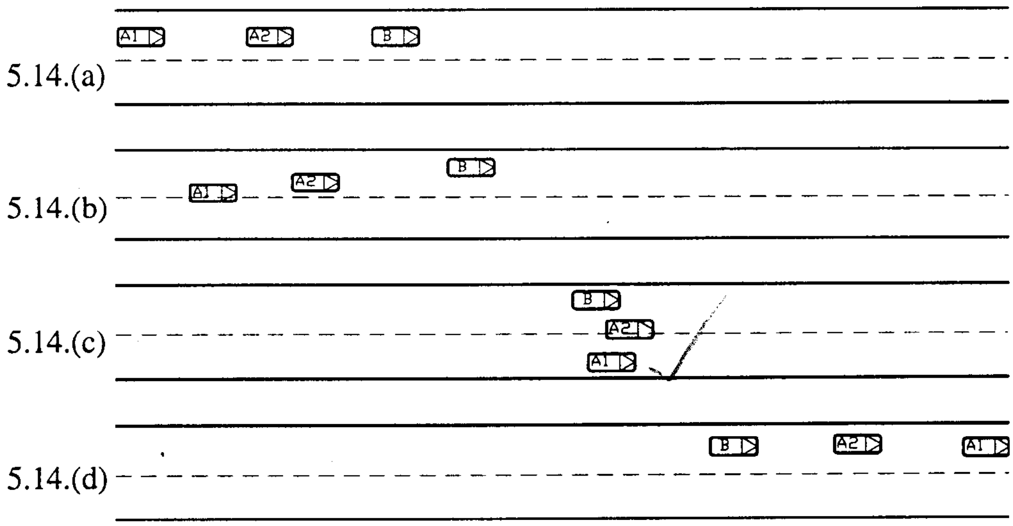


Fig 5.14. Parallel overtaking

Consider the initial positions of vehicles A1, A2 and B as shown in the Fig 5.14(a). Fig 5.14(b) indicate, the position in which A1 is attempting to overtake A2, whereas, A2 itself is in the process of overtaking another vehicle B. Somewhere along , all the vehicles appear to occupy similar position along the length of the road, as shown in the Fig 5.14(c). At the end of overtaking, the positions of the vehicles are shown in Fig 5.14(d). Even though the parallel overtaking is a special type, additional mathematical models are not needed to be developed to explain this. The vehicle B is an overtaken vehicle with respect to A2, A2 is a normal overtaking vehicle and A1 is a normal overtaking vehicle with respect to A2. The parallel overtaking is observed in the simulation model even without implementation of any other special features in the program logic.

5.3.5 STREAM LINED OVERTAKING

Small platoons have been observed in highways, which appear to run concurrently for considerable lengths. Slow moving platoons are formed with slow moving vehicles and fast moving platoons are formed with fast moving vehicle. If the variations in the desired speeds of the vehicles inside a platoon are less, then the life (duration of the platoon in that traffic stream) of the platoon will be more. Such type of platoons are termed as stable platoons, which are formed by long run of very similar vehicles in the traffic stream. But due to various other reasons, like the exit from a bottle neck, traffic congestion, etc., platoons may be formed, in which the variations of the desired speeds of vehicles inside the platoon may be more. The vehicles having higher desired speeds in that platoon will try to overtake the vehicles having lesser speeds in the same platoon. Therefore, the life of the platoon will be less. Such type of platoons are termed as unstable platoons. If vehicles in a platoon, say A1, A2 and A3 approach a slow moving vehicle B, and if there are no other vehicles in the nearby locality as indicated in the Fig.5.15(a), the front vehicle A1 in the platoon will try to overtake the slow moving vehicle B, as indicated in the Fig 5.15(b). The second vehicle A2 in the platoon, while following the frontal vehicle A1, appears to accept the same path as followed by the vehicle A1. This process may be repeated for the other vehicles in the platoon also, as indicated in Fig 5.15(c). Such type of overtaking is termed as Stream lined overtaking. This type of overtaking is also observed in the simulated environment as in the parallel overtaking, without implementation of any other special features in the program logic.

5.15(a)

5.15(b)

5.15(c)

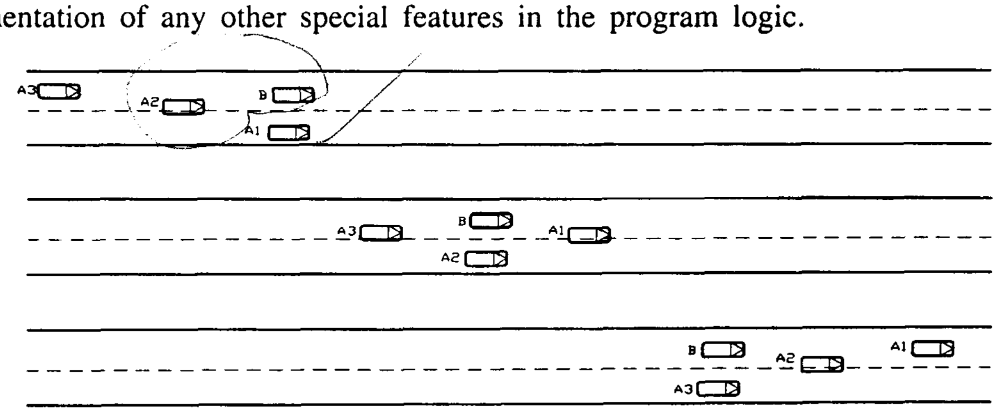


Fig 5.15. Stream lined overtaking

5.3.6 OVERTAKING A BUNCH OF VEHICLES

Whenever a fast moving vehicle approaches a slow moving stable platoon, that vehicle has been observed to behave like a normal vehicle overtaking a slower vehicle. As in the case of normal overtaking operation (Explained in the section 5.3.2), this kind of bunch overtaking also has three stages.

Fig.5.16 shows the three stages of bunch overtaking with three vehicles in the platoon. The vehicles A is the overtaking vehicle and the individual vehicles in the bunch are B1, B2 and B3.

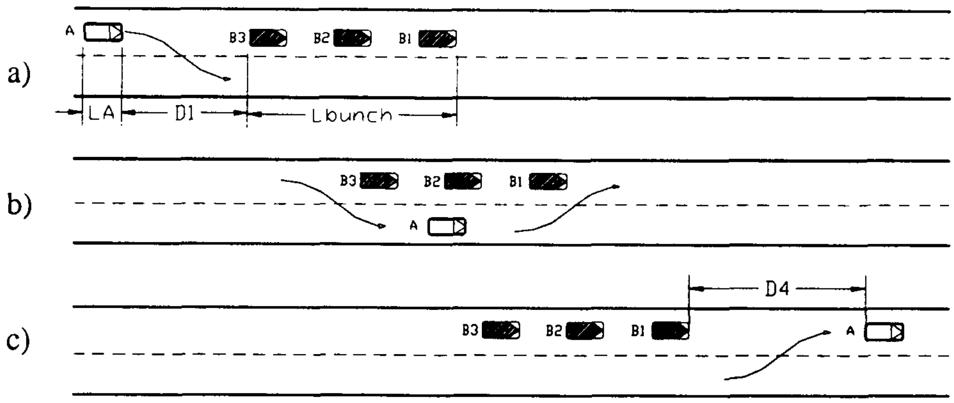


Fig 5.16 Overtaking a bunch of vehicles.

5.3.6.1 DURATION AND SIGHT DISTANCE FOR OVERTAKING A BUNCH OF VEHICLES

The duration and the length of overtaking zone of normal overtaking is explained in the section 5.3.2.2. We can directly use those equations by substituting the length of bunch in place of L_B .

i.e. the equation 5.10 can be rewritten as :

$$L_R = D_1 + L_A + L_{Bunch} + D_4$$

$$T = ((V_A - V_B) + \sqrt{[(V_A - V_B)^2 - 2a_a L_R]}) / a_a \quad \text{---------------- Eq.5.16}$$

$$\text{and } L = V_A.T + 0.5a_a.T^2. \quad \text{-- Eq.5.17}$$

where, L_{Bunch} is the distance from the front of first vehicle in the bunch to the rear of the last vehicle in the bunch.

5.3.7 ABANDONING OF OVERTAKING OPERATION

Once a driver decides to overtake, and when the overtaking is in progress, the conditions for a smooth overtaking may not be available at all. In such situations, the drivers of the overtaking vehicles may decide to move back from the overtaking operation by decelerating their vehicle. Acceleration of the overtaken vehicle as explained in the Section 5.3.3.1 and the fast approaching of the opposing vehicle as explained in the Section 5.3.3.2 are the two reasons generally observed in the traffic stream to lead to the abandoning of the overtaking operation.

5.4 A CAR-FOLLOWING MODEL FOR SIMULATION

A fundamental component of any micro simulation model is a car-following model which describes the movement of individual vehicles with respect to the clearance available in front of the vehicle. Mathematical models of car-following developed in the early 1960s are based on the hypothesis that a following driver adjusts speed according to the stimuli perceived from the leading vehicle. While those models had performed reasonably well in many situations, they were found to be unable to simulate properly the full range of flow conditions. Car-following models based on desired spacing condition has been observed to be more suitable for micro scopic traffic simulation. A car-following model developed specifically for the micro-scopic simulation of traffic flow is presented here. The main objective is to create a model which is able to handle traffic interruptions to the free flowing vehicles based on the desired spacing concept.

5.4.1 THE MODEL

The model is based on the assumption that, when approaching and following a leader vehicle (n-1) at any time t, the driver of the following vehicle (n) attempts to adjust his acceleration so as to reach a desired spacing after a time-lag which takes T seconds. This condition can be described by the following equation:

$$X_{n-1}(t+T) - X_n(t+T) = D_n(t+T) \quad \text{----------------------} \quad \text{Eq. 5.18}$$

Where $x_i(t)$ is the position and $D_i(t)$ is the desired spacing of vehicle i at time t. The desired spacing is assumed to be a linear function of the vehicle speed:

$$D_n(t+T) = \alpha\, V_n(t+T) + \beta \quad \text{----------------------} \quad \text{Eq. 5.19}$$

Where $V_i(t)$ is the speed of vehicle i and α and β are constants. If we assume that the acceleration of both vehicles is constant during the time-lag T, then the above condition can be rewritten as (omitting the reference of t from now on):

$$X_{n-1}+T.V_{n-1}+0.5T^2a_{n-1} - X_n - T.V_n - 0.5T^2a_n = \alpha V_n + \alpha T a_n + \beta \text{---------} \quad \text{Eq. 5.20}$$

Where a_i is the acceleration of vehicle i.

By re-arrangement, this leads to:

$$a_n = [\ T(V_{n-1}-V_n) + X_{n-1}-X_n-\alpha V_n-\beta + 0.5T^2 a_{n-1}\ ] \ / \ (\alpha T+0.5T^2) \text{ --------} \quad \text{Eq.5.21}$$

The term $X_{n-1}-X_n$ in the above equation is the current spacing between the two vehicles. Therefore the above equation calculates the current acceleration of the follower vehicle with respect to the speed, acceleration and position of the leader vehicle. The time lag can be taken as the scanning update time used in the simulation program, which also reassess the situation at every interval of the scanning update time so that it will reflect the instantaneous dynamics as in real situation.

The calculated acceleration a_n should not be more than the maximum acceleration possible for the vehicle (i.e. $a_n \leq A_{max}$), need not be more than the acceleration to reach its maximum speed (i.e. $a_n \leq (V_{max}-V_n) / T$) and it should not be less than the maximum deceleration possible (i.e. $a_n \geq B_{max}$). Where, A_{max} is the maximum acceleration possible for the vehicle, V_{max} is the maximum speed of the vehicle and B_{max} is the maximum deceleration of the vehicle. Therefore, the practical acceleration a_n' can be represented with the above conditions as in the equation 5.22 and corresponding flow chart to calculate the value of a_n' is presented in Fig.5.18

$a_n' = MAX[\ MIN(a_n,\ A_{max},\ (V_{max}-V_n)/T\ ),\ B_{max}\ ]$ --------------- Eq 5.22

To calculate the value of a_n using (Eq.5.22), the only two unknowns are α and β, which are the two constants derived in the desired spacing equation (Eq. 5.19). Extensive field observations have been conducted to obtain the values of α and β. It has been observed that the desired spacing varies for different types of leader and follower vehicles. One such relation is graphically presented in the Fig 5.18 and the values of α and β for all types of leader and the follower vehicles are presented in Table 5.4.

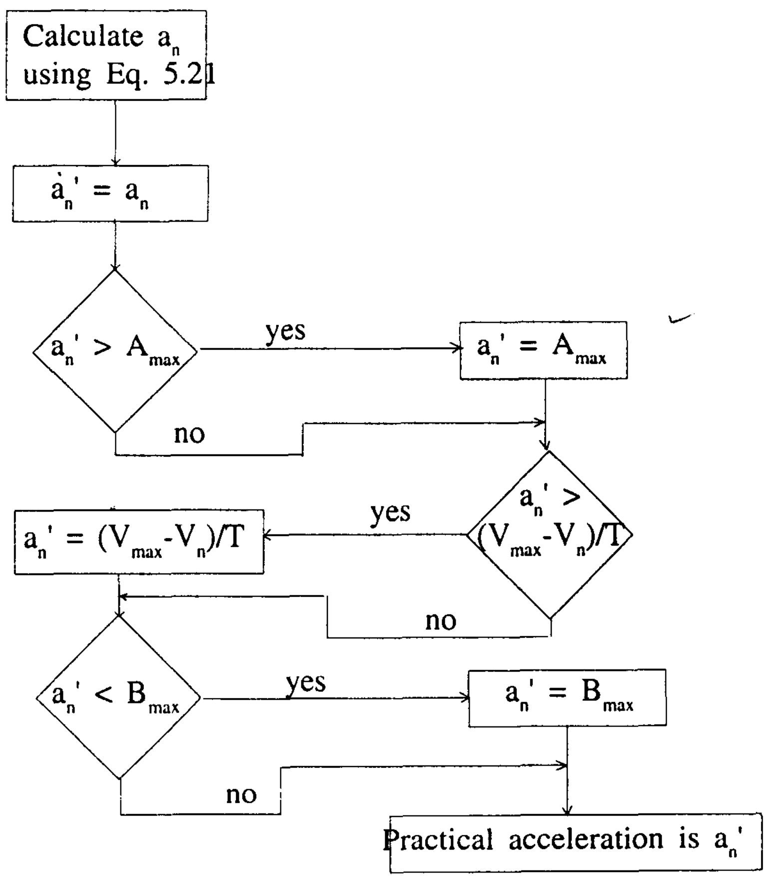


Fig 5.17 Flow chart to calculate the practical acceleration.

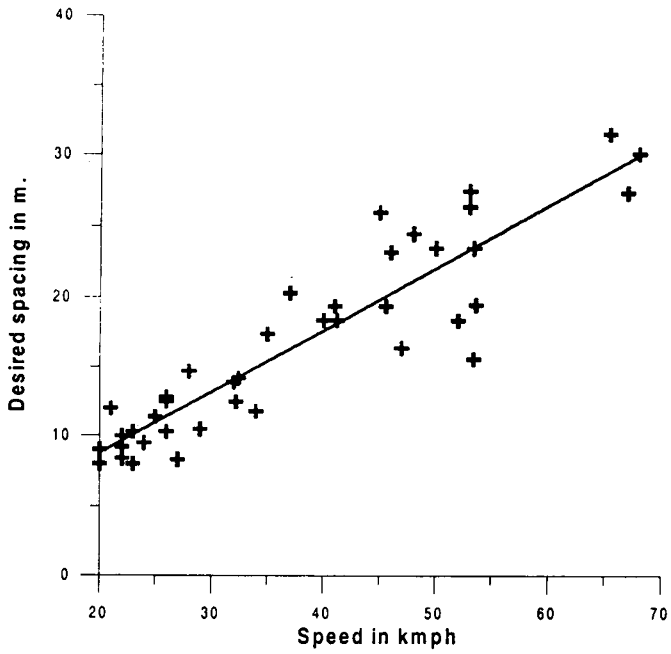


Fig 5.18 A sample diagram of desired spacing v/s speed of the vehicle.

Table 5.4 Values of α and β for different types of leader and the follower vehicles.

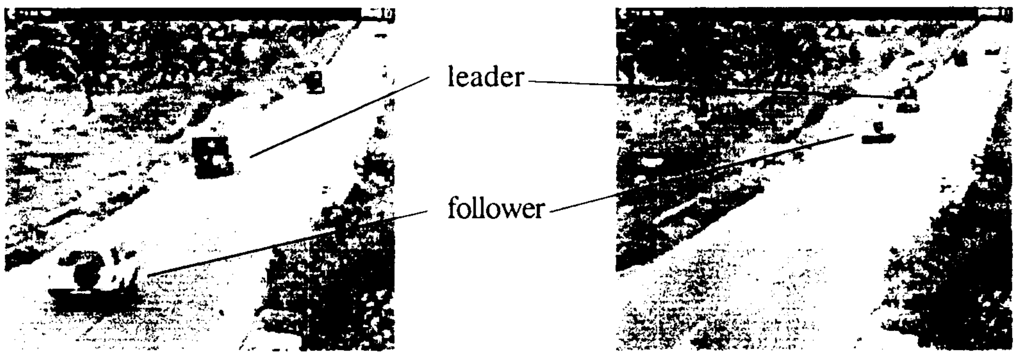
	Follower vehicle															
	Car		Bus		Auto		Truck		T/w		M.Bus		M.Truck		Jeep	
Leader vehicle	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β
Car	0.495	0.301	0.543	0.265	0.584	0.368	0.649	0.192	0.422	0.244	0.404	0.390	0.515	0.461	0.496	0.749
Bus	0.545	0.403	0.523	0.448	0.583	0.853	0.693	0.299	0.402	0.293	0.530	0.483	0.495	0.301	0.543	0.265
Auto	0.295	0.240	0.324	0.496	0.543	0.843	0.495	0.294	0.395	0.294	0.402	0.395	0.545	0.403	0.523	0.448
Truck	0.515	0.461	0.496	0.749	0.476	0.726	0.593	0.184	0.469	0.092	0.593	0.204	0.573	0.394	0.583	0.842
T/W	0.193	0.405	0.298	0.154	0.553	0.525	0.395	0.194	0.249	0.204	0.395	0.591	0.437	70.321	0.393	0.383
M.Bus	0.394	0.355	0.469	0.183	0.493	0.335	0.693	0.294	0.493	0.204	0.593	0.293	0.495	0.301	0.543	0.265
M.Truck	0.477	0.321	0.593	0.383	0.532	0.215	0.538	0.284	0.395	0.842	0.503	0.253	0.515	0.461	0.496	0.749
Jeep	0.523	0.353	0.496	0.204	0.592	0.295	0.693	0.294	0.351	0.627	0.633	0.488	0.477	0.321	0.593	0.383

5.4.2 VALIDATION

The model can be applied for the following two cases - i) when the follower approaches from a large spacing and ii) when the spacing is increased due to the acceleration of the leader vehicle. The observed results are compared with the simulated results in the following sections.

5.4.2.1 WHEN THE FOLLOWER APPROACHES FROM A LARGE SPACING

When a fast moving vehicle approaches from a large spacing to a relatively slow moving leader, the follower will decelerate gradually. Fig 5.19(a) shows such a condition, in which the speed of the follower is 42kmph and that of the leader is



(a) Deceleration starting (b) Deceleration ending

Fig 5.19. Follower approaching from large spacing

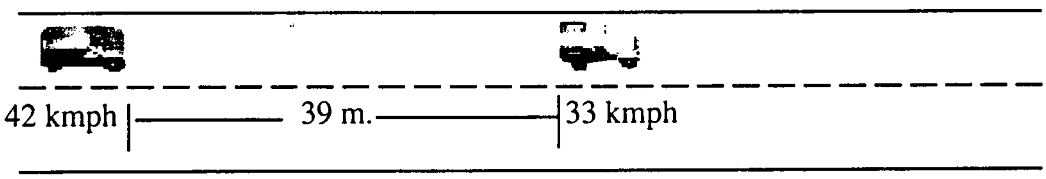


Fig 5.20(a) Initial condition applied to the simulation

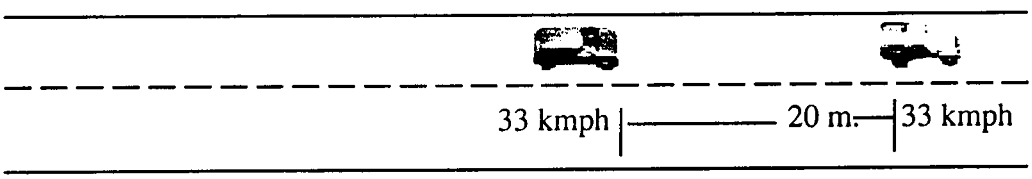


Fig 5.20(b) Final condition obtained from the simulation

33kmph and the spacing is 39m. Fig 5.19(b) is the actual view at the end of deceleration process. The instantaneous speed and the spacings observed from the field and from the models are presented in Fig 5.21 and Fig 5.22 respectively. It is very clear from the figures that, the instantaneous speed of the follower and the spacings are almost matching with the real situations observed from the field.

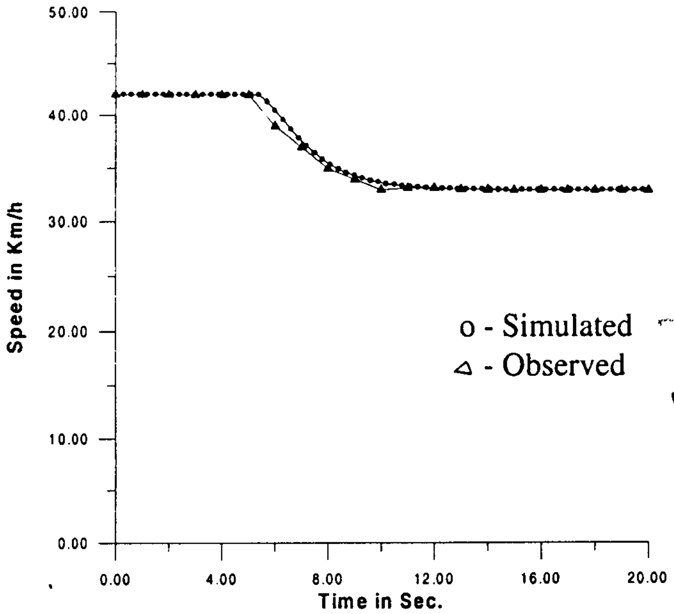


Fig 5.21 Observed and the simulated instantaneous speed of the follower vehicle.

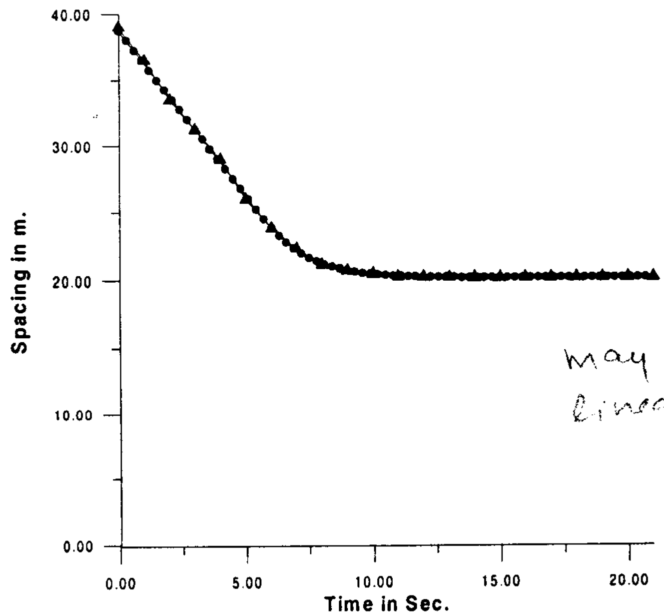


Fig 5.22 Observed and the simulated spacing between vehicles.

5.4.2.2 WHEN THE LEADER ACCELERATES

When a leader vehicle accelerates, the spacing of the follower will increase. Therefore, the follower vehicle will also increase its speed gradually. Fig 5.23 shows the initial and the final conditions observed from the field(video clips). Its initial and final positions were marked on Fig.5.24(a) and Fig.5.24(b) respectively. It is very clear from Fig 5.25 that the simulated speeds and spacings are almost matching with the field observation.

(a) Initial condition

(b) Final condition

Fig 5.23 Both follower and the leader vehicles accelerating

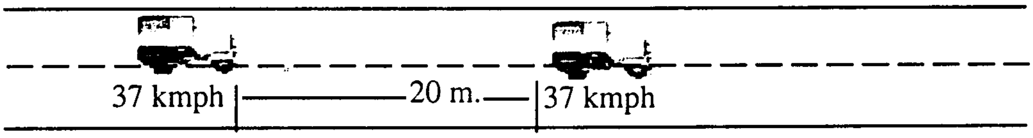


Fig 5.24(a) Initial condition to the simulation

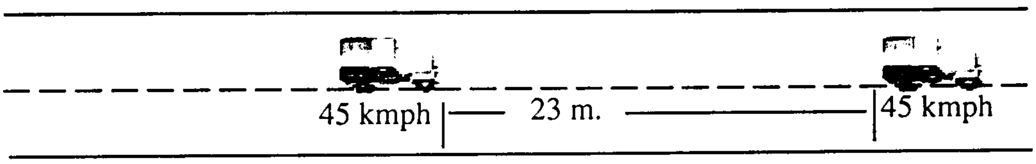


Fig 5.24(b) Final condition from the simulation

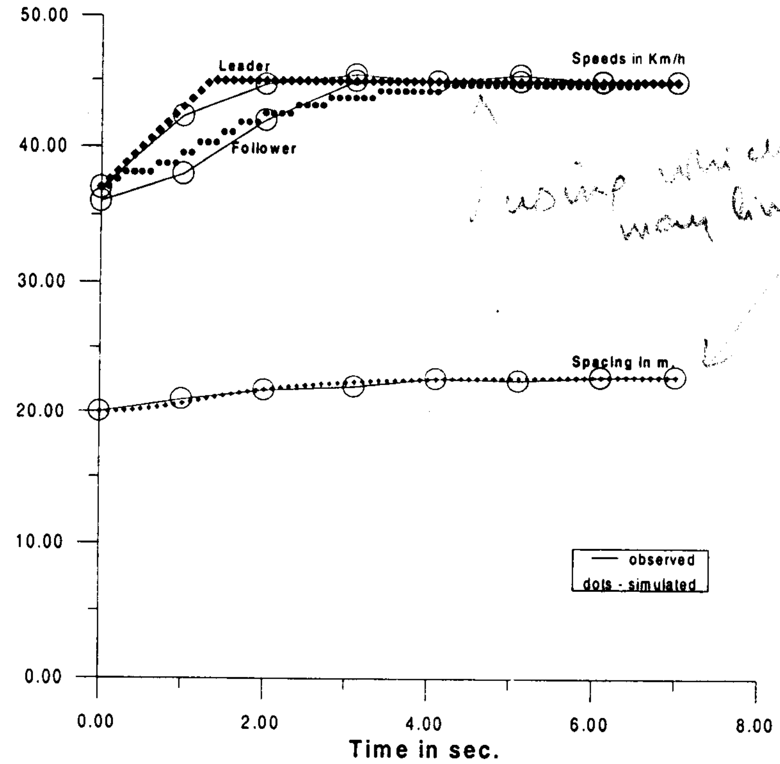


Fig 5.25 Instantaneous speeds and spacings of the follower, when the leader vehicle accelerated.

5.5 LANE CHANGING BEHAVIOUR

Any type of overtaking will have one lane changing operation at the beginning and one lane changing operation at the end. The shape of the path has been observed to be highly varying with respect to the different traffic situations. Let the initial and the final positions of an overtaking vehicle during a lane changing operation be A and B, as shown in Fig.5.26.

If the lateral shift is S and the movement along the length of the road is D_1, then the lane changing path AB will be as shown in Fig 5.26. The equation of the lane change path may be modelled as a sine function as:

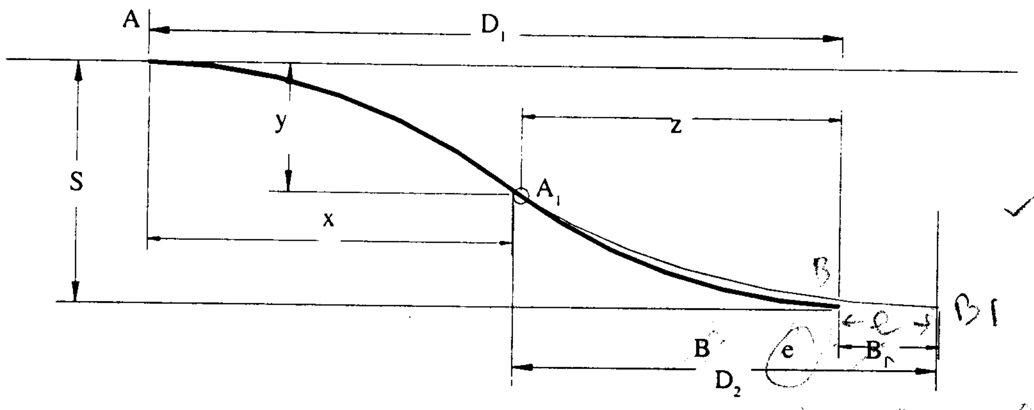


Fig 5.26. Lane changing model

$$y = S / 2 \, . \, [\, 1 - \cos\, (\, \pi \; x / D_1 \,)\,] \text{ ---------------------- Eq.5.23}$$

where,

y	=	the lateral shift at any time
x	=	the distance moved by the vehicle from the position A
D_1	=	the distance between A and B.

But the driver of the overtaking vehicle will always be interested in the distance remaining to be completed in the lane change operation, than the distance progressed in the operation.

$$x = D_1 - z$$

Thus:

$$y = S / 2 \, . \, [\, 1 - \cos\, (\, \pi \; (\, D_1 - z \,) / D_1 \,)\,] \text{ -------------- Eq.5.24}$$

This equation is a simple sine function, which has a definite shape. But in practice, it has been observed that the above equation holds good only in the case of a normal overtaking in which the estimated length of lane change (D_1) and the actual are the same. But in most of the cases, due to the error in the driver's estimation and the changes in the traffic situations, the value of D_1 will not be a constant. So the above equation cannot be used in all the cases.

Let the position of the overtaking vehicle is at A_1, at x distance from A. Let the driver re-estimate his destination as B_1 instead of B. Let the difference be e. Then the vehicle will select the path A_1B_1 instead of A_1B. Here the tangent of both the curves at A_1 will be the same. Or the derivative of these two curves at the point will be equal.

i.e. $$\frac{d(A_1B)}{dz} = \frac{d(A_1B_1)}{dz} \quad \text{at } A_1.$$

i.e. $d/dz(S/2[1-\cos(pi(D_1-z)/D_1)]) = d/dz(S/2[1-\cos(pi(D_2-z-e)/D_2)])$

by simplification:

$$D_2 = D_1(z+e)/z \qquad \text{-- Eq.5.25}$$

where, D_2 is the distance to be travelled to the new destination point(see Fig 5.26)

.

Thus the change in the lateral shift with respect to the changes in the traffic situations are established.

5.5.1 VALIDATION OF THE LANE CHANGING MODEL

The lane changing model described above has been observed to handle many practical variations in the traffic situations. Some of them are presented below:

Fig 5.27 shows the lane changing operation of a normal overtaking vehicle, in which the speed of the overtaken vehicle is almost constant. In some cases, when the overtaken vehicle accelerates, the destination point of the end of the lane change of the overtaken vehicle will increase. Thus the length of the lane changing operation will increase, such a situation is presented in Fig 5.28. When the leader decelerates while overtaking, then the destination point of end of lane change will decrease. In such a situation, a sudden lane changing operation will take place as shown in Fig 5.29. By the implementation of the above model, these types of fluctuations have been simulated as in real life.

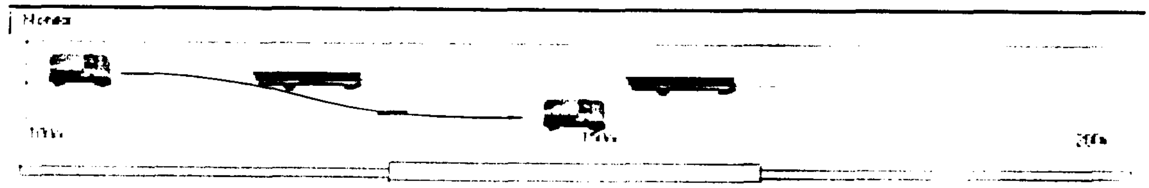


Fig 5.27 Lane changing for a normal overtaking operation.

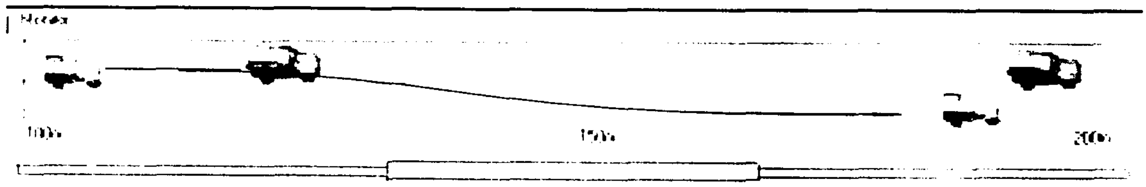


Fig 5.28 Lane changing, when the overtaken vehicle accelerated.

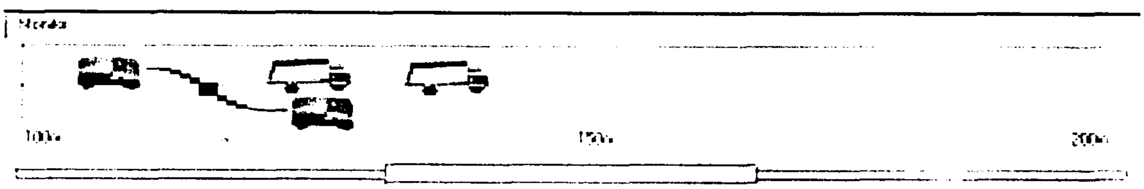


Fig 5.29 Lane changing, when the overtaken vehicle decelerated.

5.6 SUMMARY AND CONCLUSION

This chapter has described and modelled the types of overtaking manoeuvres that are seen in the mixed traffic environment. Unlike, the one and only normal overtaking condition that is suggested by the Indian Roads Congress for calculation of safe overtaking sight distance, the present study proposes FIVE different types of overtaking possibilities, which are captioned as: Free Passing, Normal Overtaking, Forced Overtaking, Parallel Overtaking and Stream lined Overtaking, respectively. Equation system has been developed for safe overtaking distances and time of overtaking for all the above types of vehicle manoeuvres. The study also proposes, a Dynamic Sine Function for describing the lateral shifts of vehicles while overtaking a leader and merging with the main vehicular stream, and has developed the equation system for describing the path of these vehicular manoeuvres. A car following model, based on the 'Desired Speed Concept' has been put forward even for mixed traffic flow and a procedure for calculation of practical acceleration of vehicles has been developed. Thus the ideas proposed and modelled are altogether new and deviate very much from the very rudimentary ideas that are available in the literature and which are developed mostly for homogenised traffic flow conditions only. Most of the hypotheses proposed have been validated from field studies. The next and the subsequent chapters describe the integration of many of the submodels into a micro simulation package and the use of that package for the conduct of real life experiments

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CHAPTER - 6

DEVELOPMENT OF THE SIMULATION MODEL "AUTOTRAFFIC"

6.1 GENERAL

The development of the various component models for the proposed simulation models have been described in the previous chapters. These component models are integrated into a single model for various applications considered in this chapter.

6.2 TRAFFIC SIMULATION

The basic concept of any simulation system is to develop a computer program which has to work exactly similar to the real system and to experiment with various input levels so as to study the system behaviour in different conditions, which may be difficult and expensive to observe in real situation.

Fig 6.1 shows the basic flow diagram of a general traffic simulation problem. The vehicles will be generated on the road environment with respect to the various input data, and will be allowed to move with certain vehicle movement logics during testing period (simulation time). At the end of a simulation exercise, the outputs will be summarised and printed.

6.3 HIGHWAY MIDBLOCK SIMULATION

The step wise flow diagram of a highway midblock simulation is presented in Fig 6.2. The various input data like the length and width of road, the composition

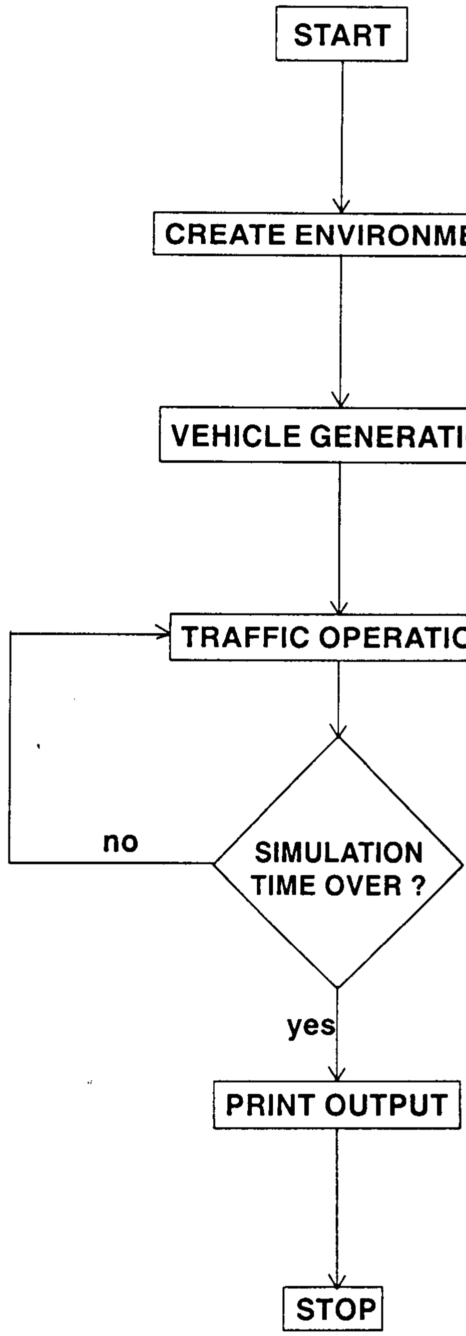


Fig 6.1 General flow diagram of traffic simulation

of different classes of vehicles, expected flow level, etc., are to be entered and the system has to be developed with its environment ready for vehicle generation. Before beginning the initialization process, the standard data like the dimensions, the free flow speeds of different classes of vehicles, other constants, etc., are to be read from respective data files.

The three important steps of a vehicle generation process are the selection of vehicle type, its initial headway and its desired speed. The vehicle type is selected with respect to the composition of vehicles. The vehicle type generation flow diagram is presented in Fig.6.3. The vehicles have to be generated for the two directions as described in the vehicle generation part of Fig 6.2.

The second part of the vehicle generation module is to select initial headway to individual vehicles so as to make a queue of vehicles on both directions as shown in Fig 6.4. A number of experiments were conducted in this area to find the best fit distribution for the initial queue to be developed for simulation. Head ways were measured on four stretches (see Fig 6.5), at 100m. intervals from the front of the queue. It was observed that irrespective of the initial head way distribution, the vehicles got their positions adjusted on the road which lead to certain known head way distribution. The road length required to move the vehicles during this adjustment period is known as warm-up zone. In this study, warm-up zone length of 1000m. was provided as shown in Fig 6.6.

The initial head way distribution for low flow levels (less than 500vph) and the observed head way distribution for the subsequent four sections at 100m. intervals are presented in Fig 6.7. It is very clear from the figure that even in the initial extreme case of spike distribution, the distribution after 300m. was observed to be exponential and all the calculated values of chi-square is less than the tabulated value (see Table 6.1) and hence this distribution was chosen. The same phenomenon was observed in different mix of vehicles and at different flow levels, as shown in Figs 6.8 and 6.9.

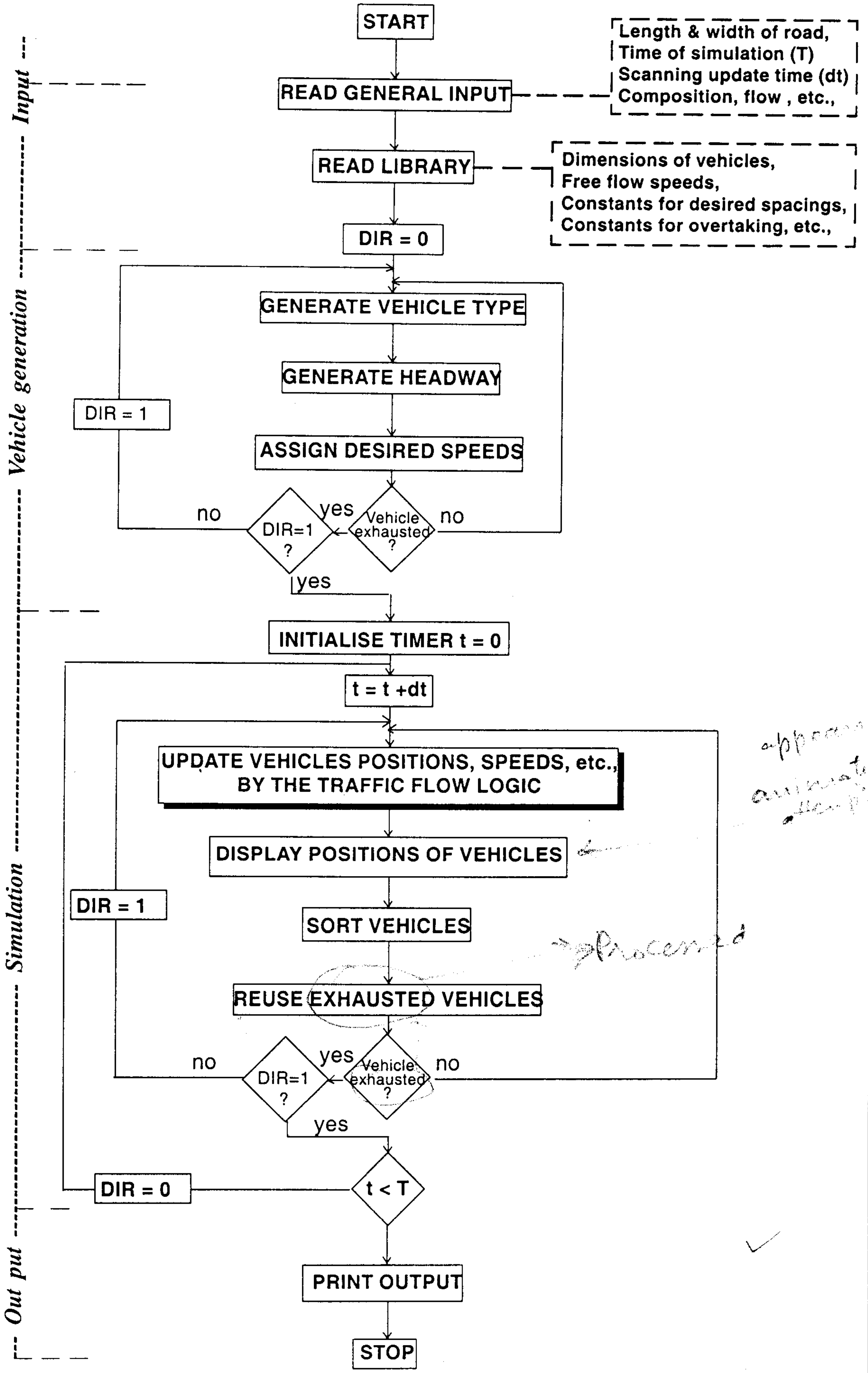


Fig 6.2 Stepwise flow diagram of the traffic simulation

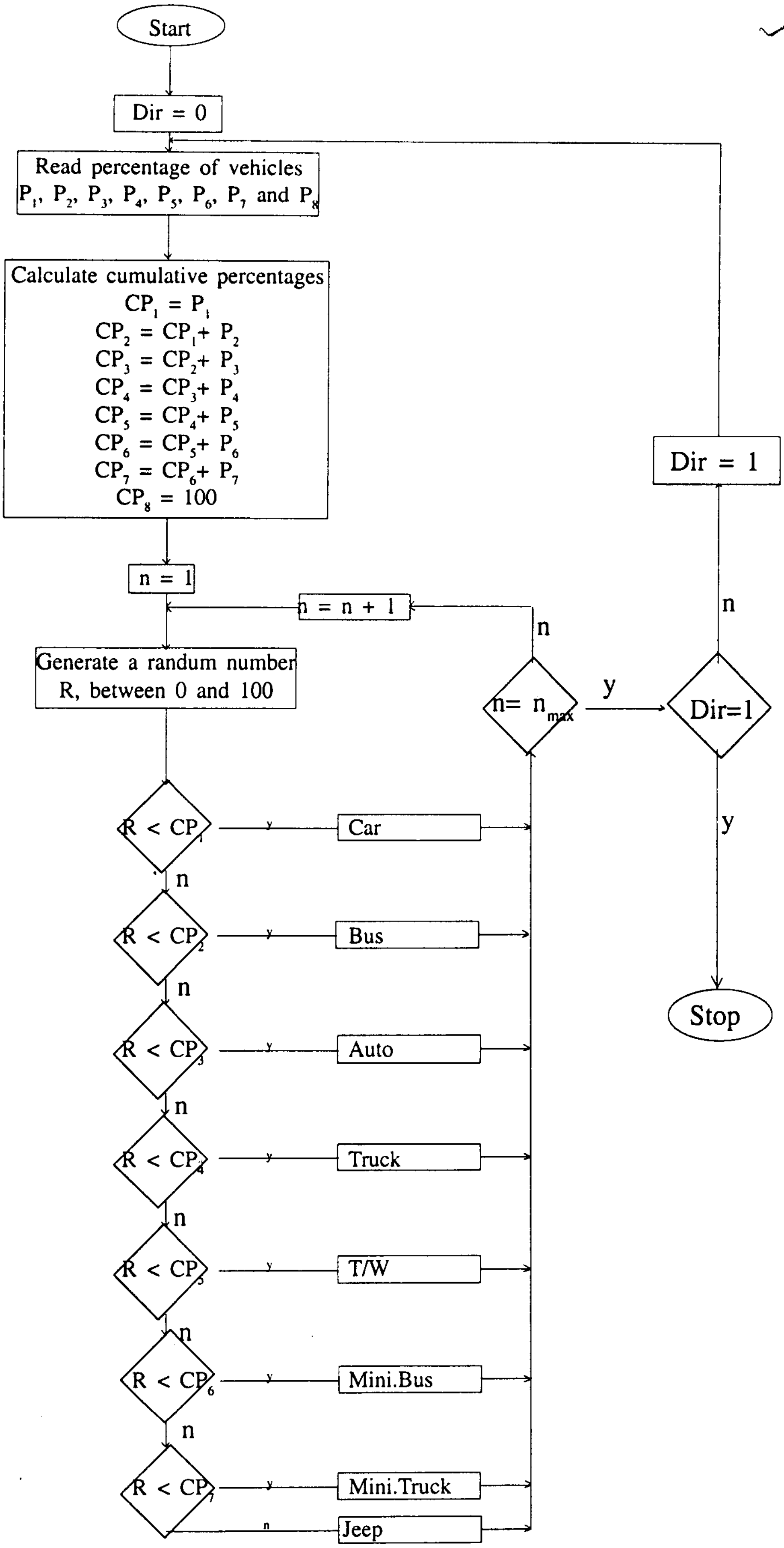


Fig 6.3 Flow chart to generation vehicle type.

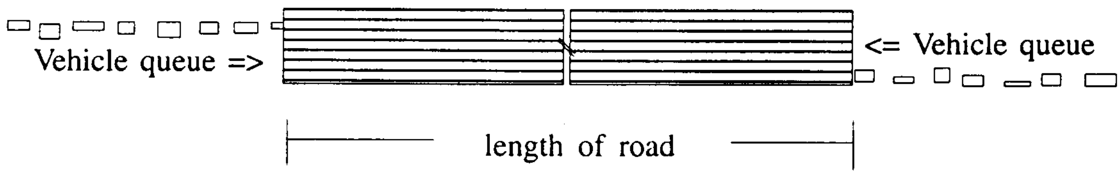


Fig 6.4. Vehicle queues on both the directions

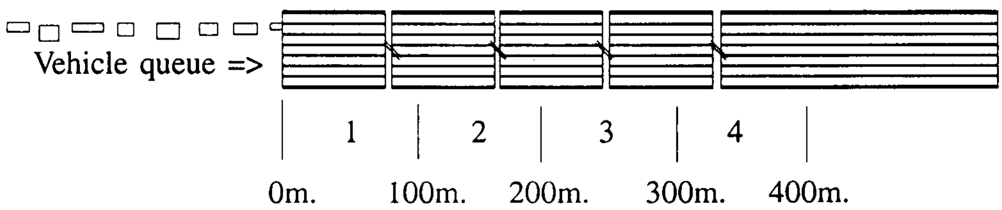


Fig 6.5. Head way measurement regions from the end of road

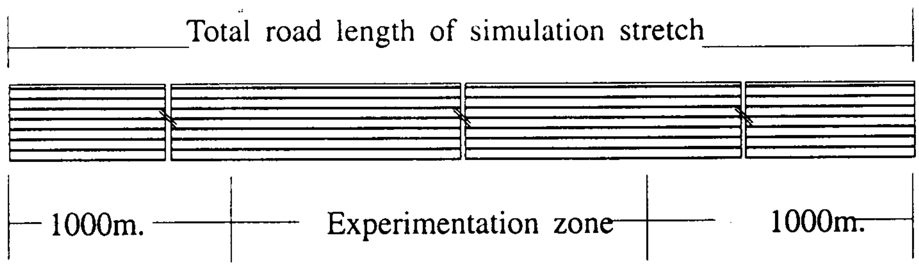


Fig 6.6. Warm-up zone length 1000m. on both sides

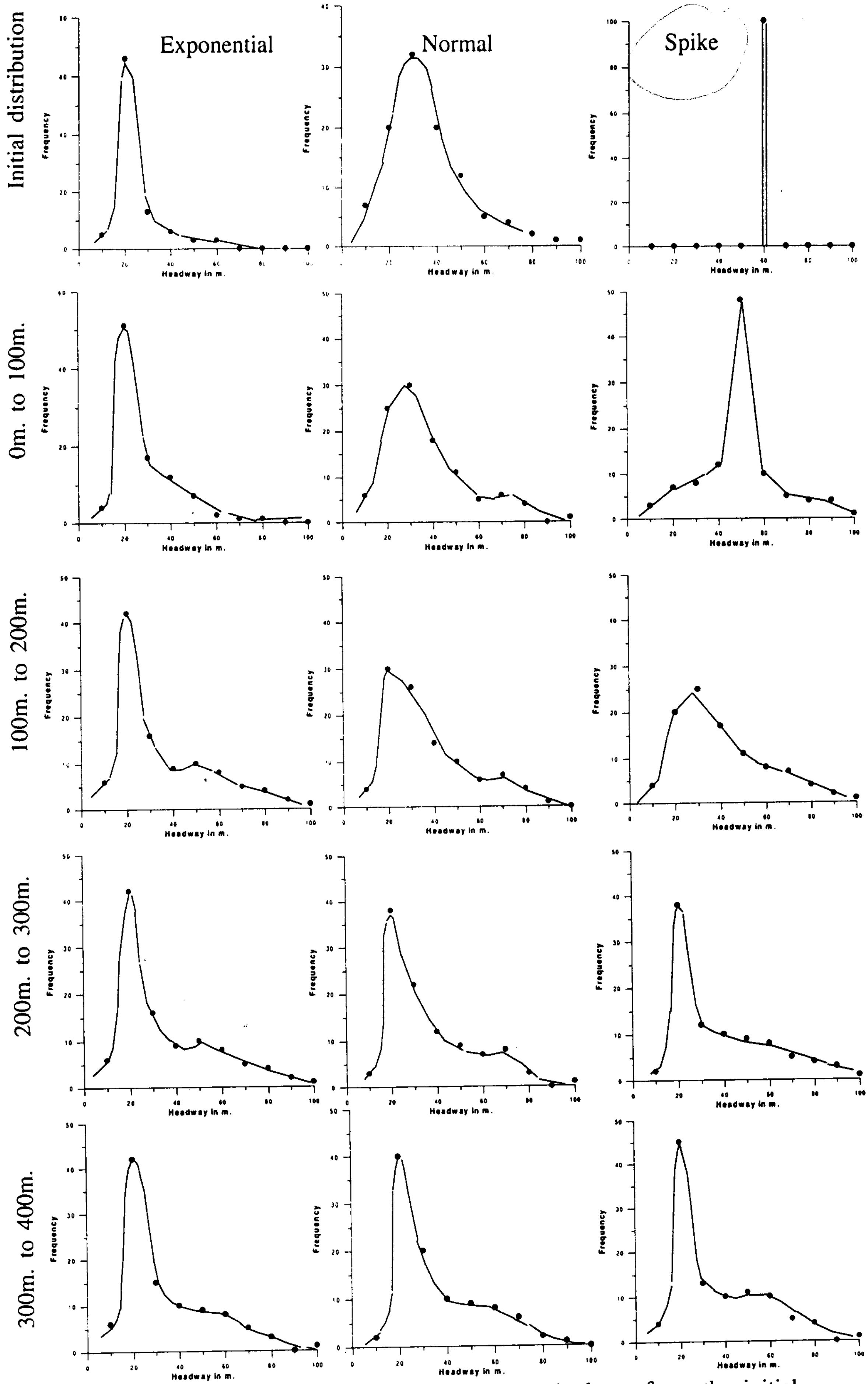


Fig 6.7 Frequency distribution of headway at 4 places from the initial queue with respect to the initial distributions at low flow level (500vph)

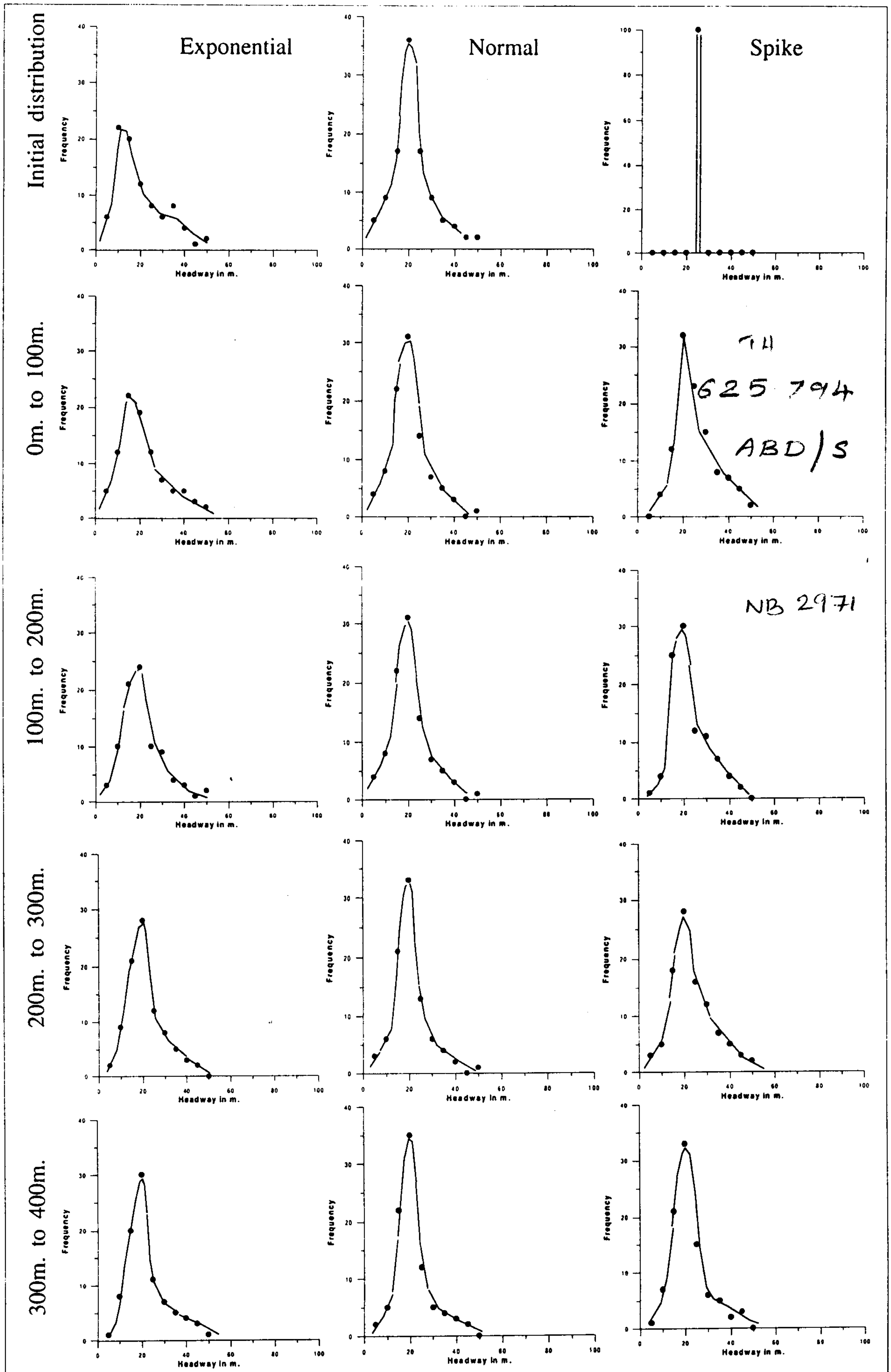


Fig 6.8 Frequency distribution of headway at 4 places from the initial queue with respect to the initial distributions at medium flow level (1000vph)

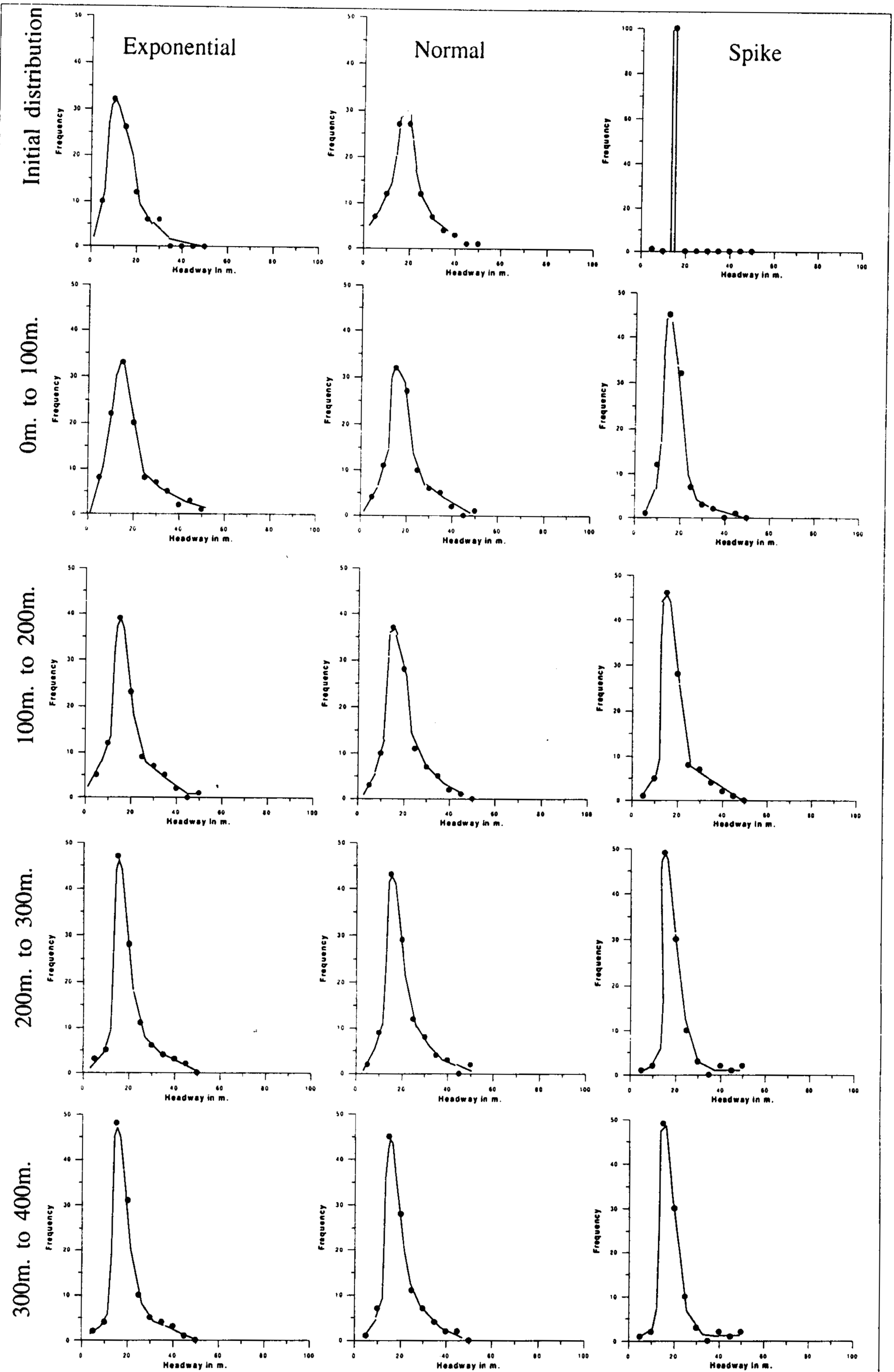


Fig 6.9 Frequency distribution of headway at 4 places from the initial queue with respect to the initial distributions at high flow level (2000vph)

Table 6.1 Results of Goodness of fit

Flow in Vehicles/hr.	Initial Headway Distribution	Chi-square value for exponential distribution	
		Tabulated	Computed
500	Exponential	15.51	6.34
	Normal	15.51	4.74
	Uniform	15.51	5.35
1000	Exponential	17.54	3.56
	Normal	17.54	8.24
	Uniform	17.54	5.75
2000	Exponential	13.36	4.34
	Normal	13.36	3.73
	Uniform	13.36	6.34

The third part of the vehicle genration module was to assign desired speeds to the vehicles in the queue. Desired speed is the speed at which a vehicle/driver desires to travel under free flow condition. The details of the data collection are presented in article 4.3. The desired speeds of vehicles were found to be following normal distribution with means and standard deviations as presented in Table 6.2, for different types of vehicles. The observed minimum and maximum desired speeds are also presented in the same table for different types of vehicles. The probability is not zero out side the above range in a normal distribution. Therefore random speeds have to be generated to follow normal distribution with specific mean and standard deviation within a permissible range as shown in Fig 6.10. Fig 6.11 shows the flow chart for the generation of desired speeds of vehicles.

The next stage is the actual simulation, in which the positions of all the vehicles in the system will be recalculated and placed on the road at every simulation time interval with certain flow logics developed. This is the core of the work. The vehicle flow logics are developed based on the sub models presented in the Chapter 5. For the development of computer programming, a systematic method has been adopted in the implementation of flow logics, as explained in the following sections.

6.4 VEHICLE STATE APPROACH

Any vehicle in the traffic stream may be grouped under: i) Free Flowing vehicle group ii) Overtaking vehicle group iii) Disturbed vehicle group. If a vehicle is moving with its desired speed without any disturbance from other vehicles, such vehicles are termed as Free Flowing Vehicle. Whenever a vehicle is in any of the overtaking operation as explained in the chapter 5, those vehicles can be categorised as Overtaking Vehicles. All other vehicles are grouped under Disturbed Vehicle category. This classification is only to simplify the complex problem of clubbing the simulation sub models into a single computer simulation program.

Table 6.2 Desired speed parameters for random generation

Code No.	Type of vehicle	Desired Speed (kmph)			Std.Dev.
		Mean	Minimum	Maximum	
1.	Car	56.73	43.92	89.49	6.32
2.	Bus	51.32	38.27	78.36	5.54
3.	Auto.	43.65	28.59	64.21	4.41
4.	Truck	40.97	27.37	72.56	7.42
5.	T/W.	46.09	27.40	72.68	9.26
6.	Mini. Bus	47.13	31.56	68.24	7.61
7.	Mini. Truck	42.75	26.37	79.36	9.14
8.	Jeep	52.03	39.25	82.50	8.46

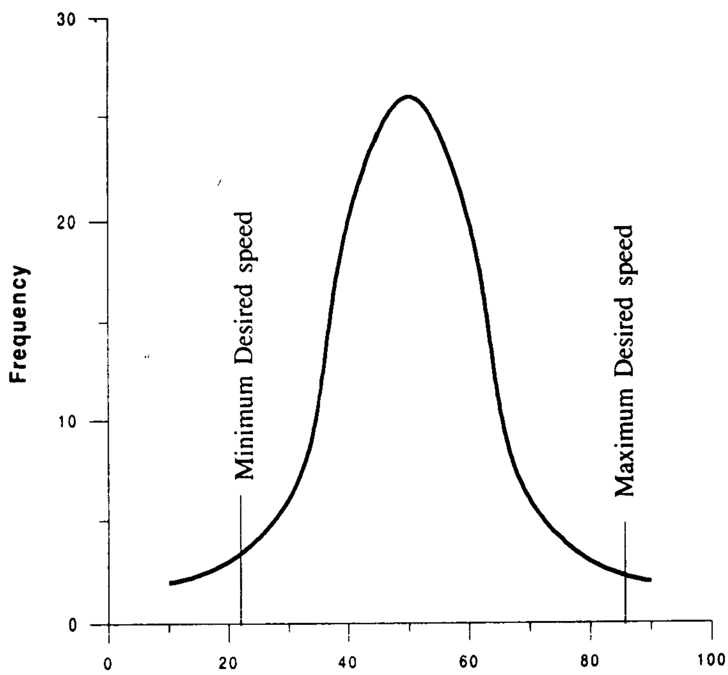


Fig 6.10 Distrubution followed by desired speeds of vehicles

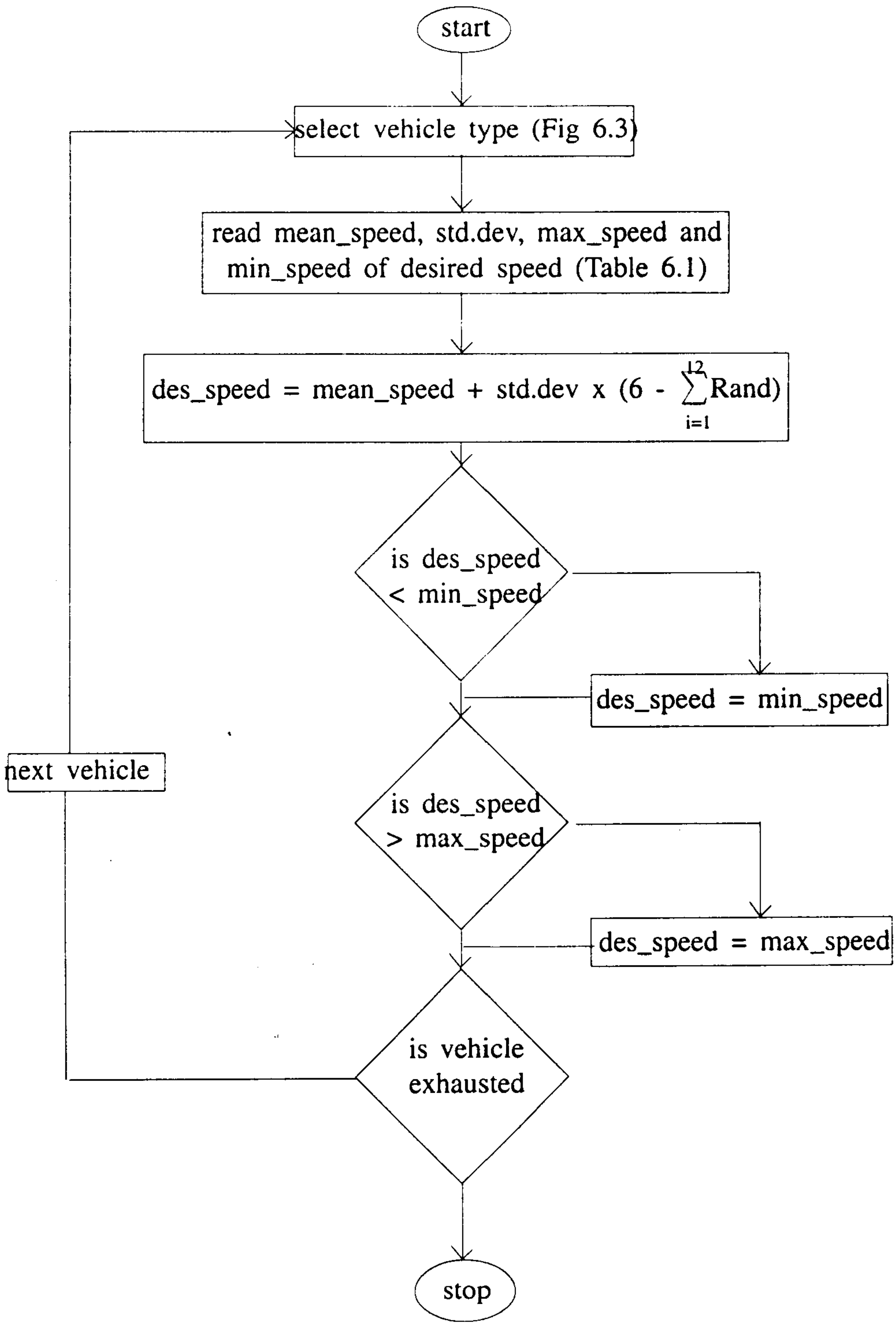


Fig 6.11 Flow chart for generation of desired speeds

6.4.1 STATE NUMBER

The data structure of a vehicle includes many variables like type of vehicle, current speed, current acceleration, desired speed, current location in xy coordinates, state number, etc., as shown in Apendix 6.1. The state number is a three digit number to identify the state of the vehicle in the traffic stream directly, so as to minimise the checking and updating mechanisms explained in the next section and there by to improve the speed of the program significantly.

The first digit can be 1, 2 or 3 to identify the whether the vehicle is in the Free Flowing or Overtaking or in the Disturbed condition. Second digit indicates the sub type within the major class as shown in Table 6.3. The third digit is the status of sub type. For example STATE number 111 means it is an absolutely free flowing vehicle and 223 means it is a normal overtaking vehicle at its third stage, ie. at the end of overtaking operation.

6.4.2 CHECKING AND UPDATING MECHANISM

Vehicles in the system have to be updated at every simulation time interval and which has to be checked for many traffic conditions. So, these updating and checking mechanisms are based on the condition of the vehicle and thus with respect to the STATE number. This is pictorially presented in Fig 6.12.

6.4.3 OPTIMUM CHECKING

Traffic simulation involves, millions of instructions within a fraction of a second, therefore, to reduce the time requirement, unnecessary large calculations have to be strictly avoided or minimised. For example, a freely flowing vehicle need not to be checked for the condition for the end of overtaking process. In such cases, by avoiding unnecessary checking operations, thousands of instructions can be saved. In this point of view, the maximum number of checking operations required for each

Tab 6.3 First and Second digits of STATE number

FIRST DIGIT		SECOND DIGIT	THIRD DIGIT
1	Free Flowing Vehicles	1. Absolute free flow 2. With a passing of vehicle from the same direction 3. With a passing of vehicle from the opposite direction	0. Beginning of the operation. 1. In the first stage of the operation 2. In the second stage of operation 3. In the third stage of the operation
2	Overtaking Vehicles	1. Passing 2. Normal overtaking 3. Forced overtaking 4. Parallel overtaking 5. Stream lined overtaking 6. Overtaking a bunch of vehicles	
3	Disturbed Vehicles	1. Overtaken vehicle 2. Obstruction due to opposing vehicle 3. Withdrawal from an overtaking 4. Forced to follow 5. Increasing spacing	

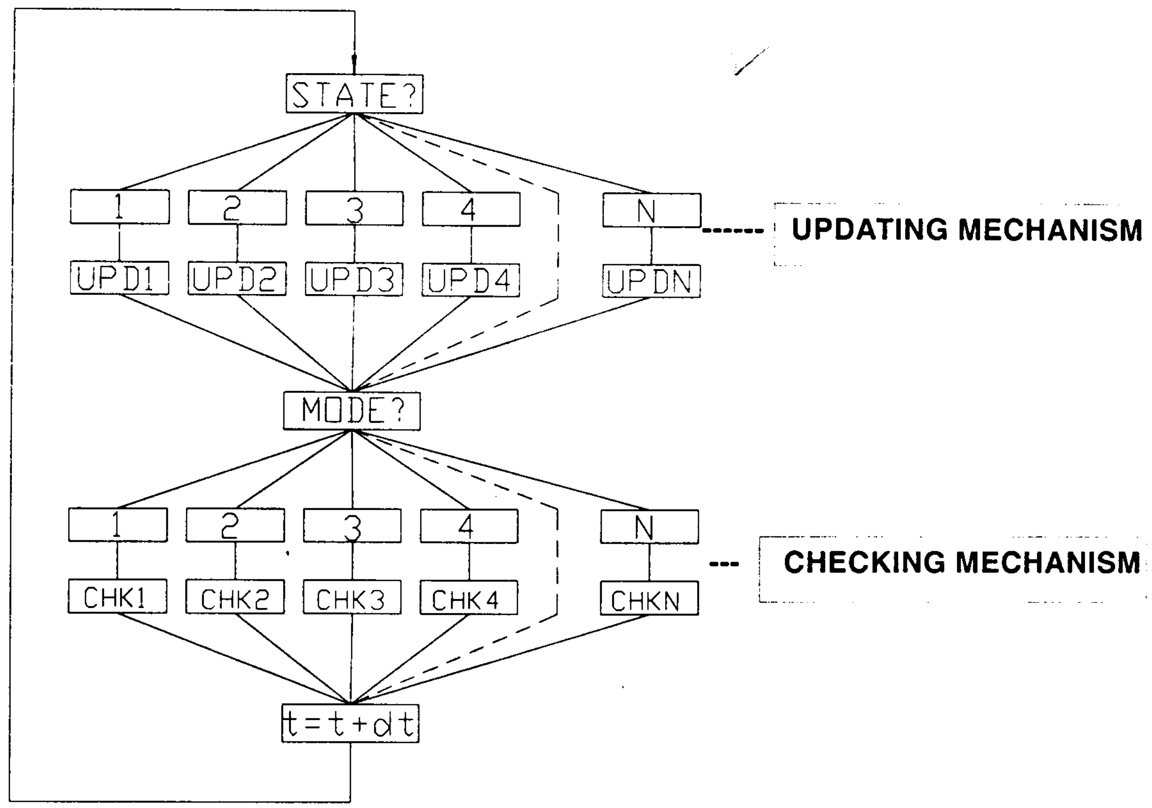


Fig 6.12 Updating and Checking mechanisms.

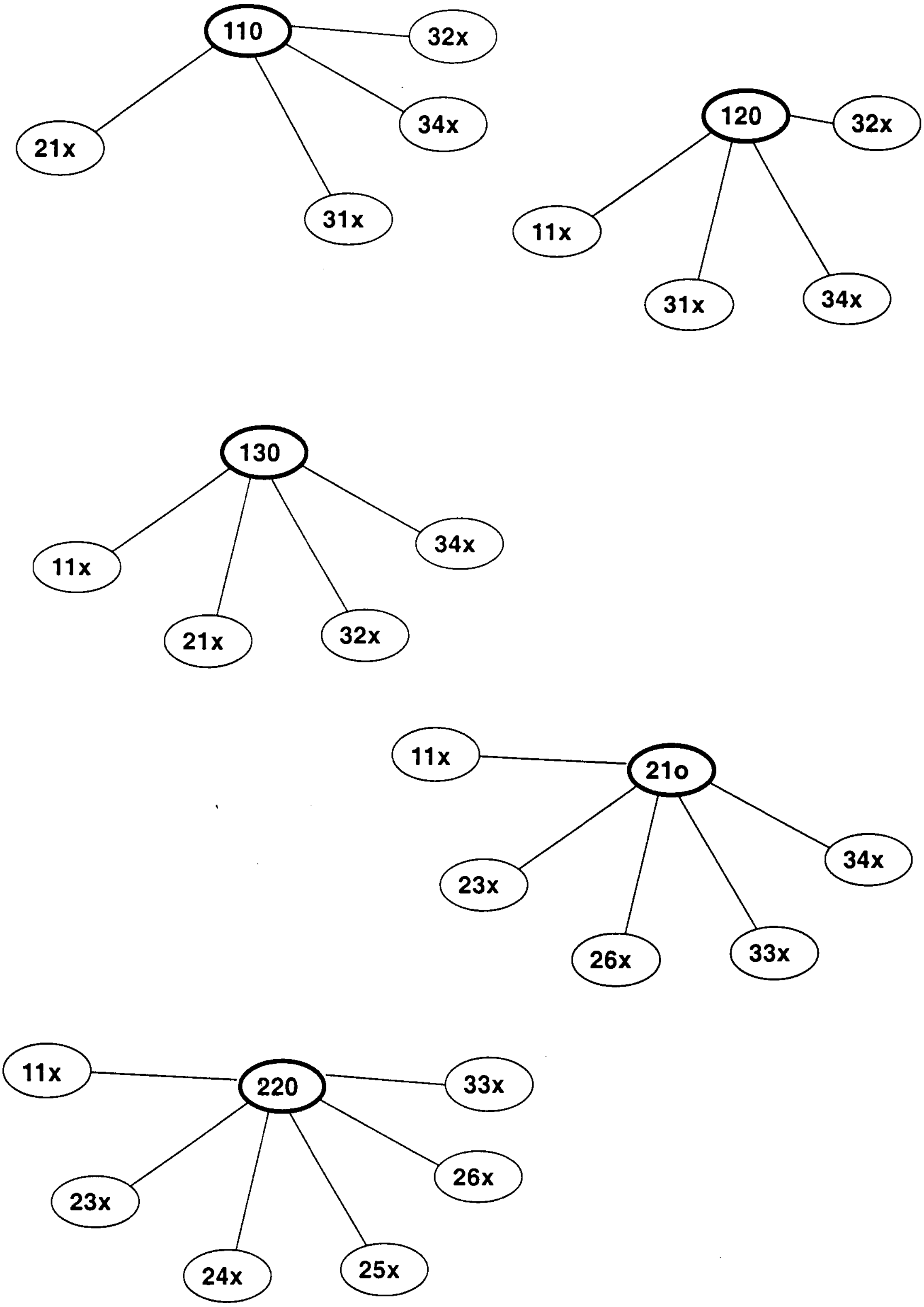


Fig 6.13(a) Optimum checking diagrams.

x means any third digit of the STATE number

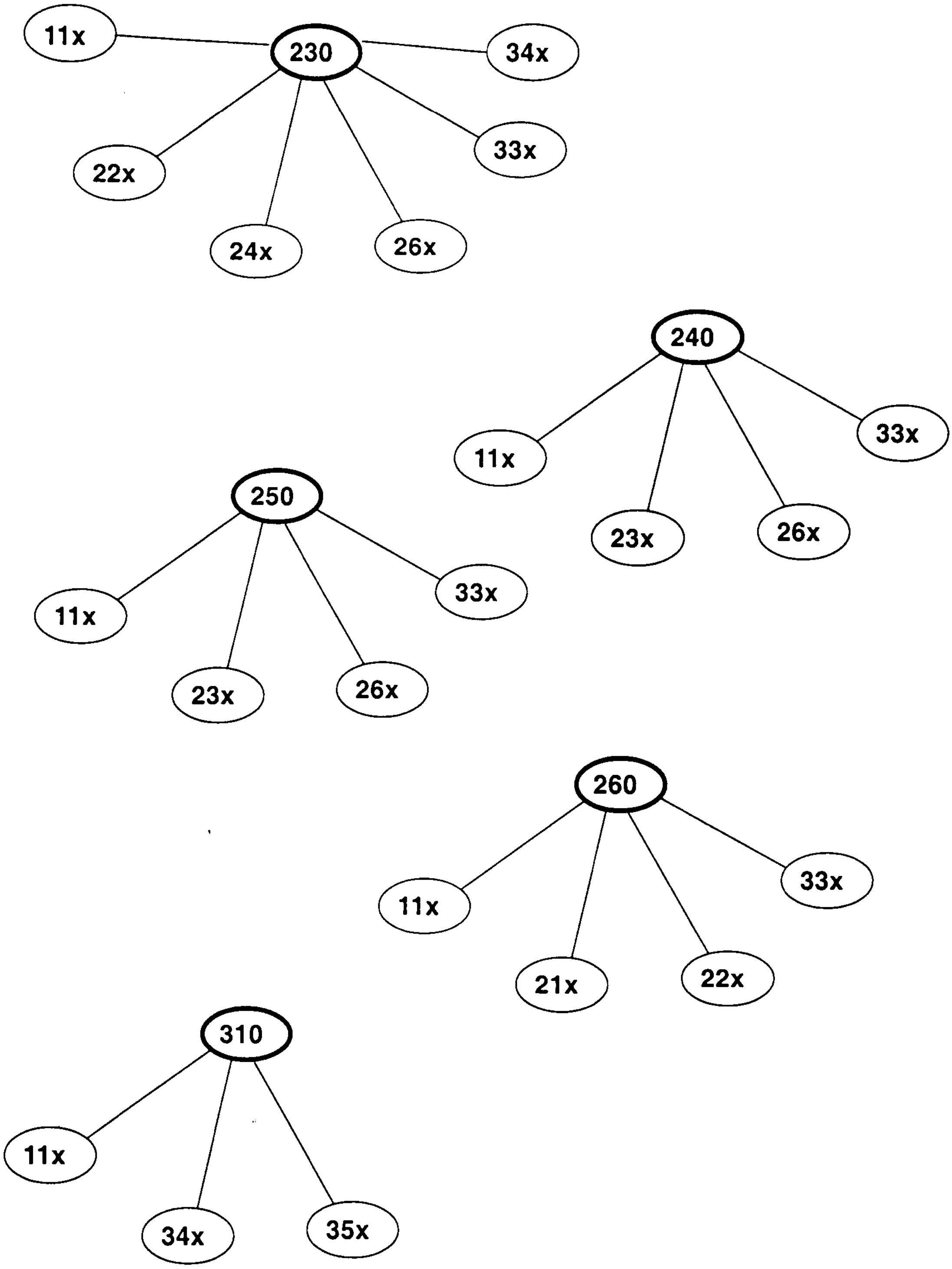


Fig 6.13(b) Optimum checking diagrams.

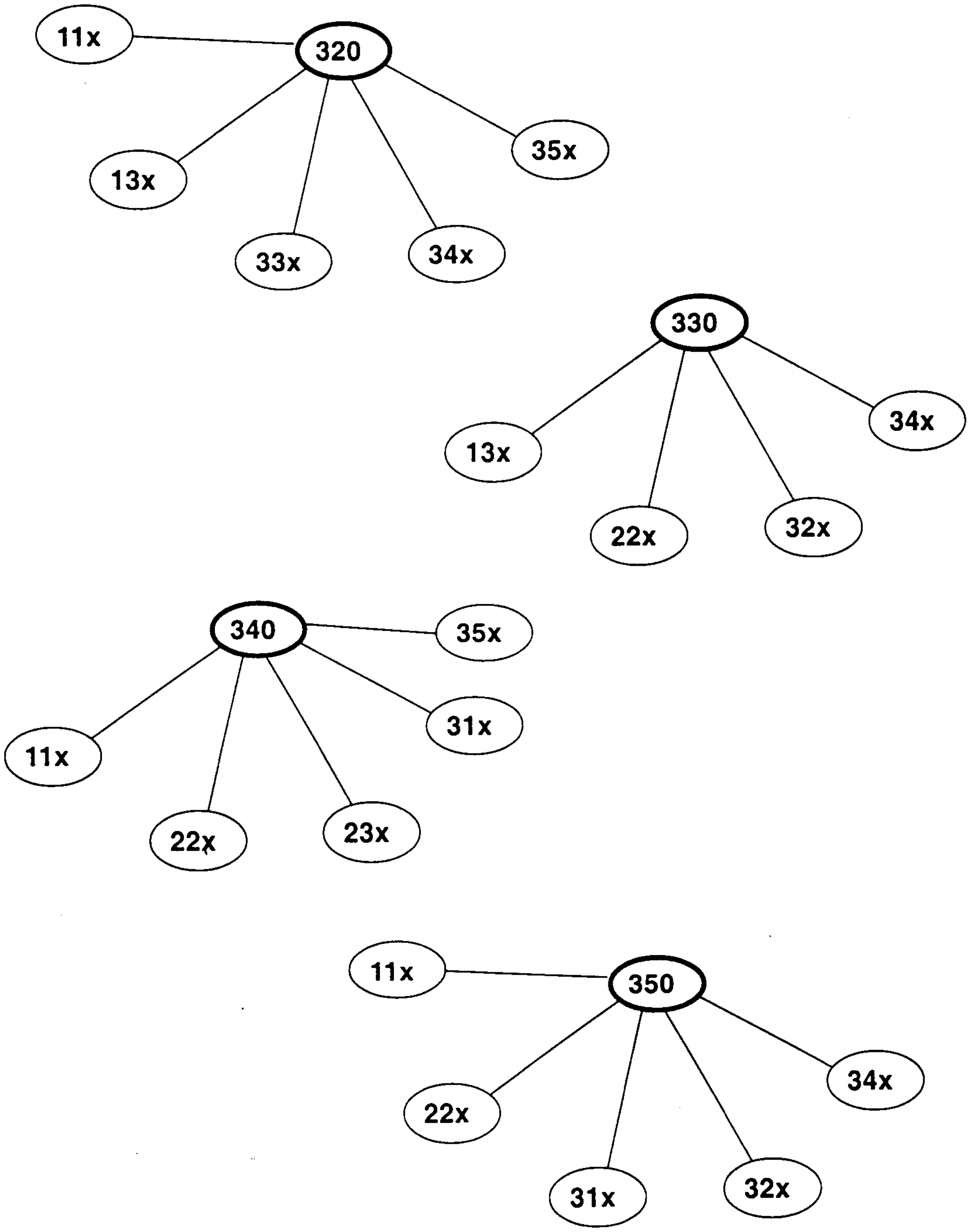


Fig 6.13(c) Optimum checking diagrams.

STATE number has been observed and these are presented in Figs 6.13(a) to 6.13(c).

For example, the top part of Fig 6.13(a) is an optimum check-links diagram for state number 110, for a free flowing vehicle referred to by the state number 110. A free flowing vehicle will have at least its desired spacing in its front. The availability of a space larger than the desired space need not to be checked for a free flowing vehicle in any case. Thus, we can avoid a check for 350. All the check-links digrams (Fig.6.13(a) to Fig.6.13(c)) are developed under similar assumptions.

6.5 FLOW LOGICS

The vehicle numbering convention is presented in Fig 6.14. The main flow logics used in the simulation program are presented in Figs 6.15 to 6.24. If the vehicle under consideration (highlighted in the figure) is *n*, then its leader vehicle is *n-1* and its follower vehicle is *n+1*. In order to reflect the positions of vehicles on the computer screen, the origin (0,0) of the road is considered the left top corner point of the road and its sign convention is as shown in the figure.

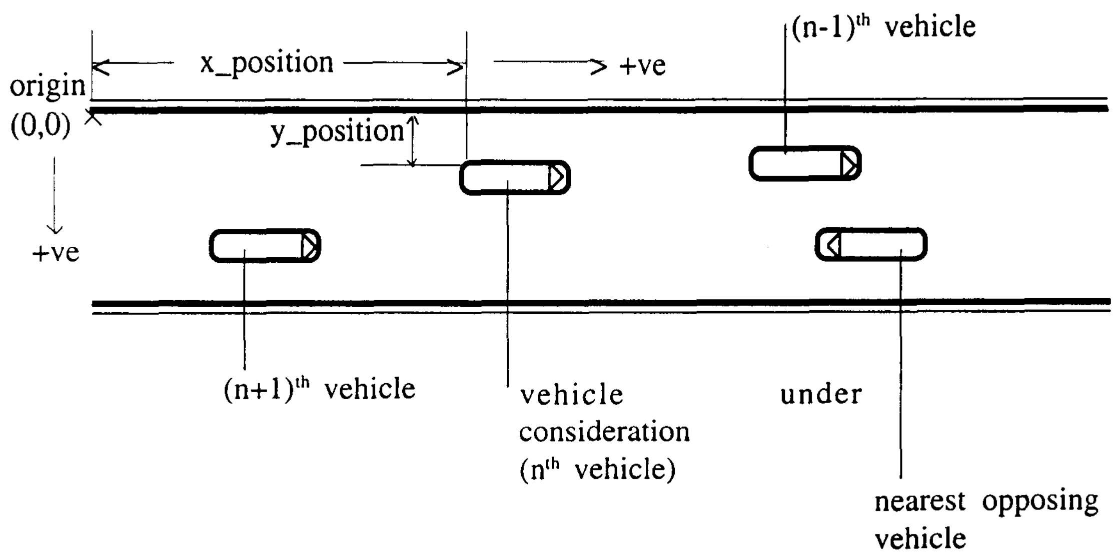
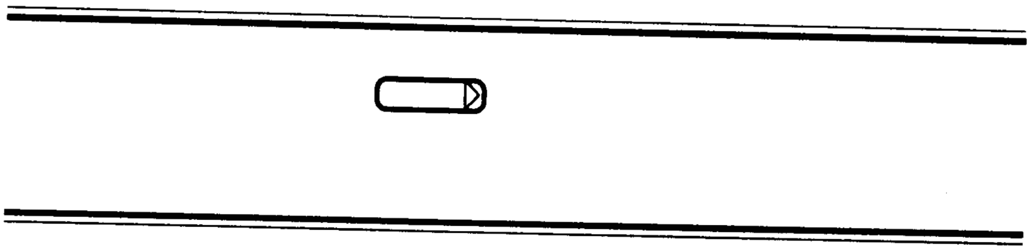


Fig 6.14 vehicle numbering convention

The major variables used in the computer program are listed below:

Sl. No.	Variable		Description
1.	n	-	Vehicle number under consideration
2.	x_position	-	Distance from the origin to the vehicle measured along the length of road.
3.	y_position	-	Distance from the origin to the vehicle measured across the road
4.	mean_y_position	-	Default lateral position
5.	dt	-	Scanning update time interval
6.	dx	-	Distance travelled during the time dt
7.	current_speed	-	Current speed of the vehicle
8.	fspace	-	Available headway
9.	req_fspace	-	Required headway
10.	dvf	-	Speed difference between two vehicles
11.	req_dvf	-	Required speed difference
12.	rgap	-	Available right gap
13.	req_rgap	-	Required right gap
14.	ospace	-	Spacing between two opposing vehicles
15.	req_ospace	-	Required ospace
16.	state(n)	-	State number of n^{th} vehicle
17.	req_y_pass	-	Required y_position for a passing
18.	bspace	-	Available rear spacing
19.	bspace_pass	-	Required bspace for a passing
20.	req_y_ll	-	Required y_position for parallel overtaking
21.	bspace_ll	-	Required bspace for parallel overtaking
22.	req_y_strm	-	Required y_position for stream lined overtaking
23	bspace_strm	-	Required bspace for stream lined overtaking
24.	b_length	-	Bunch length
25.	req_y_bn	-	Required y_position for bunch overtaking



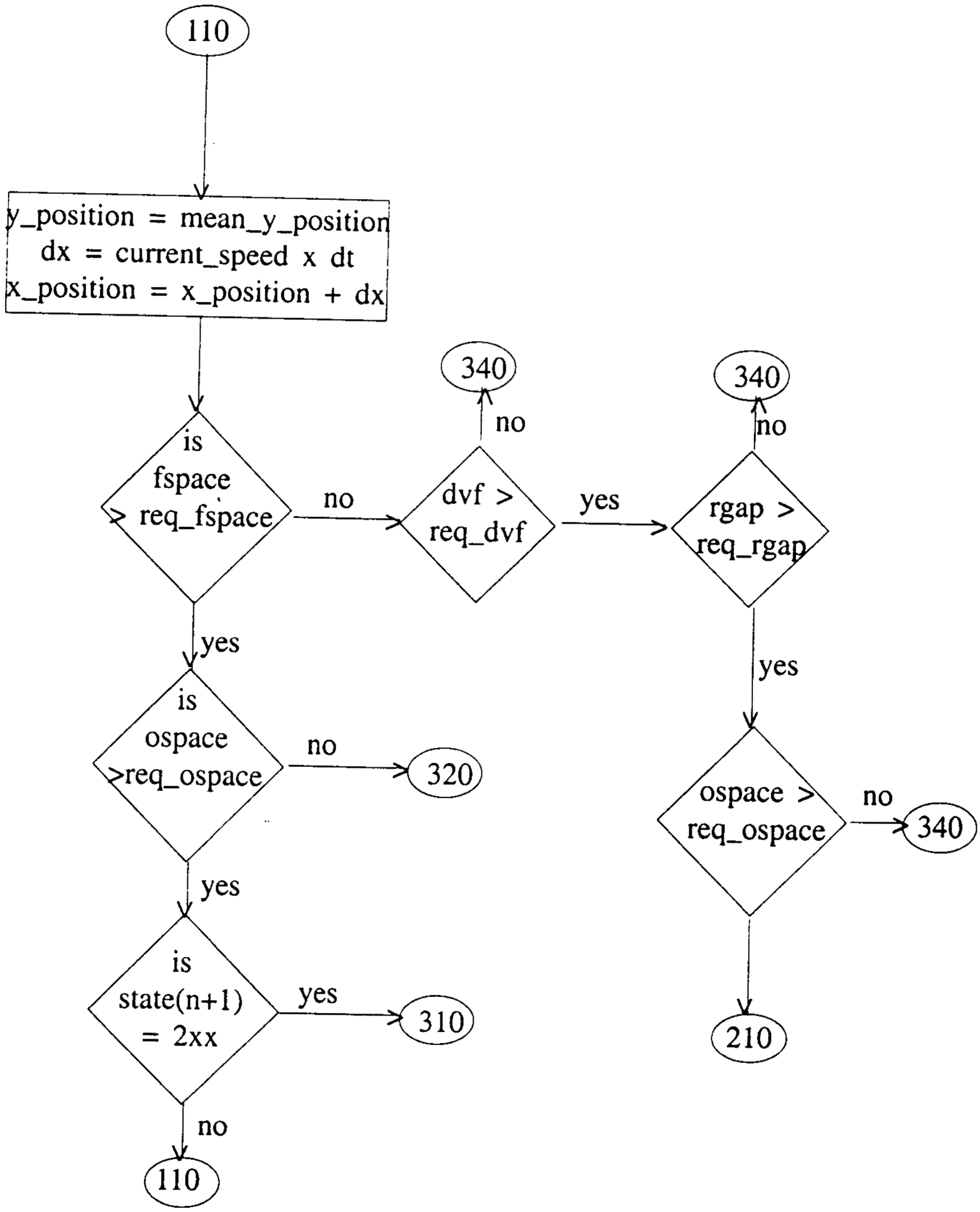


Fig 6.15 Flow logic for state 110

The flow logic for the state 110 (Fig 6.15) will be executed as follows:

Normally, an absolute free flowing vehicle (state = 110) will proceed with its desired speed (current_speed = desired_speed) and with the lateral placement through the default path (y_position = mean_y_position). Thus, its acceleration will be zero(dx=current_speedx dt).But, such a vehicle has to be constantly watched for its existence with state = 110. In other words, if the traffic environment does not permit to flow as a free flowing vehicle, it has to be shifted to appropriate state number associated with its conditions.

Therefore, the first check will be the sufficiency for the front spacing to continue as a absolute free flowing vehicle (fspace > req_fspace). If this condition is not satisfied, the next check will be for obstruction due to nearest opposing vehicle(ospace > req_ospace), its failure will lead to state 320. If this condition satisfied, another possibility is being an overtaken vehicle, this is checked by whether the follower(n+1) is in an overtaking mode (first digit of state(n+1) = 2). If this condition is not satisfied, the vehicle can proceed with 110 itself (see bottom of the diagram).

If the first condition (fspace > req_fspace) is not satisfied, there are only two ways to proceed, either as a free passing vehicle or forced to follow the leader vehicle. This is explained by the right side part of the flow diagram(see Fig 6.15). There are three conditions to start a free passing operation: i) the speed difference should be enough to execute free passing(dvf > req_dvf), ii)right clearance should be enough(rgap>req_rgap) and iii)enough distance from the nearest opposing vehicle(ospace>req_ospace). If all the three conditions are satisfied the vehicle can start with a free passing(state=210), else it has shift to forced to follow the leader mode(state=340). All these are covered in the flow diagram(Fig 6.15).

Thus the first figure in the optimum checking diagrams(Fig 6.13-a) and the flow diagram are matching with each other.

Similarly, all other flow diagrams are developed according to certain flow logics and important flow diagrams are presented in Figs 6.16 to 6.24.

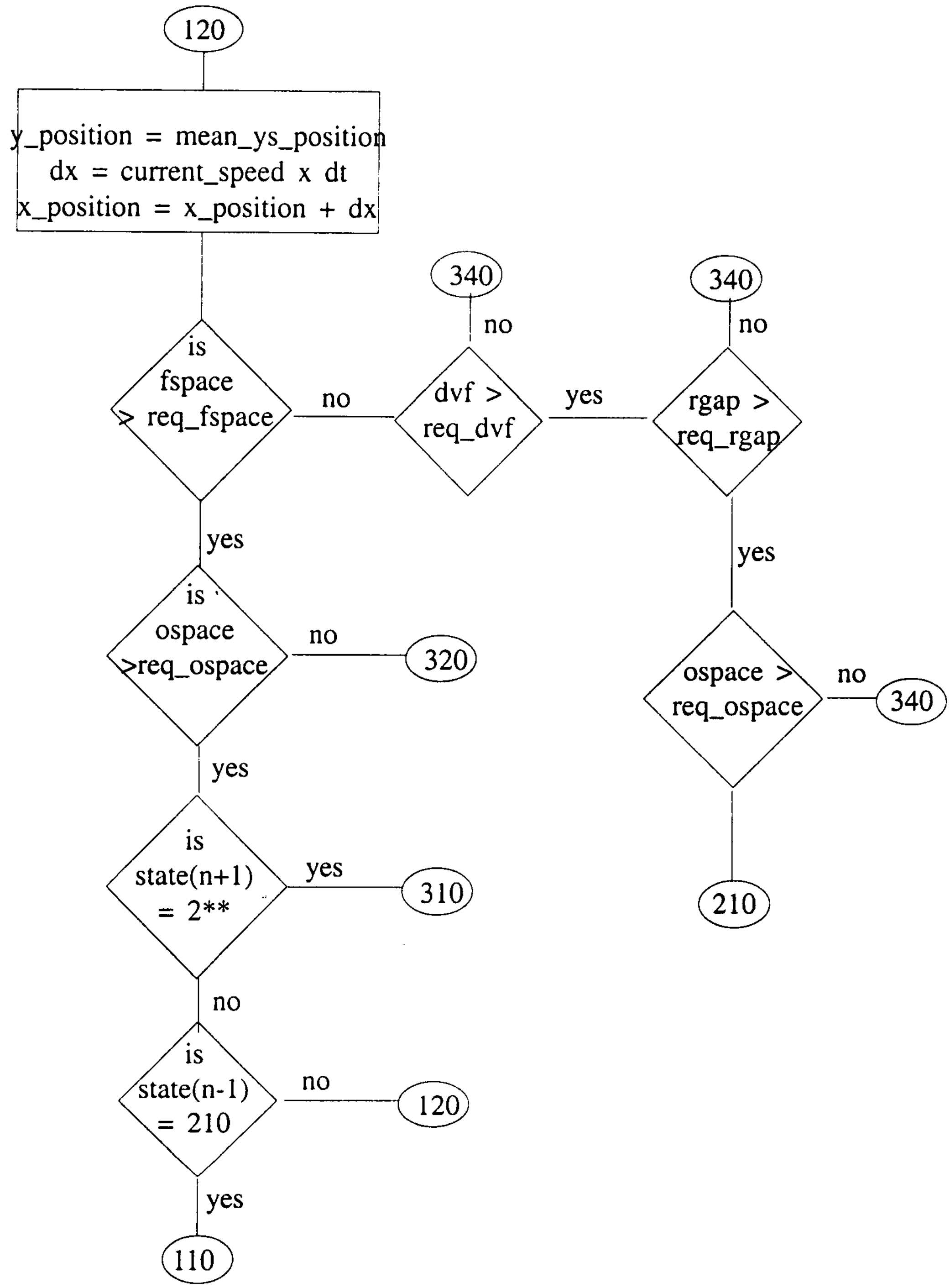
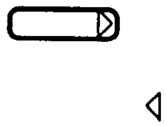


Fig 6.16 Flow logic for state 120



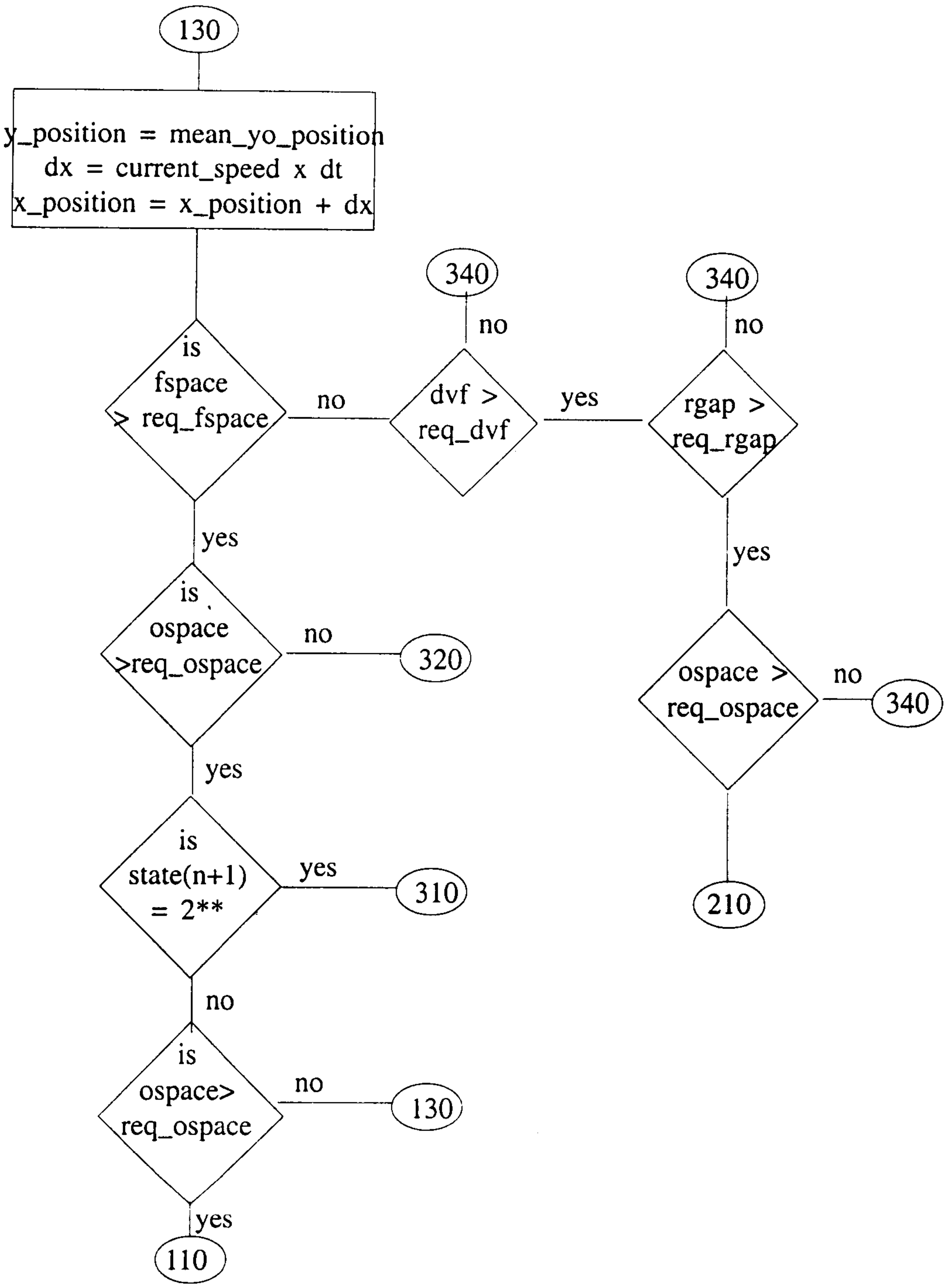


Fig 6.17 Flow logic for state 130

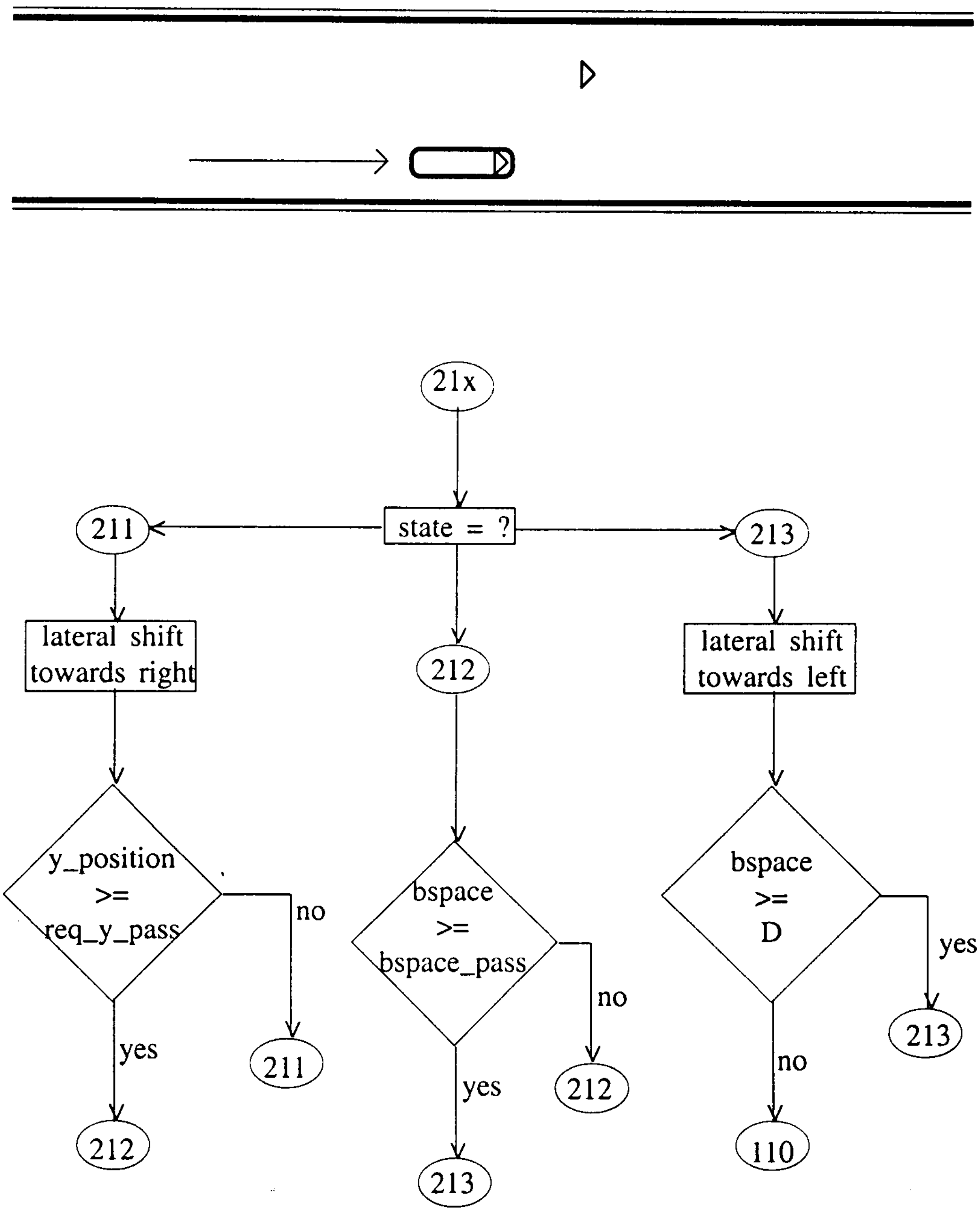


Fig 6.18 Flow logic for state 210

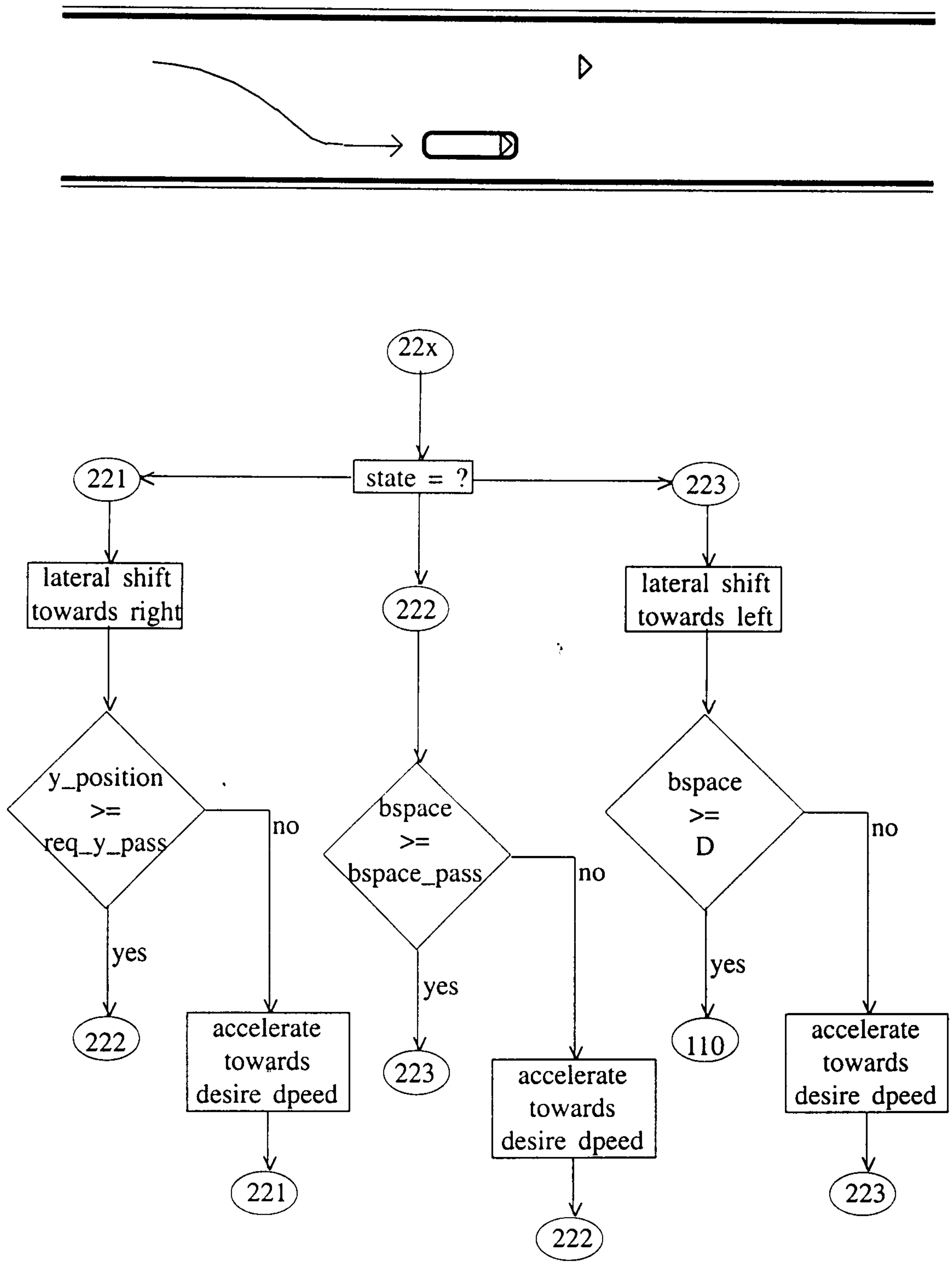


Fig 6.19 Flow logic for state 220

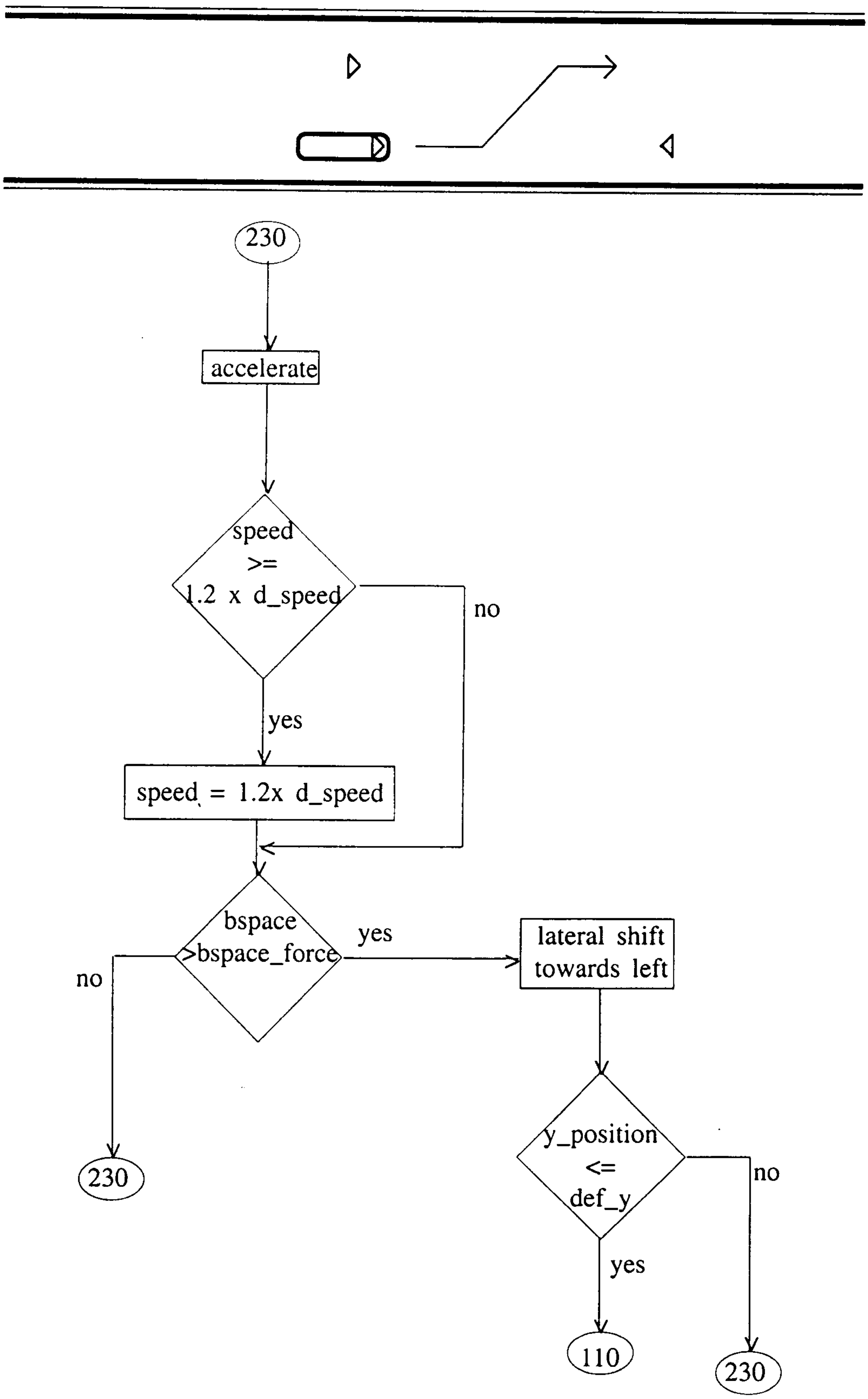


Fig 6.20 Flow logic for state 230

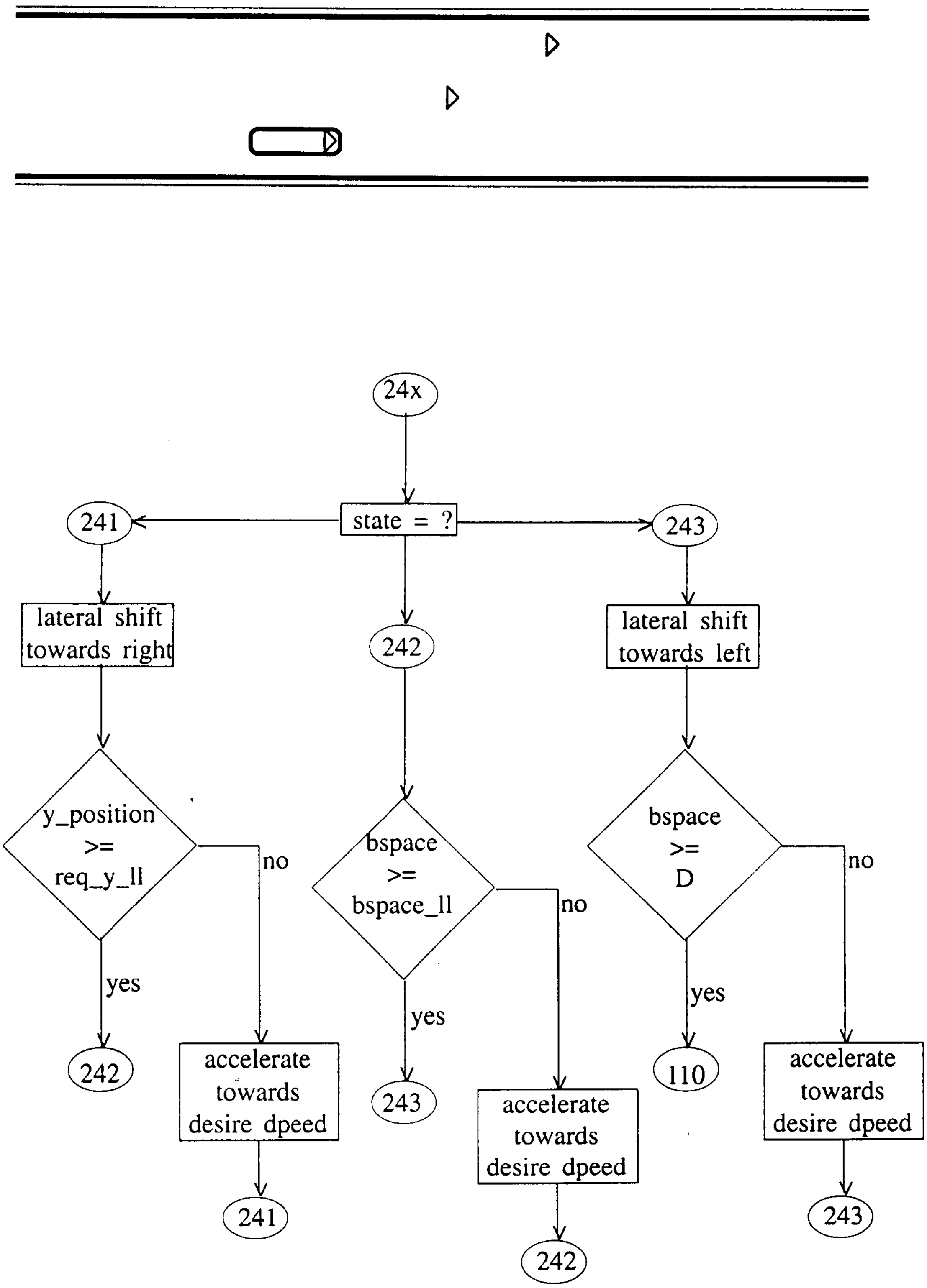


Fig 6.21 Flow logic for state 240

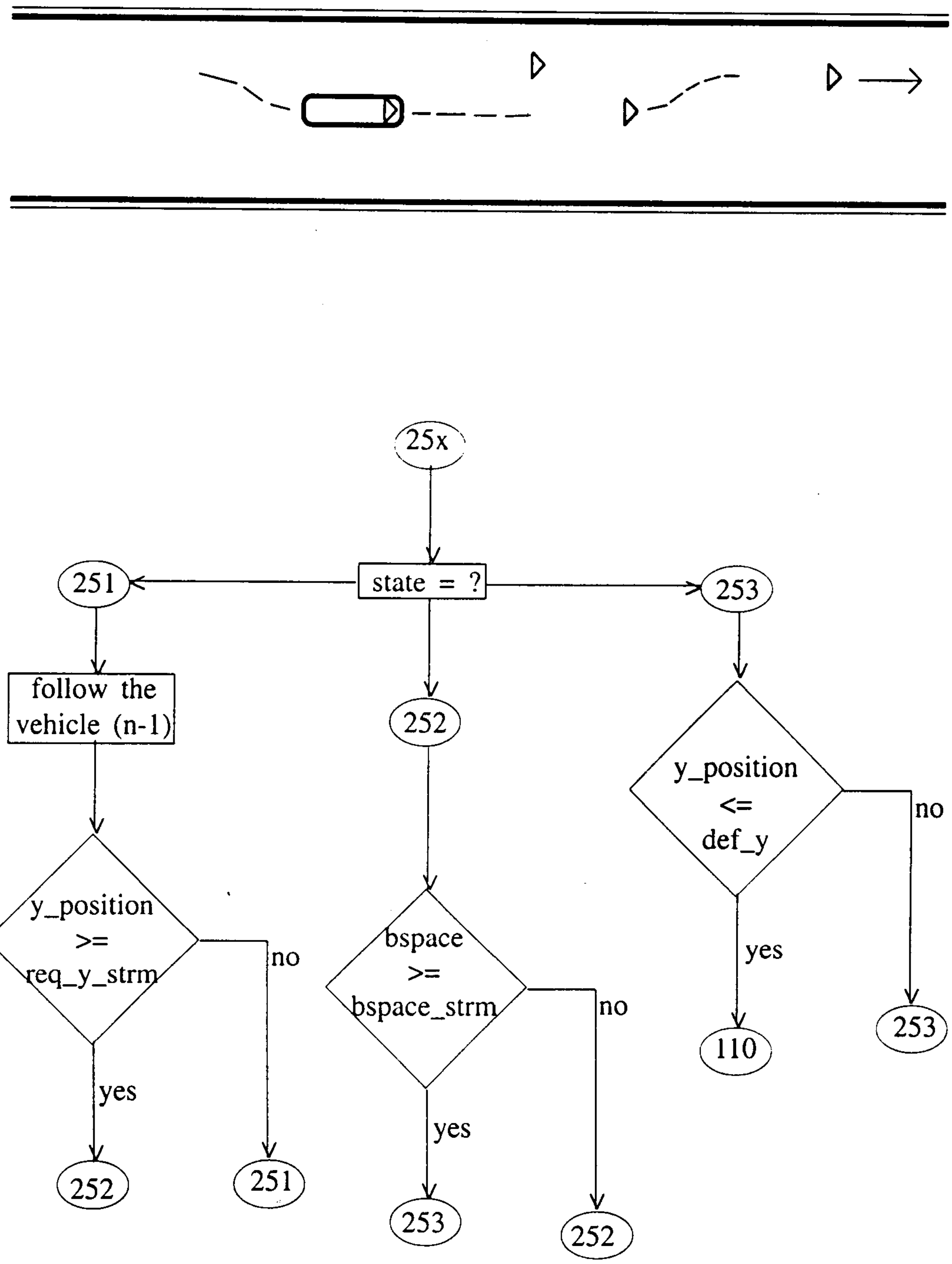


Fig 6.22 Flow logic for state 250

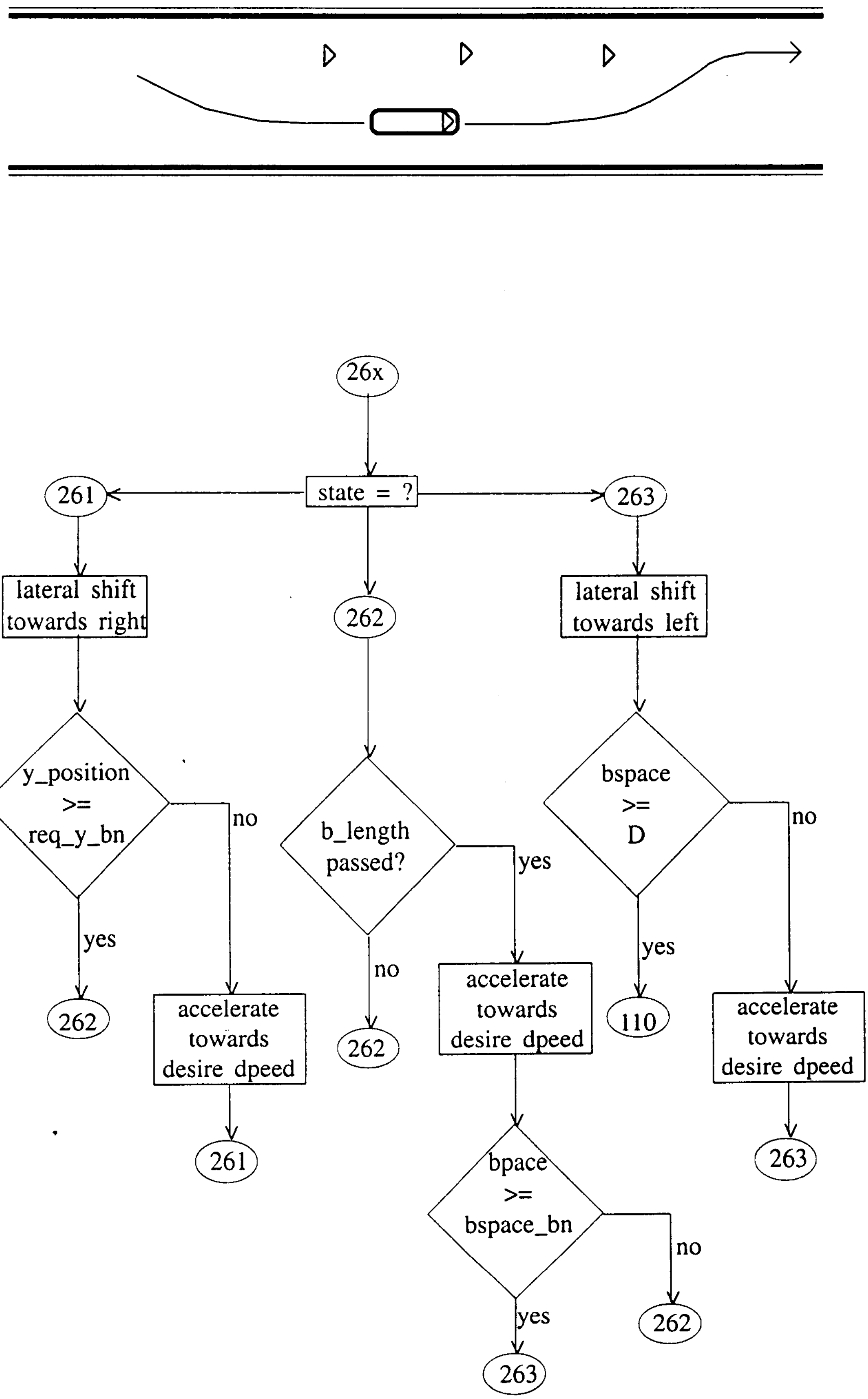


Fig 6.23 Flow logic for state 260

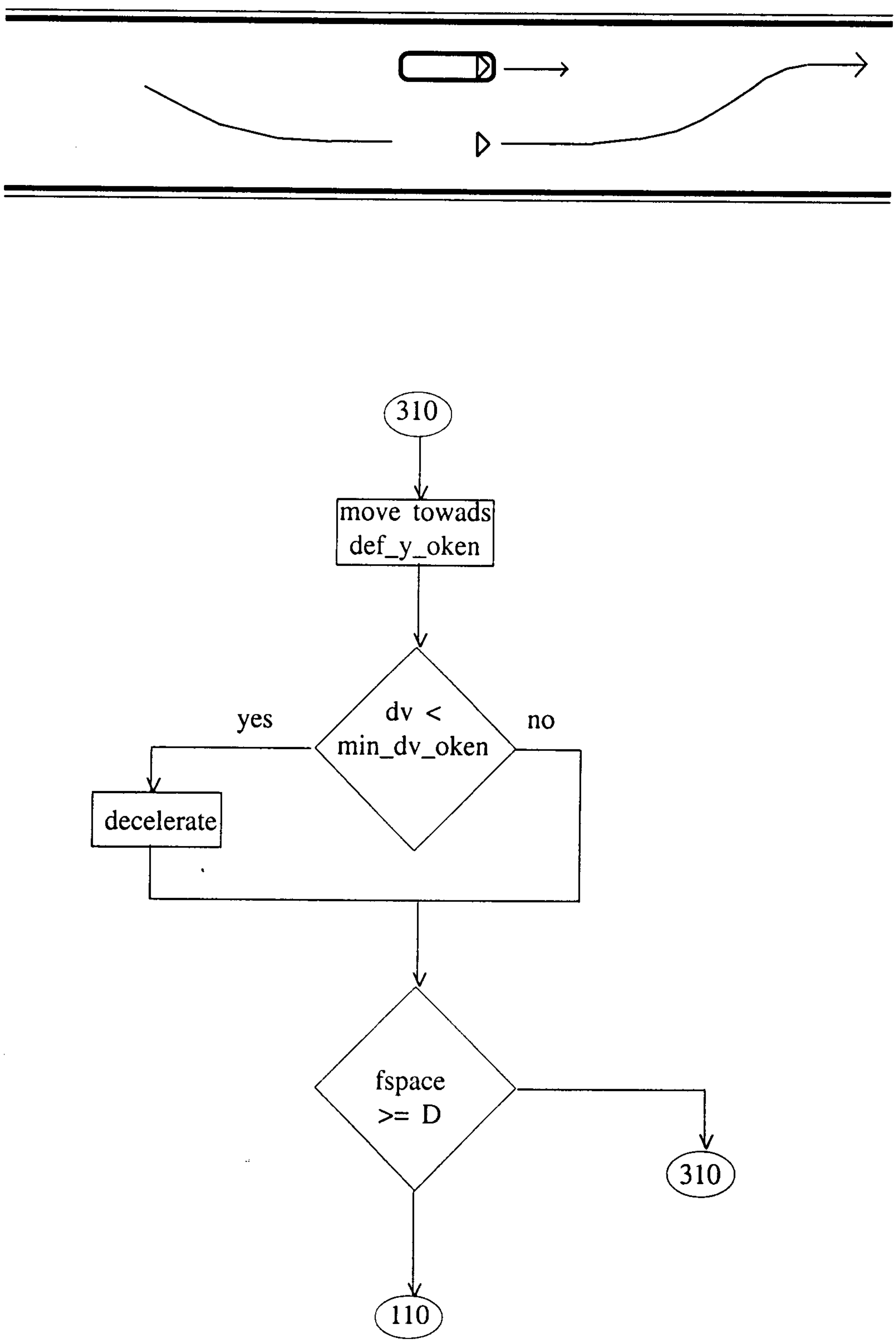


Fig 6.24 Flow logic for state 310

6.6 TIMER FUNCTION

One of the disadvantage of digital simulation is the inability of the computer to process the data simultaneously, i.e, the computer will process the data one by one, serially. But in real systems, especially as in traffic flow, all the elements (vehicles) are active participating members of the system which will simultaneously observe the environment (road and other vehicles) and will update their position.

But today, with the advent of modern computers with parallel processing architecture and softwares with multi tasking capability, this can be taken care of to some extent. The computer program is developed in the Visual Basic under Microsoft's Windows platform. The TIMER function of the Visual Basic has been effectively used to generate a parallel processing system.

A TIMER function has container functions and its time interval. The container functions will be executed at every time interval. Thus the timer interval is the simulation time interval or scanning update time. Here, each vehicle is associated with a TIMER function, i.e, all the vehicles will work independently. Or in other words, all the checking mechanisms and all the updating mechanisms presented in Fig 6.4 will be executed together. This is more true compared with real traffic systems.

6.7 VISUAL MONITORING SYSTEM

A visual monitoring system has been incorporated in the top portion of the simulation package as described in Appendix - 6.1 (portion H), to view the movements of vehicles on the selected area of the study stretch. The vehicle for both directions are separated by a dashed line and two controls (zoom and pan) are incorporated to select the desired area of the study stretch to monitor the movements of vehicles. Arial photographs of vehicles were taken and scanned to use in the program as presented in Fig 6.25. This monitoring system has been observed to be very useful in the development of the simulation program in checking the working of many sub functions at the time of its implementation.

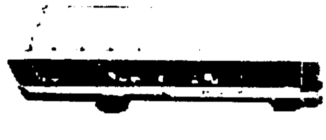
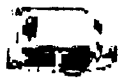
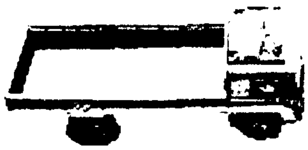
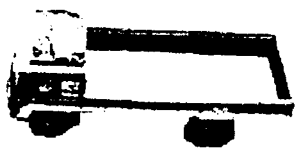
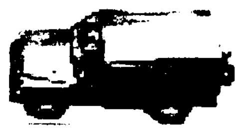
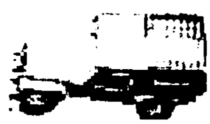
No.	Vehicle	Direction 0	Direction 1
1.	Car		
2.	Bus		
3.	Auto		
4.	Truck		
5.	Two wheeler		
6.	Mini. Bus		
7.	Mini. Truck		
8.	Jeep		

Fig 6.25 Images used for different vehicle classes in two directions.

6.8 SIMULATION TEST PROCEDURE

The sequential steps to be followed in running a simulation test is as listed below:

Step1.

Run the program *atraffic.exe* and click on "Road properties" to enter the length and width of the road. Click on "Simulation time" and enter the simulation test time.

Step2.

Enter the composition of vehicles in two directions using "Composition" button and enter expected flow using "Inflow" button.

Step 3.

By clicking on "START" button, the simulation clock will start processing. At the time of processing, the "Pan", "Zoom" and "Time interval" tools can be used, if necessary. The mode of run also can be suitably selected to save time.

Step 4.

At the end of simulation test, a message "Simulation successfully completed" will be displayed. The output files can be viewed by clicking on the output control button.

6.9 VALIDATION

The validation of the sub models was described in Chapter 5. However, entire simulation model has to be validated before running any experiments with it. Data were collected at two different location for validation purpose. The stretch lengths were 1km each and four persons were employed at A, B, C and D as shown in Fig 6.26. The results of data collected and simulated are summarised in Tables 6.4 and 6.5 for location 1 and 2 respectively. It is clear from these tables that, the simulated and the actual values were close in most of the cases.

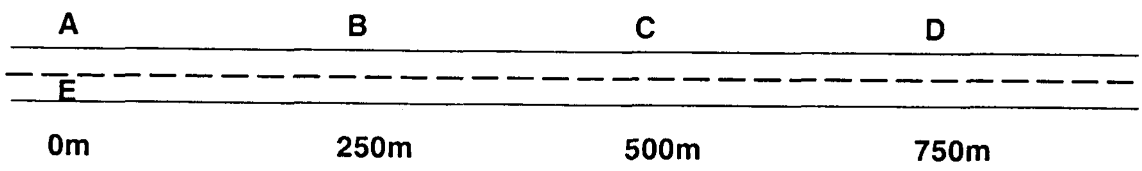


Fig 6.26 Validation stretch.

Table 6.4 Validation results for location 1

Location 1 % of vehicles = 22,14,16,7,10,5,9 &17*		
(opposite side almost same nature)		
	Observed	Simulated
(a) Flow	722	705 Veh./h.
(b) No. of overtakings	8	7 Overtaking/km/m.

Table 6.5 Validation results for location 2

Location 2 % of vehicles, in direction 0 = 23,12,7,9,12,7,13 and 16* % of vehicles, in direction 1 = 27,11,7,12,10,5,16 and 12*		
	Observed	Simulated
(a)Flowin lane 0	480	483 Veh./h.
(a)Flowin lane 1	330	312 Veh./h.
(b)Overtakings(0)	11	10 Overtakings./km/m.
(b)Overtakings(1)	14	17 Overtakings./km/m.

* Car, Bus, Auto, Truck, T/W, Minibus Minitruck and Jeep

The number of different types of overtakings were counted from the field for a particular stream using videography method. The same percentages of vehicles were applied to the simulation model and the number of overtakings were counted from the model for different types. These values are presented in Table 6.6. The simulated values are found very close to the observed values.

The PCU values are calculated with respect to the capacity levels for different classes of vehicles. The comparison with the values developed by IRC and other researchers are presented in Table 6.7

The results of validation experiments conducted for sub models (chapter 5) and for the entire simulation models described above indicate a good correlation of the simulated and observed values. Hence the model was expected to be good enough to conduct simulation experiments in the flow of two way mixed traffic at highway mid blocks.

6.10 SUMMARY AND CONCLUSION

The major conclusions arising from the development of the microsimulation package are:

1) Irrespective of initial headway distribution in the start of the warm up zone, the headways stabilise to the exponential model after covering approximately 400m to 500m. Hence, if the headway distributions are observed after a warm up zone limit of say 1km, it will be safe to assume that the headway distribution will be independant of the initially assumed distribution and traffic movement will stabilise itself into a rhythm of its own as dictated by the composition of the vehicles. The headways in this rhythmic state would be almost always be exponential in nature.

Table 6.6. Percentage of different types of overtaking operation.

No.	Type of overtaking operation	Observed	Simulated
1.	Free Passing	30 %	26 %
2.	Normal Overtaking	42 %	48 %
3.	Forced Overtaking	15 %	18 %
4.	Parallel Overtaking	7 %	5 %
5.	Stream Lined Overtaking.	6 %	3 %

Table 6.7 Comparison of PCU values.

No:	Type of vehicle	IRC	JUSTO	NAGARAJ	By the model
1.	Car	1.00	1.00	1.00	1.00
2.	Bus	3.60	2.20	1.69	1.55
3.	Autorickshaw	0.60	0.50	0.72	0.61
4.	Truck	2.80	2.20	-	1.87
5.	Two wheeler	0.25	0.45	0.58	0.25
6.	Mini Bus	-	-	-	1.14
7.	Mini Truck	-	-	-	1.11
8.	Jeep	-	-	-	0.98

2) It is possible to reduce the simulation time by adopting the STATE NUMBER approach as advanced in this study. By this approach, it is possible to reduce the number of checking operations to cut out highly impossible final state conditions of vehicle manoeuvres, there by reducing the simulation time.

3) It is possible to reduce the clock time of simulation runs by making use of the Timer Function of the Visual Basic, which can be used to generate a parallel processing system. Each vehicle is associated with a timer function and thus is capable of being processed independently, unlike, vehicle - by - vehicle processing in an ordinary Digital Simulation. The parallel processing architecture of the modern computers is made use for this purpose.

4) The simulation package AutoTRAFFIC is capable of simulating the behaviour of mixed traffic flow admirably well as evidanced by the 'Figures of Merit', viz., the observed and simulated flow of vehicles, the observed and the simulated number of overtakings/km/m, and the passenger car units of vehicles as computed by the model and compared with the values observed by other researchers.

While, this chapter has described the successful development of simulation package for replication of mixed traffic flow manoeuvres, the objective of the next chapter is to present the results of some of the real time experiments conducted using the developed pakcage.

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FEATURES OF THE SIMULATION PACKAGE "AutoTRAFFIC"

The developed package AutoTRAFFIC has many user friendly tools for inputting data, monitoring the simulation process and to get results of simulation experiments. The main display is as shown in the Fig 6.1.1 with all its tools and its short descriptions are presented below.

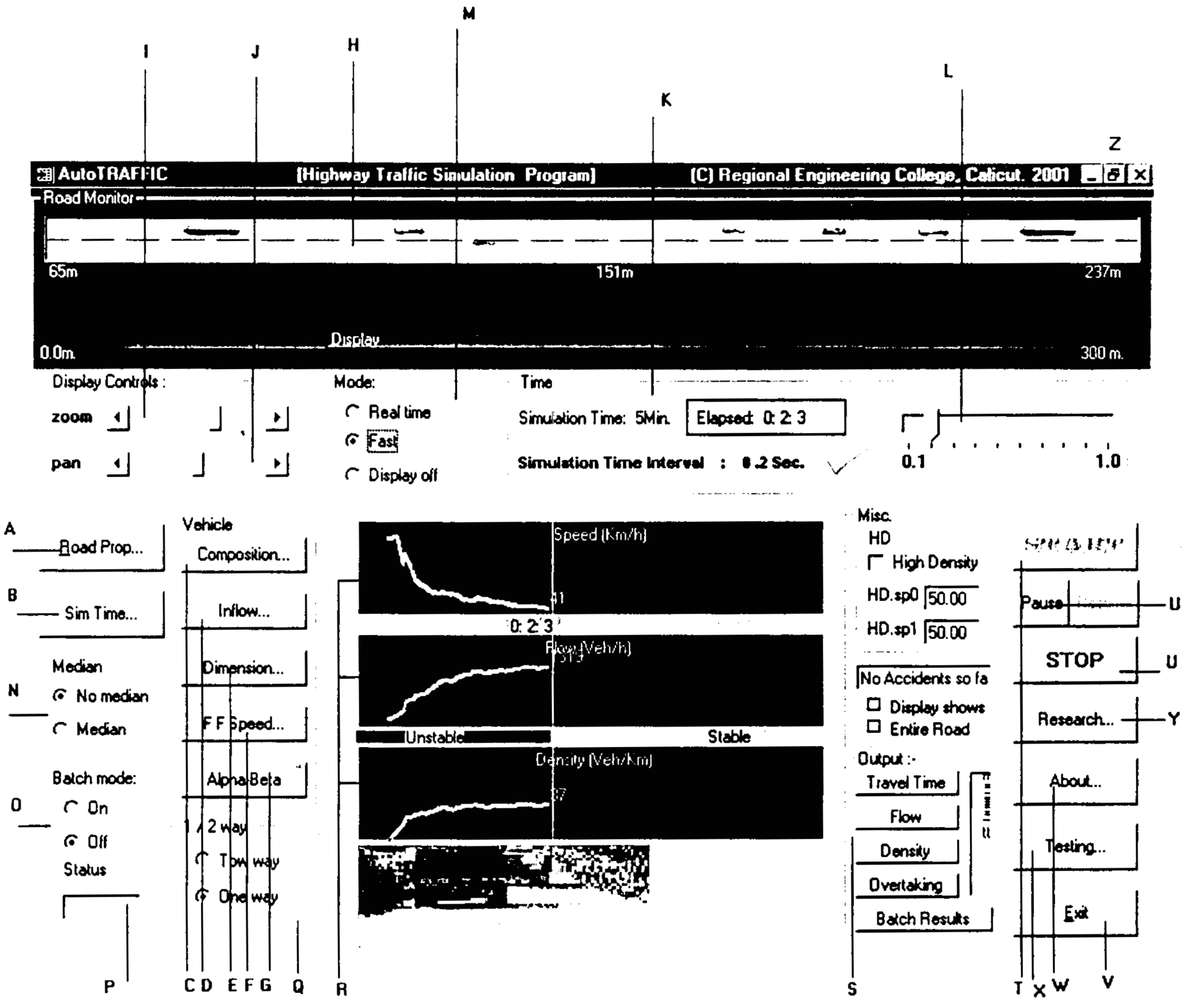

Fig 6.1.1 AutoTRAFFIC program display properties

Ref. Fig B-1 — *Name and description*

A - *Road Properties* :-

The width and the length of road can be entered through this option. The default value will be read from the file and will be displayed.One can temporarily store by click on "OK" or the value can be set to default by a single click on "Set to default" button. The values are to be entered in metres.

B - *Simulation Time* :-

This is simulation experimentation time in minutes.

C - *Composition* :-

A dialogue box will be displayed to enter the vehicle compositions in percentages for both the directions as shown in the Fig 6.1.2. The default values will be displayed from the file. The values can be set to default by clicking on "Set to default" button.

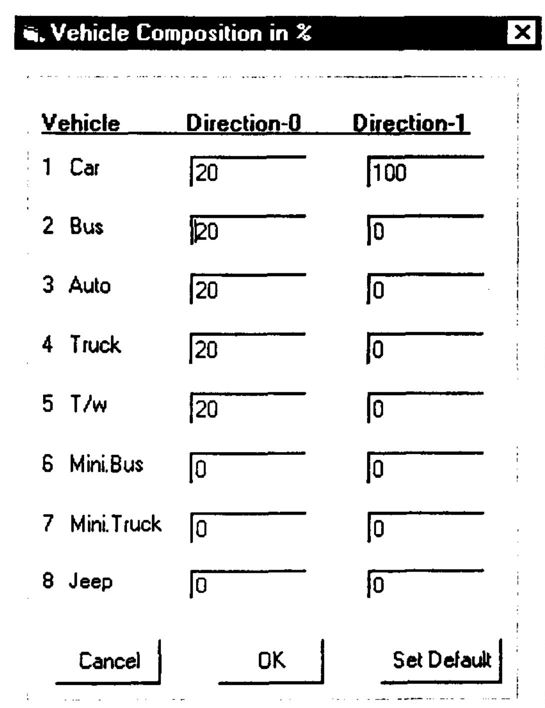

Fig 6.1.2. Vehicle composition dialogue

D - *Inflow* :-

A dialogue box will be displayed with the default values of flow of vehicle in both the directions as shown in the Fig 6.1.3.The value can be changed and used for one experiment by clicking on "OK" button or it can be set permanently by clicking on "Set Default" button. The values are in vehicles/hour.

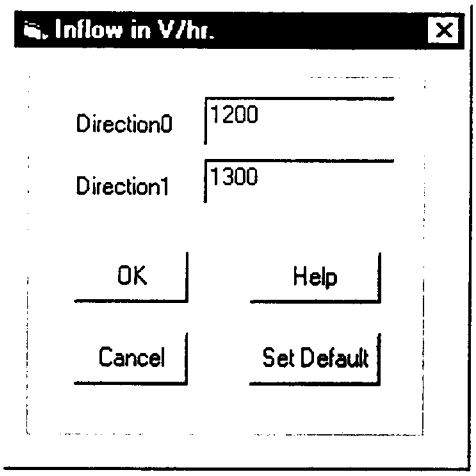

Fig 6.1.3 Inflow dialogue box

E - *Dimensions* :-

To display the dimensions of different types of vehicles in metres as shown in the Fig 6.1.4.

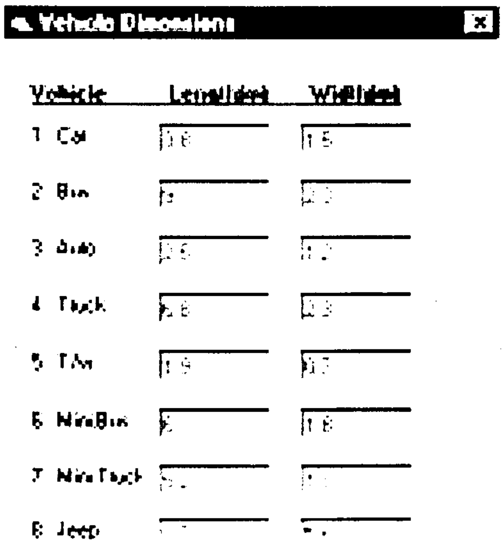

Fig 6.1.4 Dimensions of vehicles

F - *Free Flow Speeds* :-

To display mean free flow speeds and standard deviations of different classes of vehicles as shown in the Fig 6.1.5.

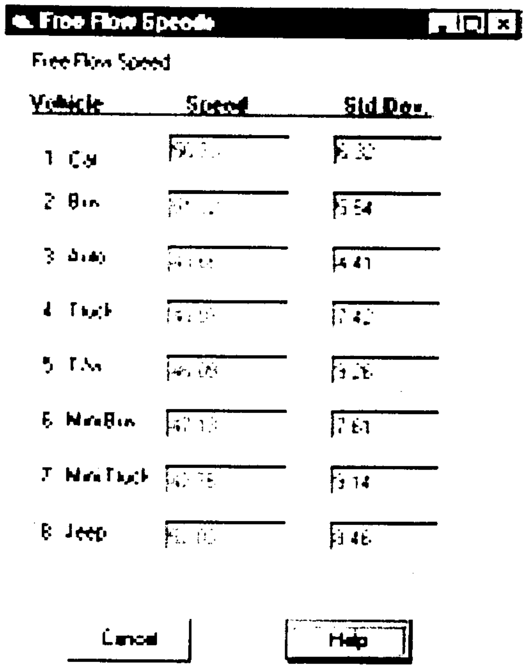

Fig 6.1.5 Free flow speeds of vehicles

G - *Constants* :-

To display some constants used in the program as shown in the Fig 6.6.1

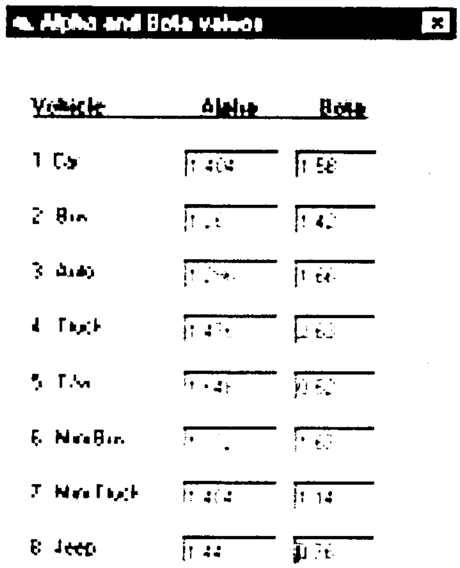

Fig 6.1.6. Constants dialogue box

H - *Monitor* :-

This is to monitor the movements of vehicles on the test stretch of roadway as shown in the Fig 6.1.7.

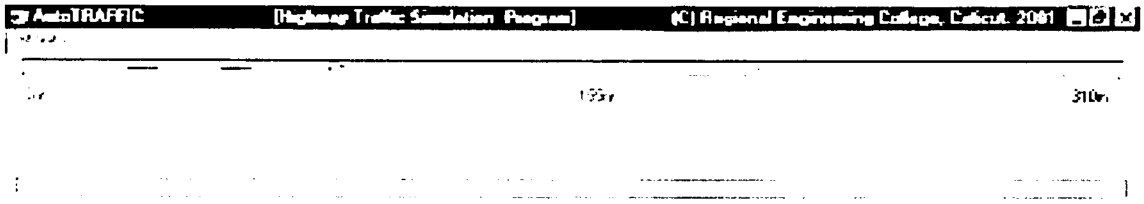

Fig 6.1.7. Real time vehicle monitor.

I - *Zoom* :-

This to increase or to decrease the length of road to be displayed on the monitor. If the slider is at left most point, then the length of the display will be the length of the road or 1000metres whichever is lesser. As the slider moves to the right the length of the road on the monitor will decreases as shown in Fig 6.1.8 and at the right most point, the minimum road length 100metres will be displayed which is the maximum zoom provided as shown in Fig 6.1.9.

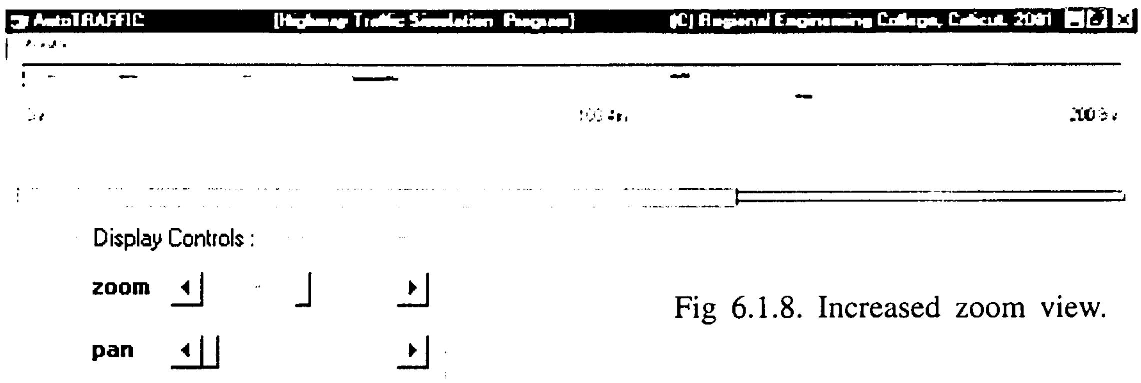

Fig 6.1.8. Increased zoom view.

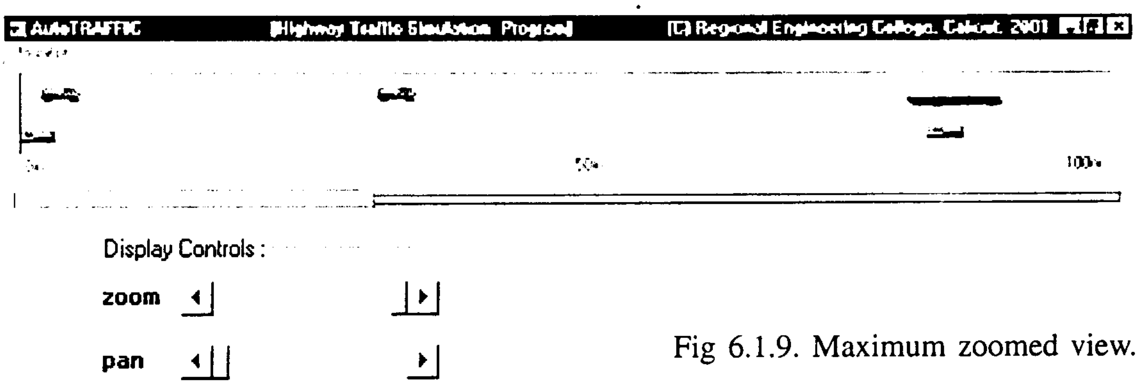

Fig 6.1.9. Maximum zoomed view.

J - <u>*Pan*</u> :-

This is to slide the zoom area along the length of the road. If this indicator is at the left most, then the display is on the left most of the study road. As the indicator moves to the right side, the view window will move towards that part and at the right most point, the display window will be at the right end of the study stretch. Fig 6.1.10 shows the middle portion of the simulation stretch.

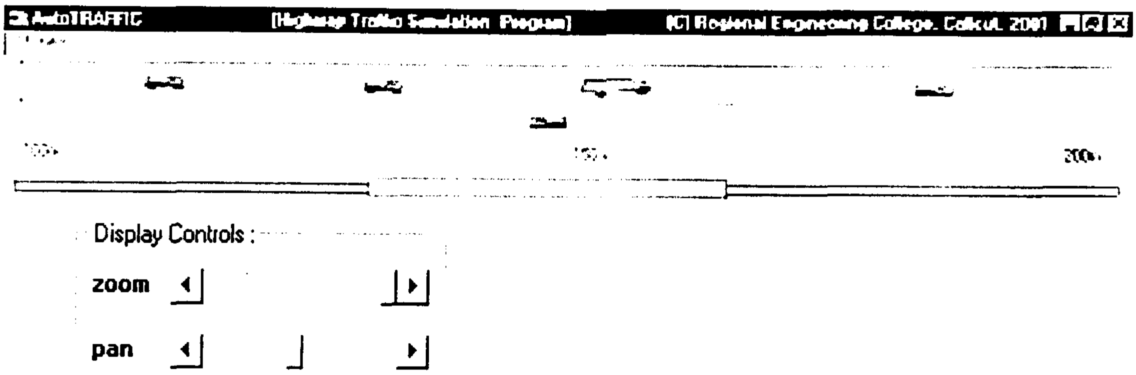

Fig 6.1.10. Right end view of the simulation road.

K - <u>*Time elapsed*</u> :-

This is just to indicate how much time has elapsed in the current simulation task so as to estimate an approximate time of completion.

L - <u>*Simulation Time Interval*</u> :-

This sliding bar will specify the simulation update time interval in seconds. The minimum value is 0.1 sec and a maximum value 1.0 sec. The simulation time interval can be changed in increment of 0.1 sec, even at the time of simulation.

M - <u>*Mode*</u> :-

There are three modes of run, a) Real time, b) Fast and c) Display off. This will not have any effect on the simulation logic or simulation results, instead it is a method to save time. If the program is in the real time mode, then the computer will process the data at every simulation time interval specified and thus it will take the exact real time of simulation experiment. For example, if a simulation test is for 60minutes, the computer will take 60minutes to complete the simulation, thus the monitor will display the real time movement of vehicles. Whereas in the Fast mode, irrespective of the simulation time interval, the computer will update data continuously, without waiting for the next time interval. Thus the program will be completed, as early as possible, depending on the computer speed. For example a 60minute actual simulation run may take only one or two minutes. In the Display off mode, the monitor will not be available, in addition to the Fast mode advantage. It is observed to result in saving of more time compared to Fast mode. So, Display off mode is the fastest mode of simulation among the three.

N - *Median* :-

This is to identify, whether a median is present or not.

The default is "no median"

O - *Batch Run* :-

To conduct a series of experiments with different inputs, this method can be used. This will avoid, separate input data at the end of each simulation run and thus it will save time. The default is batch run "off".

P - *Batch Run Status* :-

It is to observe the progress of the current task in a simulation run.

Q - *One Way / Two Way* :-

To set the traffic is one way or two way. The default is two way.

R - Real time graphs:- Real time graphs of Speed, Flow and Density.

S - *Output* :-

This is to see different types of simulation outputs like speed, flow, density, overtaking details etc.,. The out put will be loaded into "note pad".

T - *Start Simulation* :-

To start the current simulation process.

U - *Stop Simulation* :-

To stop the current simulation process. If the program is stopped using this method, then the output will not be obtained. Out put will be created only if the program automatically ends at the end of simulation time.

V - *Exit Simulation* :-

To exit simulation program.

W - *General Help* :- To display general help of the program.

X - *Test* :-

To test some special condition, or to watch a vehicle through the stream.

Y - *Research* :-

To display research findings in the simulation development.

Z - *Program tools*:-

Minimise, maximise and closing tools of the program.

CHAPTER - 7

REAL TIME EXPERIMENTS ON "AUTOTRAFFIC"

7.1 GENERAL

The development and the validation of the simulation mode "AutoTRAFFIC" is explained in the previous chapter. The computer simulation model developed was used for conducting many experiments for different applications. This chapter describes the results of simulation experiments conducted with the model "AutoTRAFFIC".

7.2 EXPERIMENTATIONS

The speed-flow, flow-density and speed-density plots were developed for different types of vehicles and they are presented in Figs. 7.1 to 7.8.

Table 7.1 shows the three composition of vehicles used for conducting simulation experiments. The first mix (mix-1) is generally observed on National Highways nearer to a town in which the proportion of Autos and Two wheelers are found to be more. Mix-2 is a typical mix of vehicles observed on a rural highway mid blocks. Mix-3 is a hypothetical mix of all vehicles in equal proportions. The standard speed-flow-density relations were plotted for all the three mixes and are presented in Figs 7.9 to 7.11.

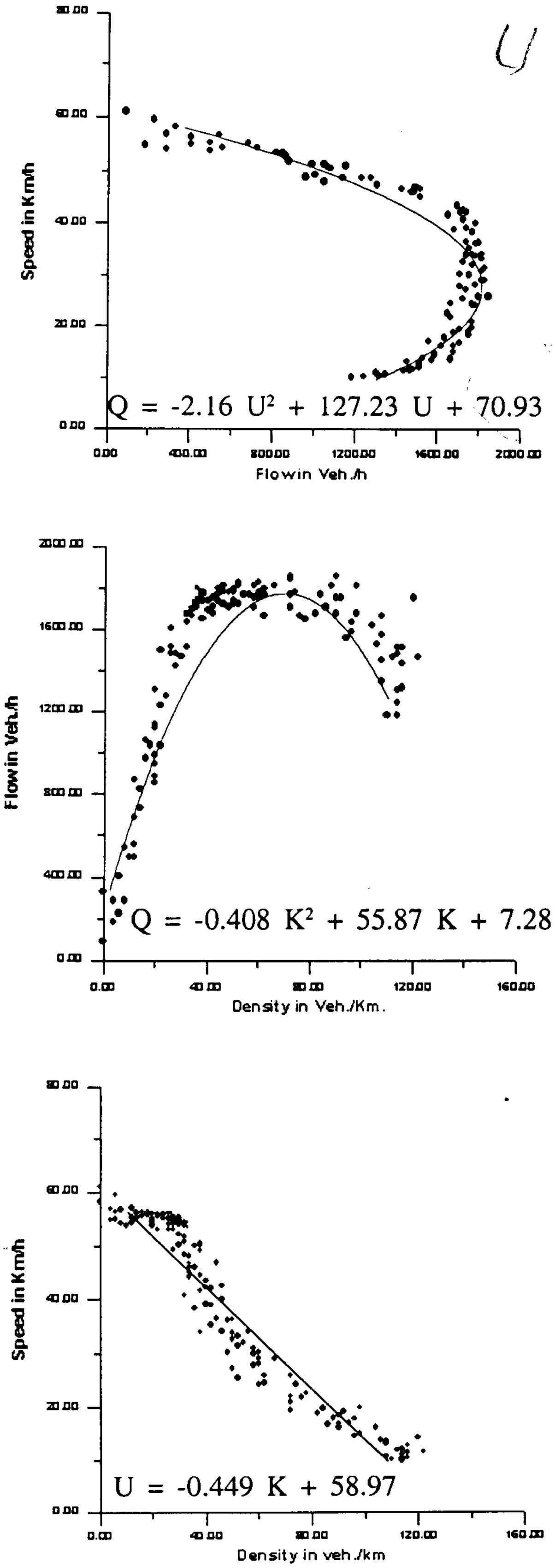

Fig 7.1 Speed-Flow-Density curves for Cars only stream.

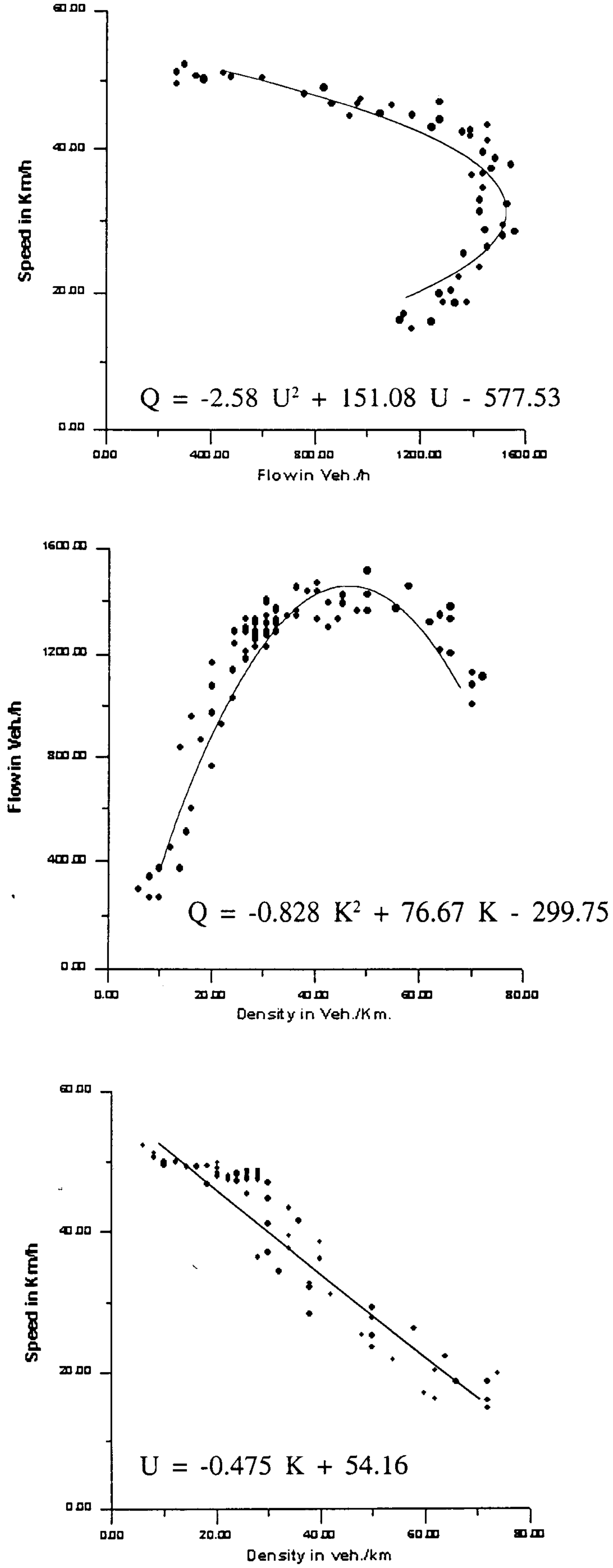

Fig 7.2 Speed-Flow-Density curves for Buses only stream.

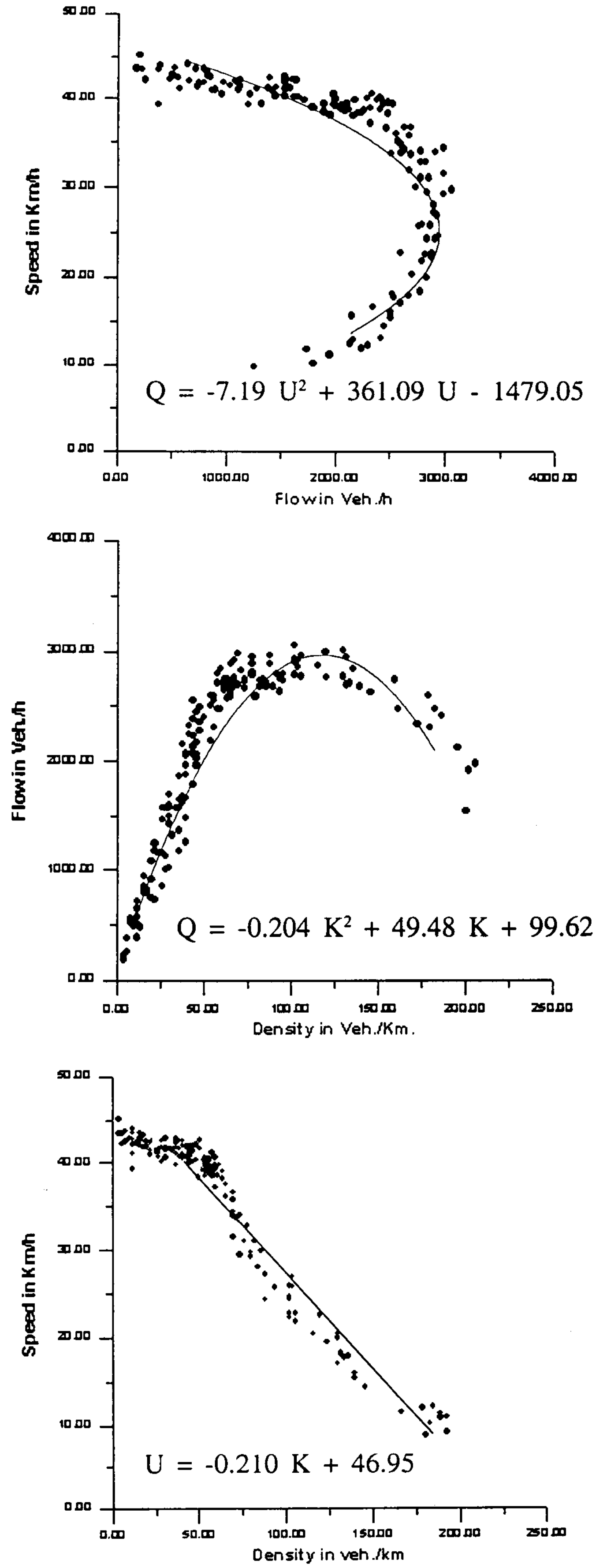

Fig 7.3 Speed-Flow-Density curves for Autos only stream.

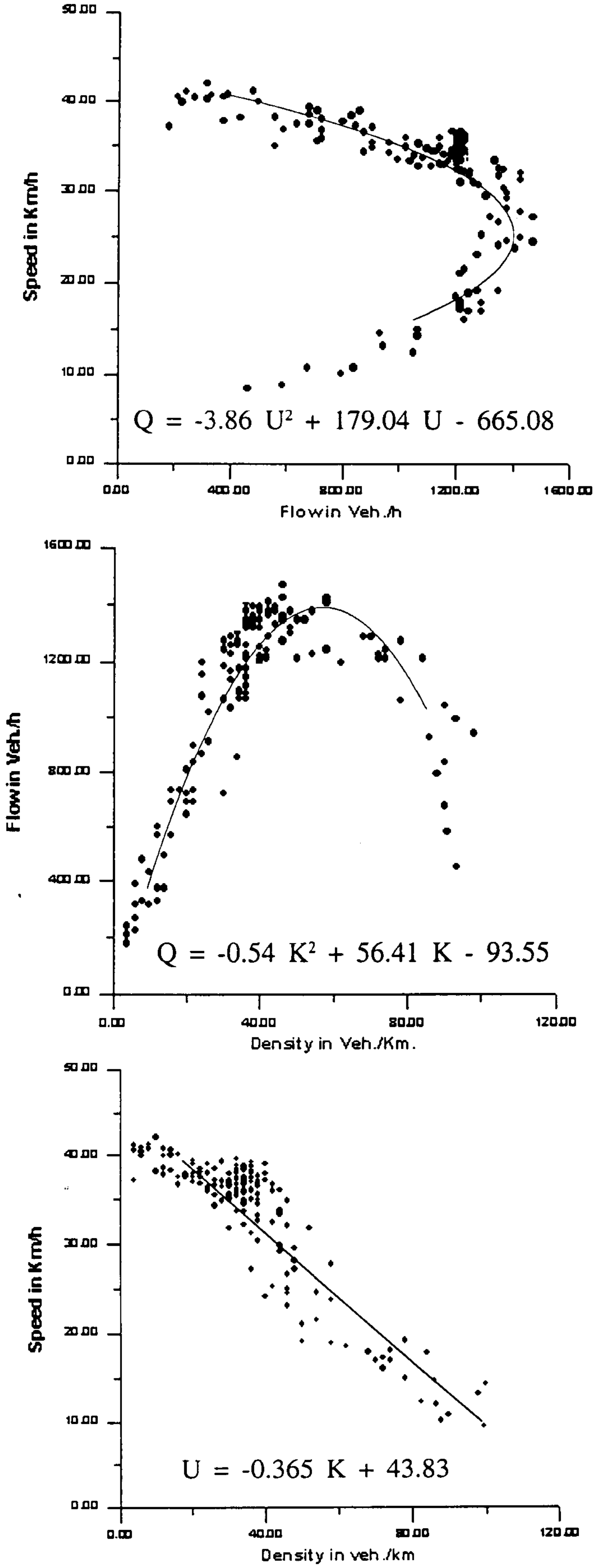

Fig 7.4 Speed-Flow-Density curves for Trucks only stream.

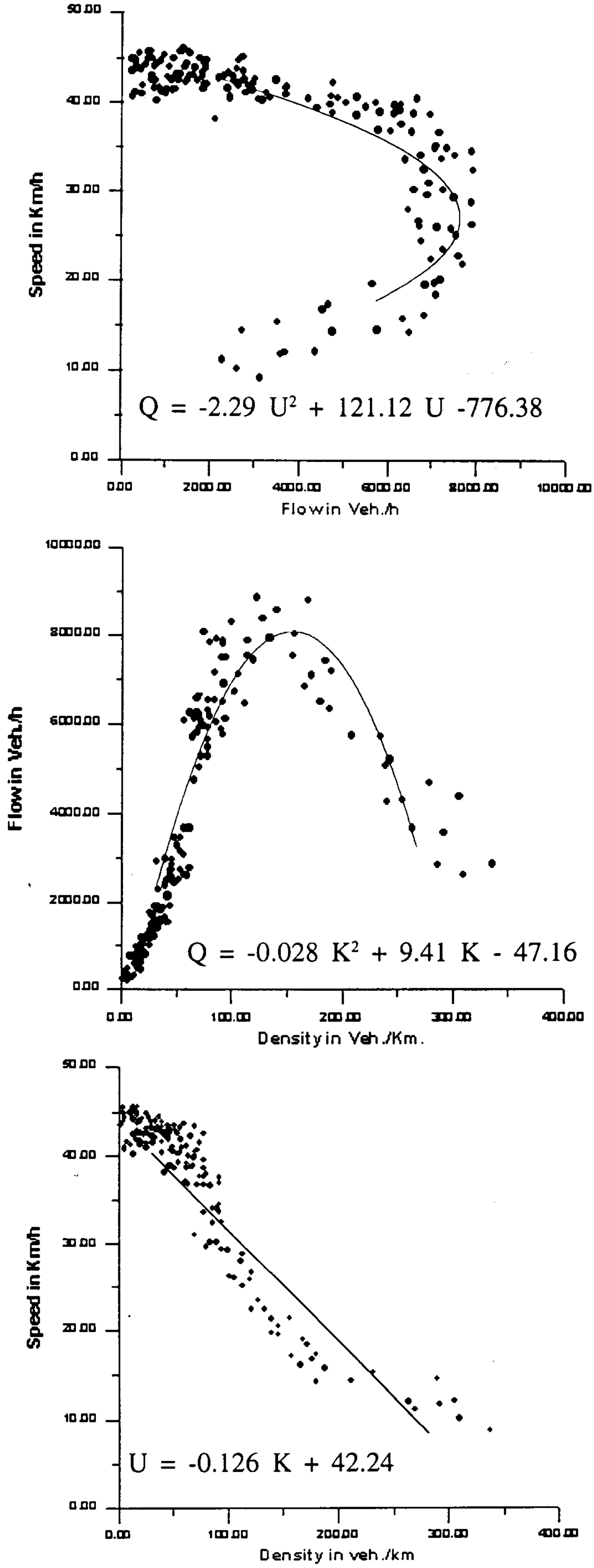

Fig 7.5 Speed-Flow-Density curves for Two Wheelers only stream.

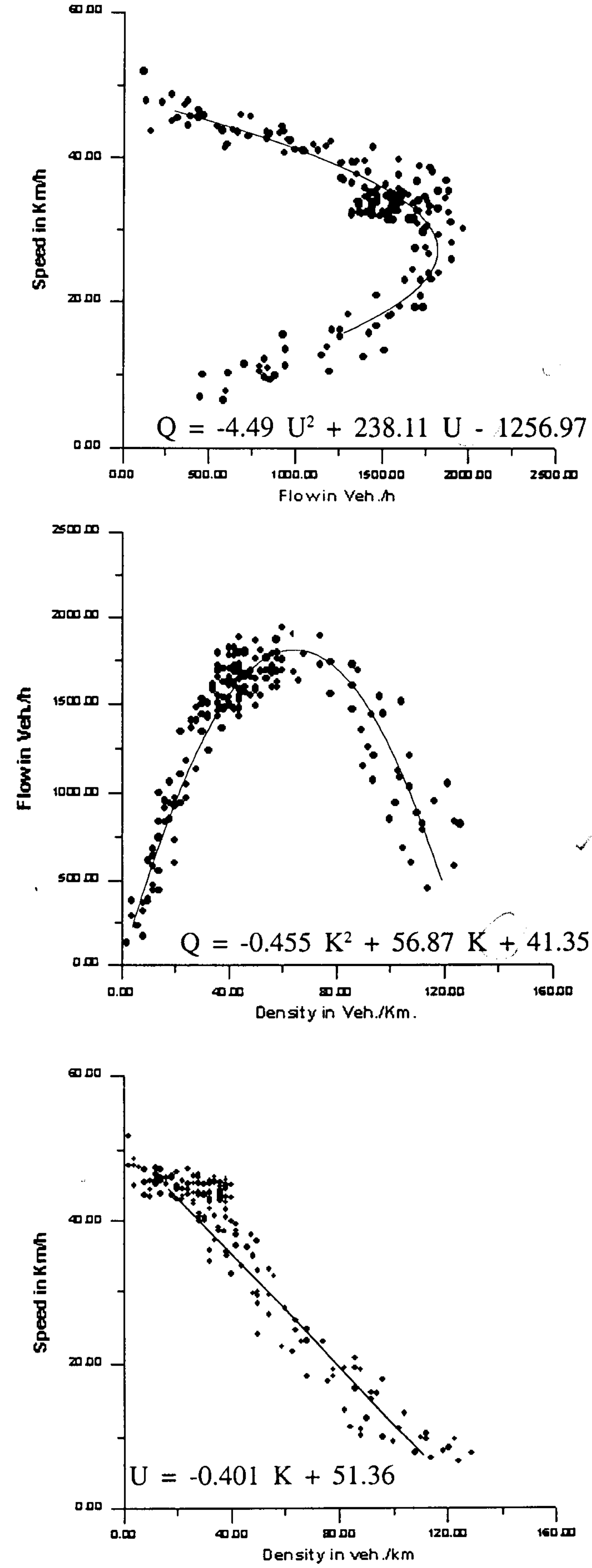

Fig 7.6 Speed-Flow-Density curves for Mini. Buses only stream.

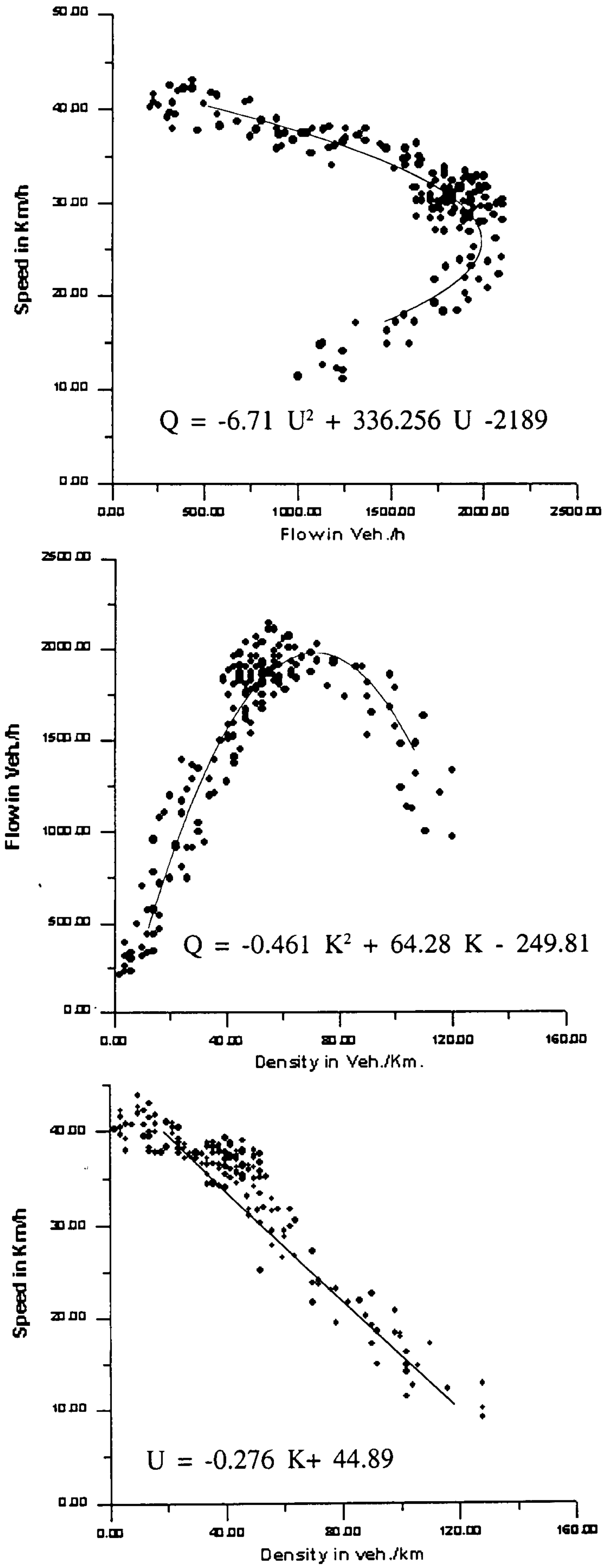

Fig 7.7 Speed-Flow-Density curves for Mini. Trucks only stream.

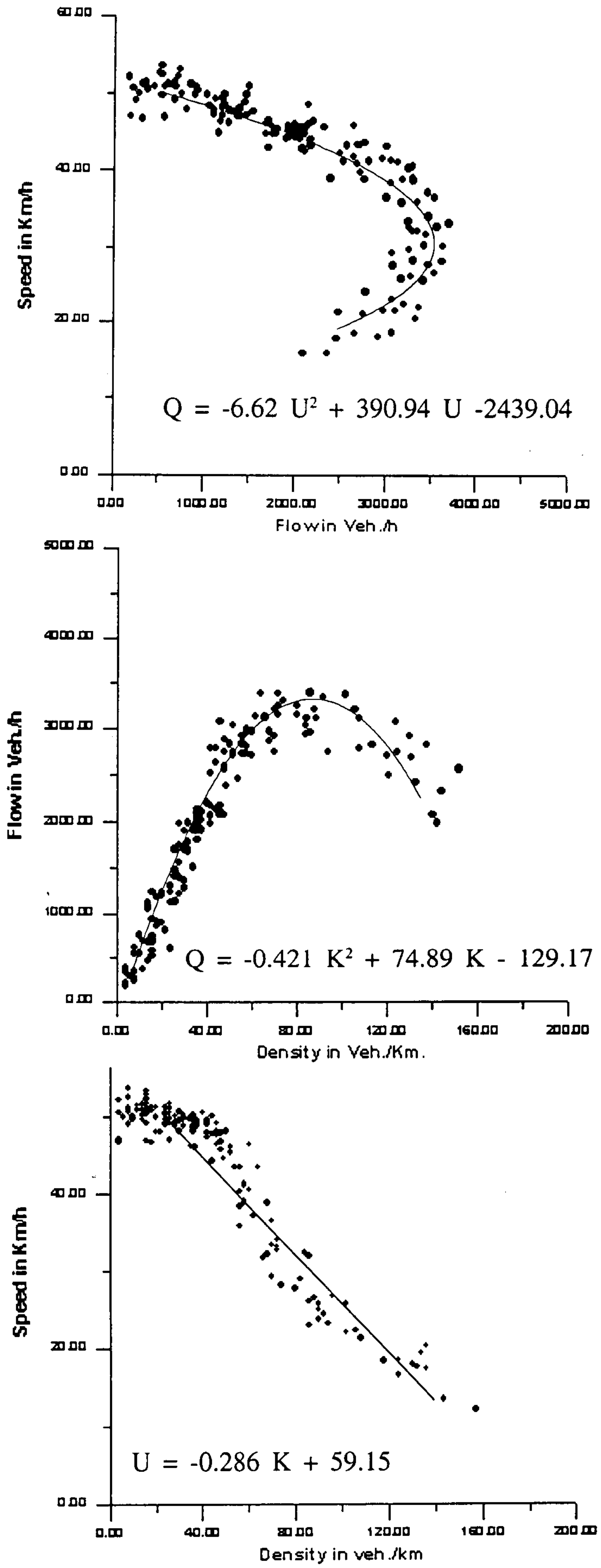

Fig 7.8 Speed-Flow-Density curves for Jeeps only stream.

Table 7.1 Percentages of vehicle mixes for experimentation.

	Vehicle Type	Mix-1	Mix-2	Mix-3
1.	Car	17	29	12.5
2.	Bus	14	17	12.5
3.	Auto	21	3	12.5
4.	Truck	7	11	12.5
5.	T/W	16	3	12.5
6.	Mini.Bus	5	7	12.5
7.	Mini.Truck	9	12	12.5
8.	Jeep	11	18	12.5

7.3 EXPERIMENT WITH VARYING WIDTH OF ROADWAY

Experiments were repeated for different width of road to find how the capacity varies with respect to the width of road. The capacity versus road width were plotted for cars only stream and two wheelers only stream and these are as shown in Figs 7.12 and 7.13, respectively. It is clear from Fig 7.13 that the capacity or the number of two wheelers per hour gradually increases with respect to the increase in the width of road. But the increase in the number of cars per hour (Fig 7.12) is not as gradual as in the case of two wheeler. The reason for this distinct nature is: a small increase in the width of road may be enough to overtake or to get a new lane for a two wheelers, which may not be sufficient for a car.

This behaviour is also observed in the case of Mix-1 and Mix-2 as presented in Figs.7.14 and 7.15. In Mix-1, the percentages of Autos and Two wheelers were large compared to Mix-2.

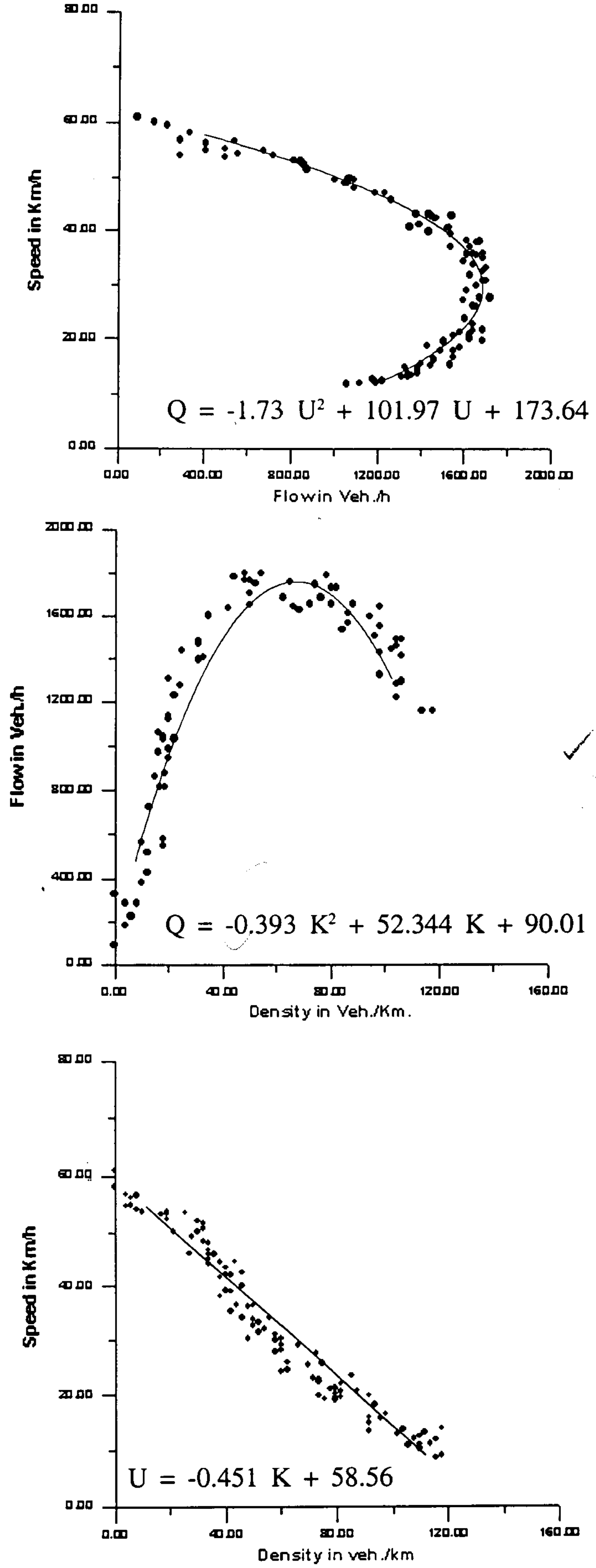

Fig 7.9 Speed-Flow-Density curves for mix-1.

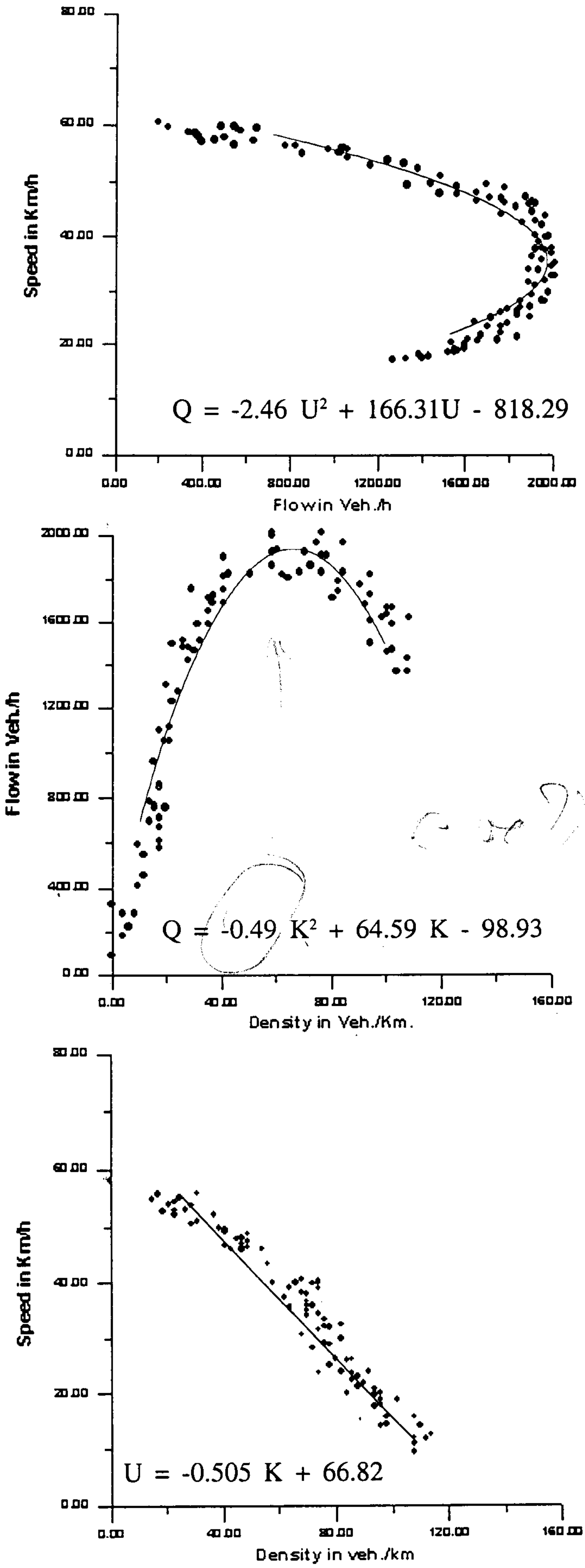

Fig 7.10 Speed-Flow-Density curves for mix-2.

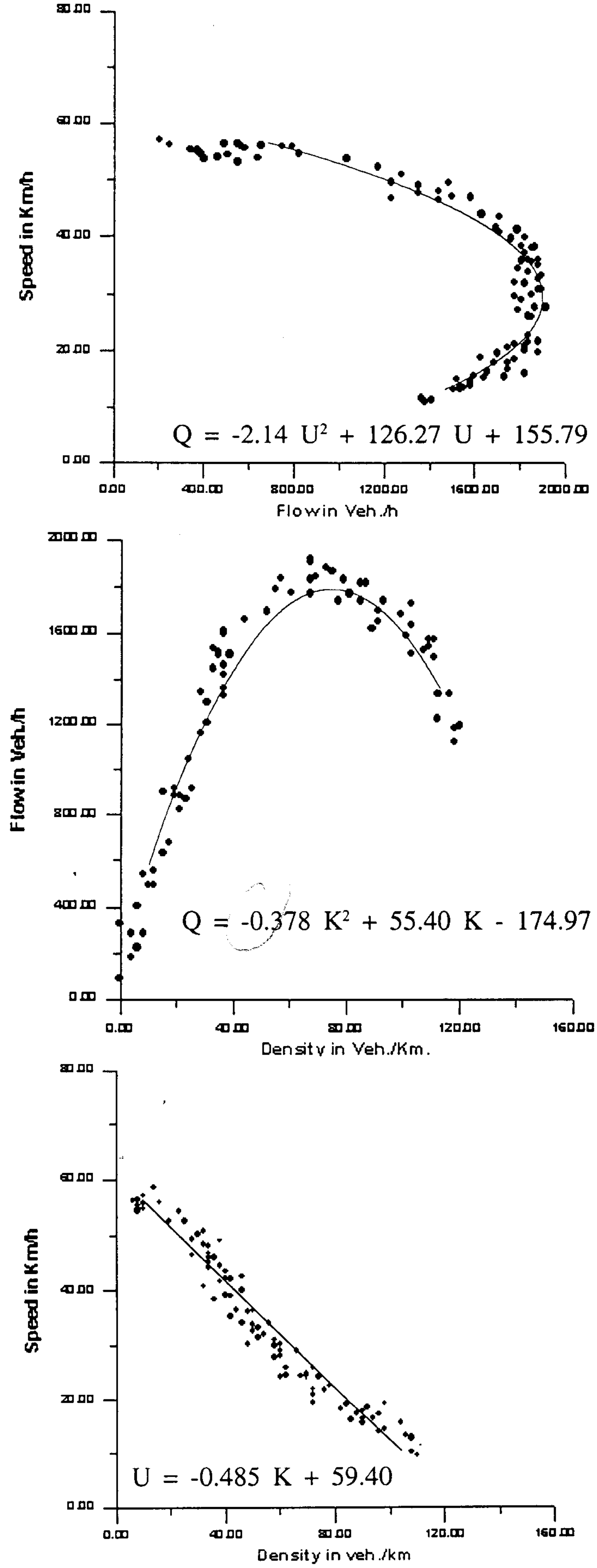

Fig 7.11 Speed-Flow-Density curves for mix-3.

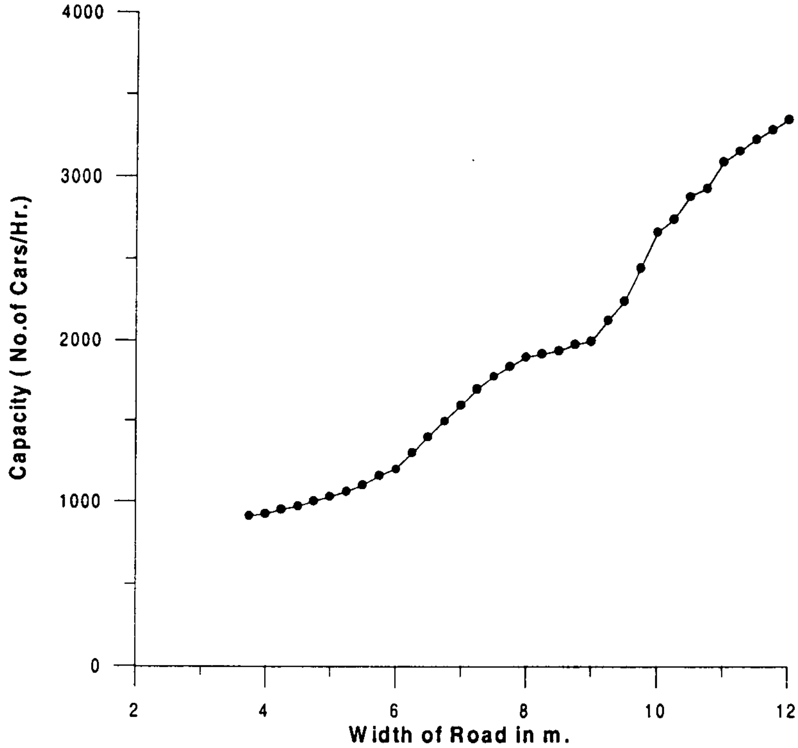

Fig 7.12 Capacity v/s road width for Cars only stream

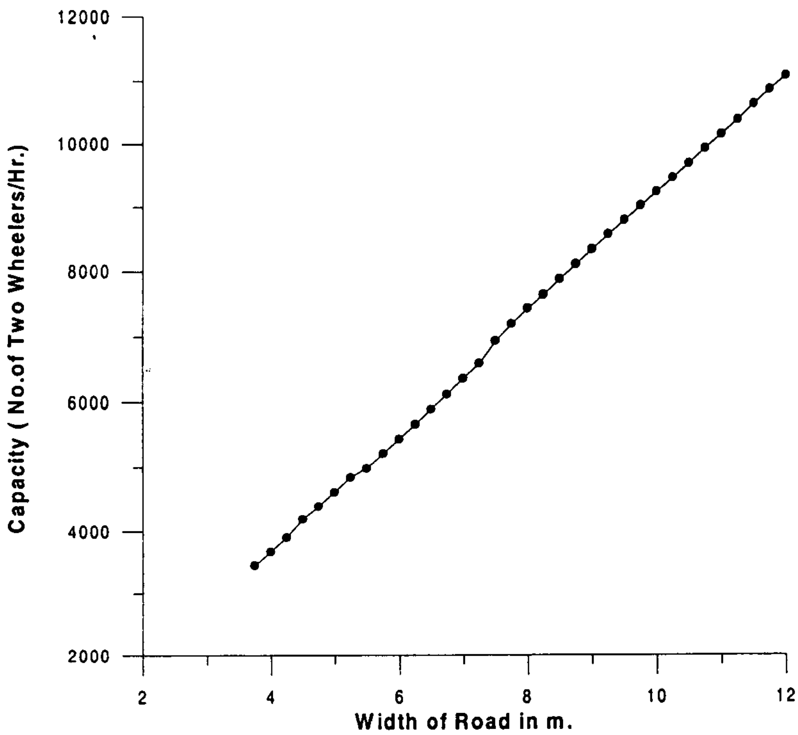

Fig 7.13 Capacity v/s road width for Two wheelers only stream

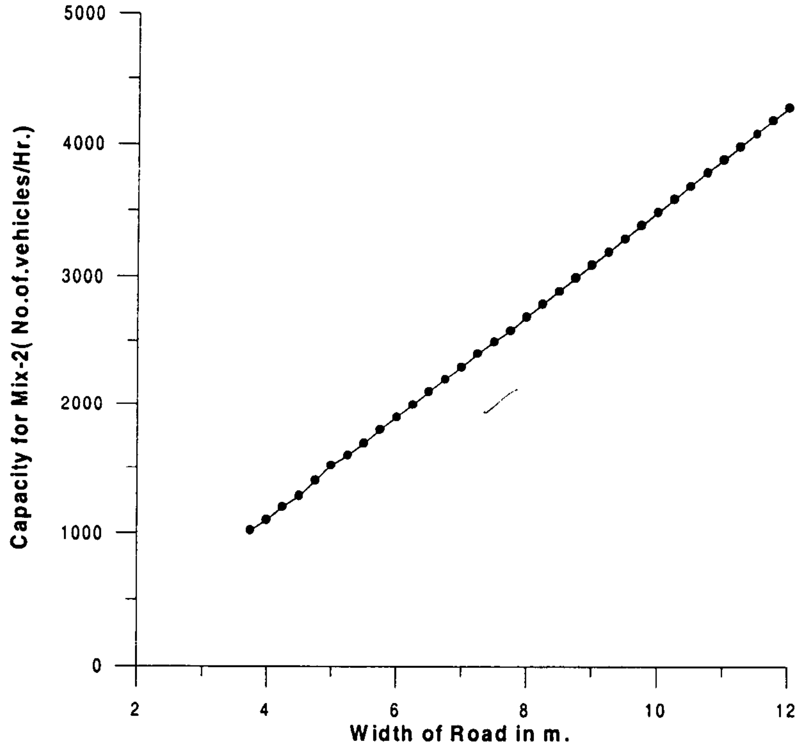

Fig 7.14 Capacity v/s road width for Mix-1 stream

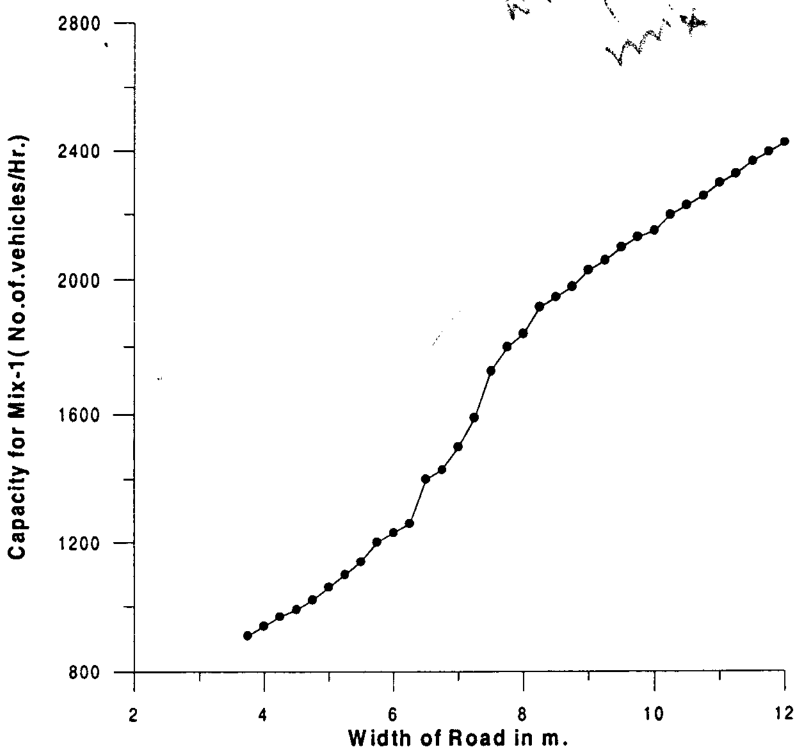

Fig 7.15 Capacity v/s road width for Mix-2 stream

7.4 NUMBER OF OVERTAKINGS AT DIFFERENT LEVELS OF SERVICE

Experiments were repeated to observe the number of overtaking (number of overtakings / km / min) for different flow levels. It is observed that at low flow levels, the number of overtakings are very less. But as the flow increases to LOS-B the number of overtaking increases gradually. Further, the increase of number of overtakings is much steeper. The number of overtaking is observed to reach a maximum and then decrease. The plots for number of overtaking versus flow are presented in Figs 7.16 to 7.21 for different types of vehicles and for different mix of vehicles.

7.5 EXPERIMENTS WITH PARTIAL RESTRICTIONS FOR OVERTAKINGS

Experiments were conducted to observe the service volumes at different restriction levels of overtakings. Figs 7.22(a) to 7.27(a) show these plots for different classes and different mixes of vehicles. It is clear from the figures that the flow considerably reduces as the restriction for overtaking increases.

The changes in the speeds are also observed for the above cases, which are presented in Figs 7.22(b) to 7.27(b). The speed also decreases gradually as the restriction on overtakings increases.

7.6 RESTRICTIONS AT CHOSEN FLOW LEVELS

Experiments were conducted to observe the speed at chosen flow, but with different percentages of overtaking operation. The variations in the speeds of such streams are presented in Figs.7.28 and 7.29. To plot this graph, initially a stream (Mix - 1) was chosen with 500 vehicles per hour and the stream was observed. Then the experiments were repeated by restricting the number of overtaking operations. Preference was given to those vehicles with greater difference between its current

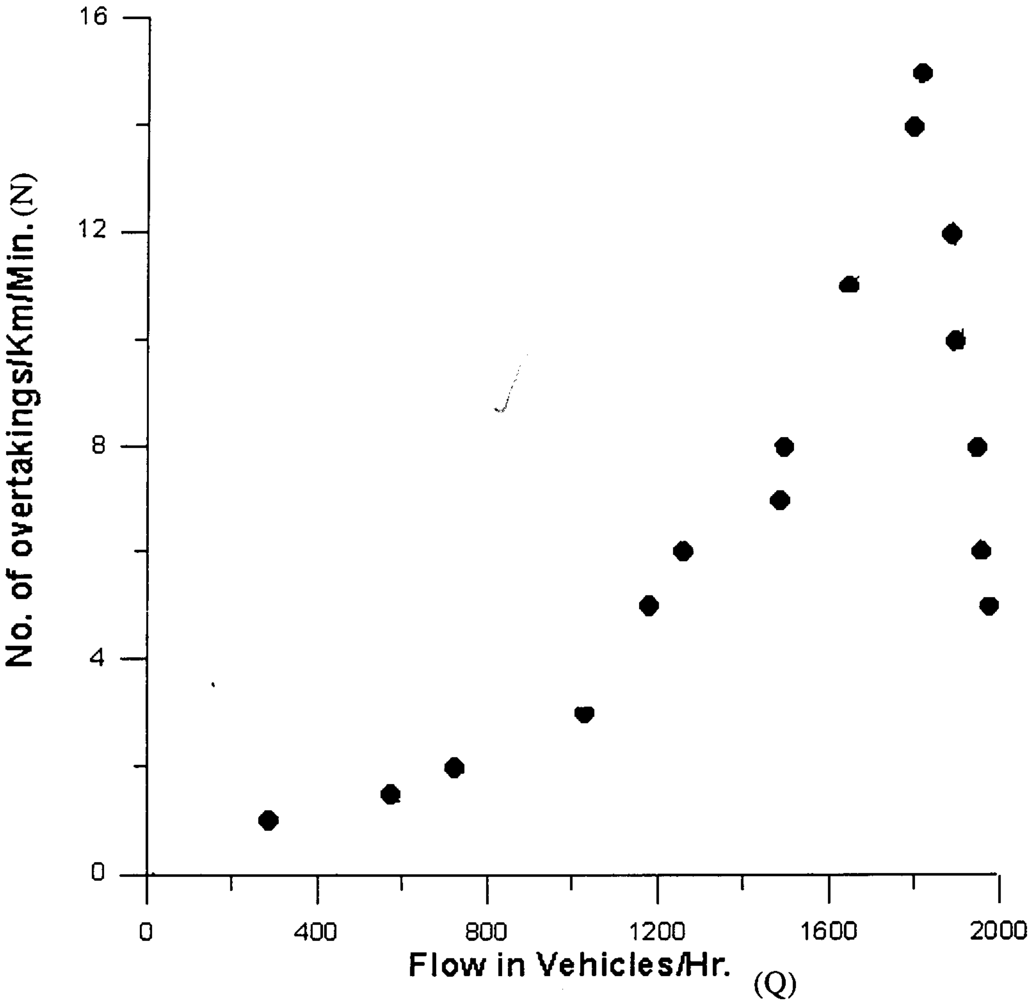

Fig 7.16 Number of overtakings in a cars only stream

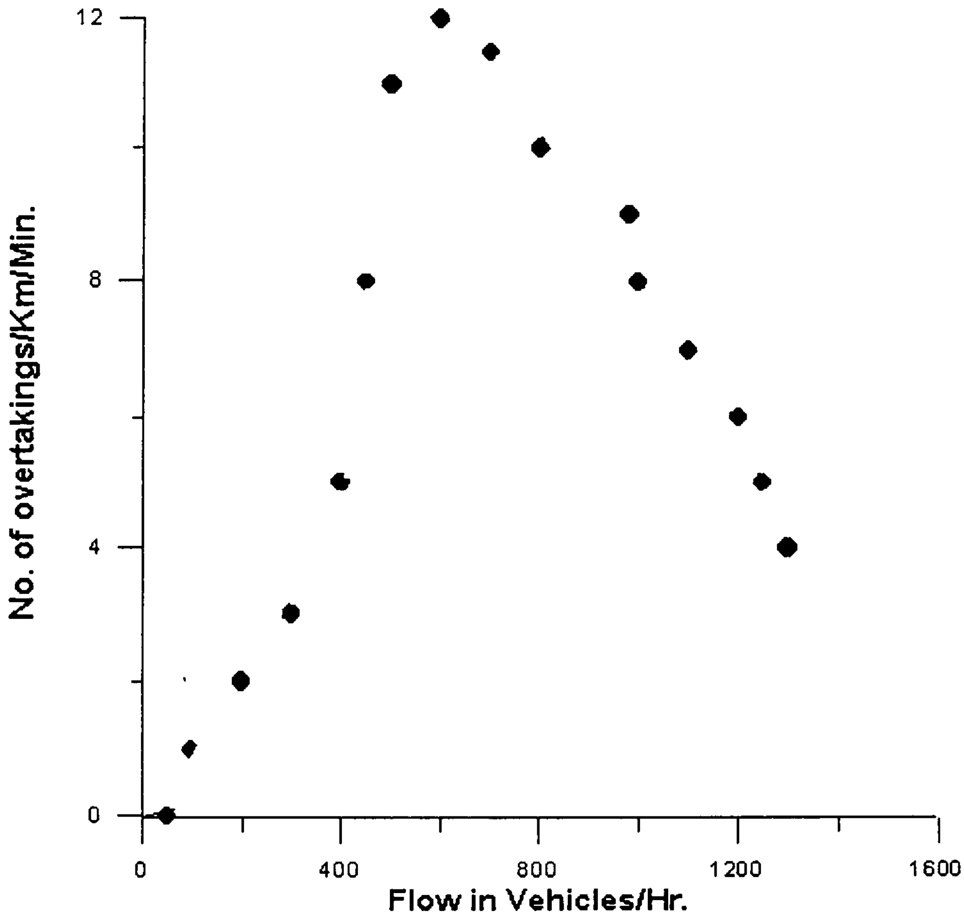

Fig 7.17 Number of overtakings in a buses only stream

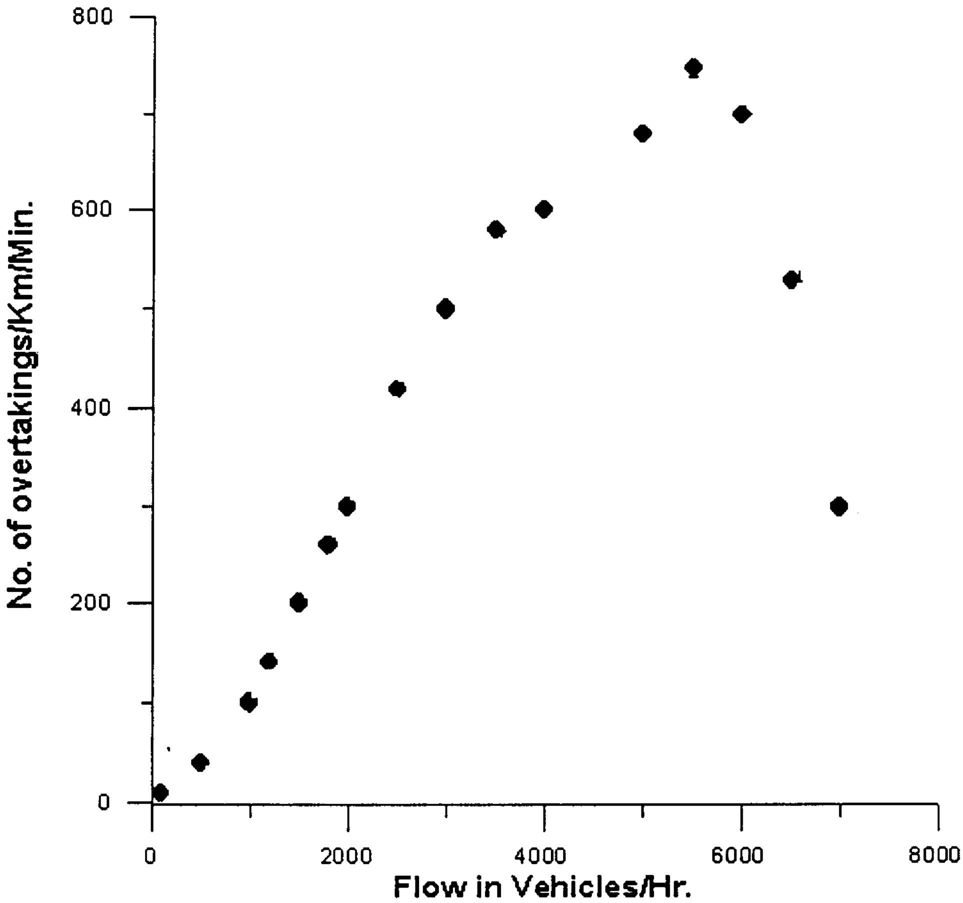

Fig 7.18 Number of overtakings in a two wheelers stream

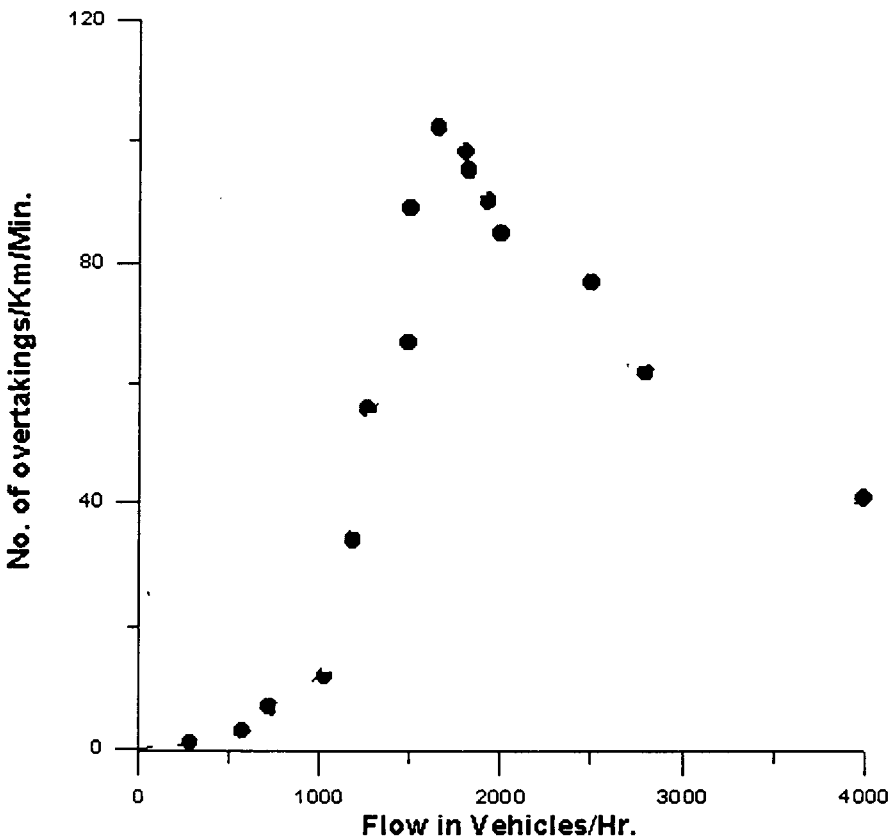

Fig 7.19 Number of overtakings in Mix-1 stream

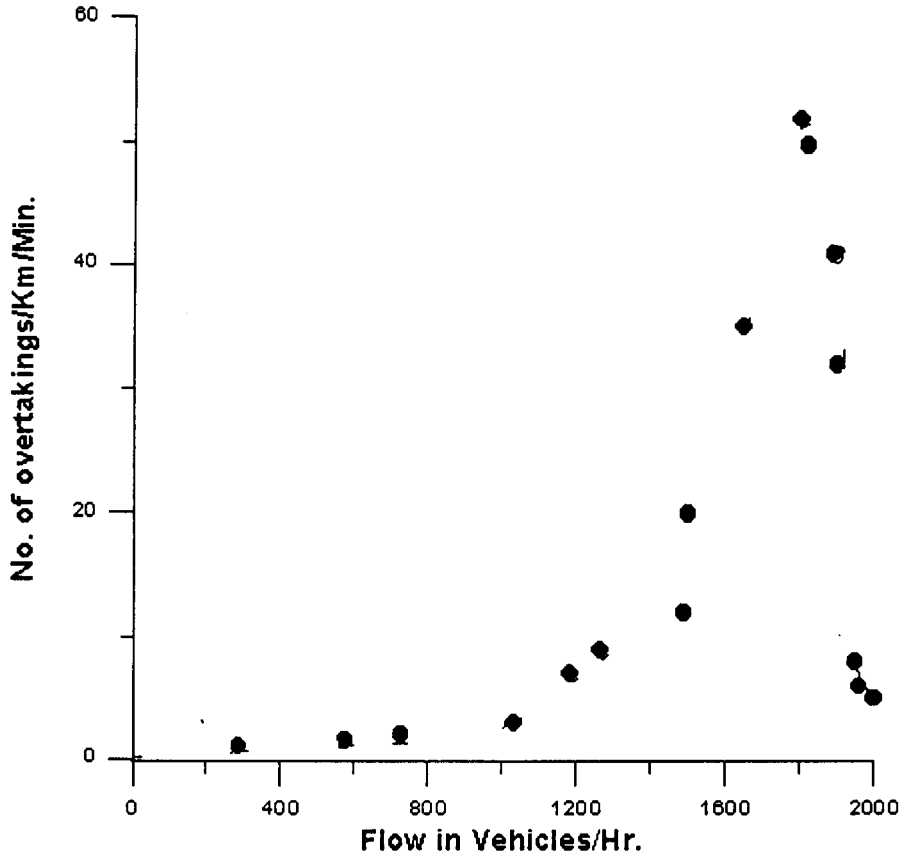

Fig 7.20 Number of overtakings in Mix-2 stream

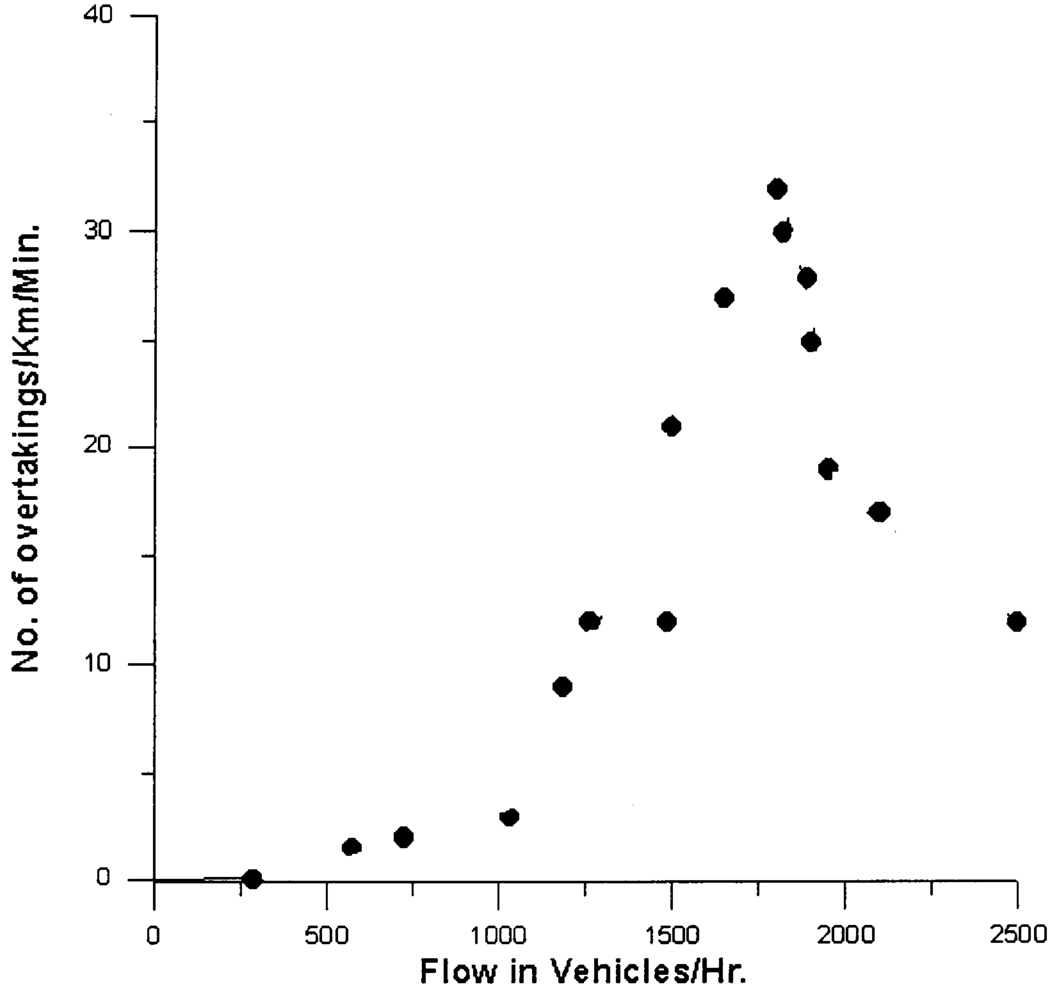

Fig 7.21 Number of overtakings in Mix-3 stream

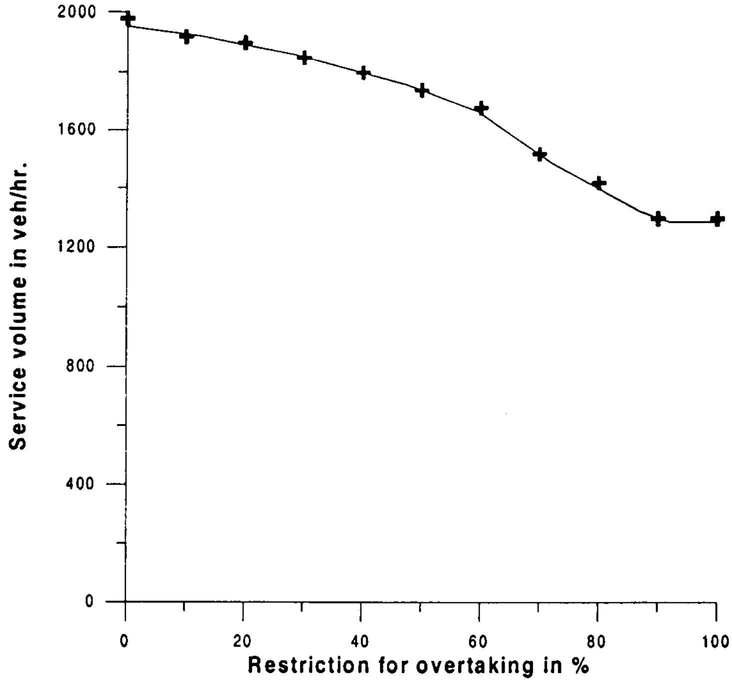

Fig 7.22 (a) Service volume v/s partial restriction in overtaking for cars only stream

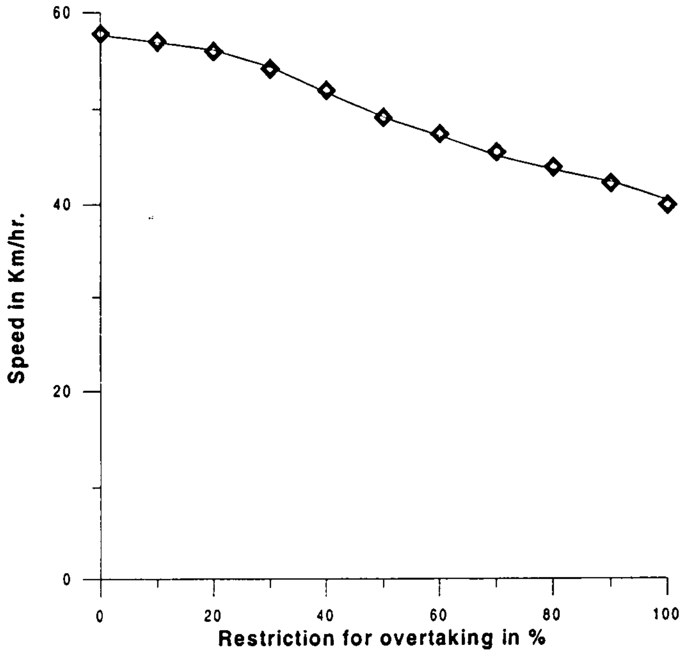

Fig 7.22 (b) Speed v/s partial restriction in overtaking for cars only stream

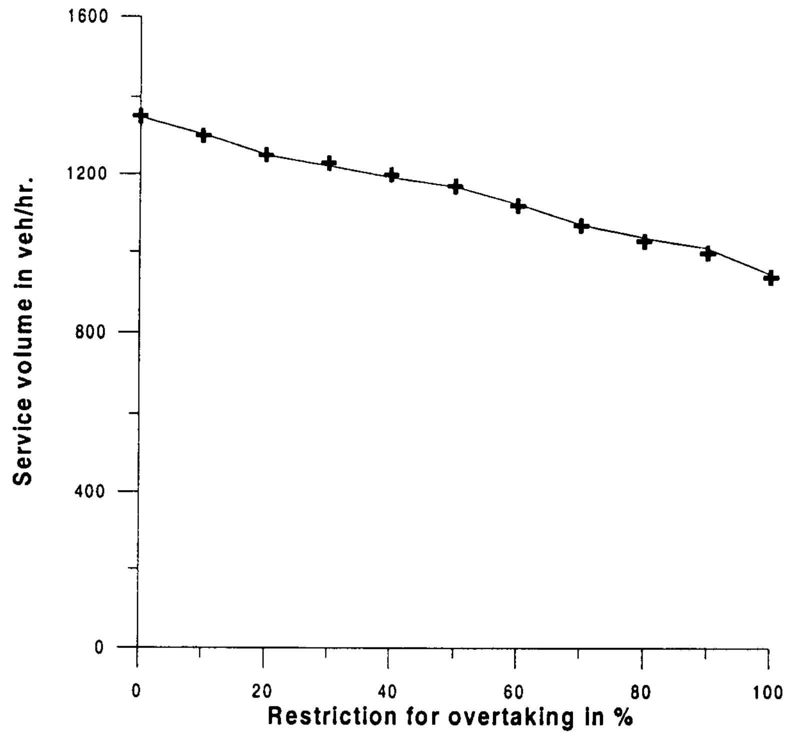

Fig 7.23 (a) Service volume v/s partial restriction in overtaking for buses only stream

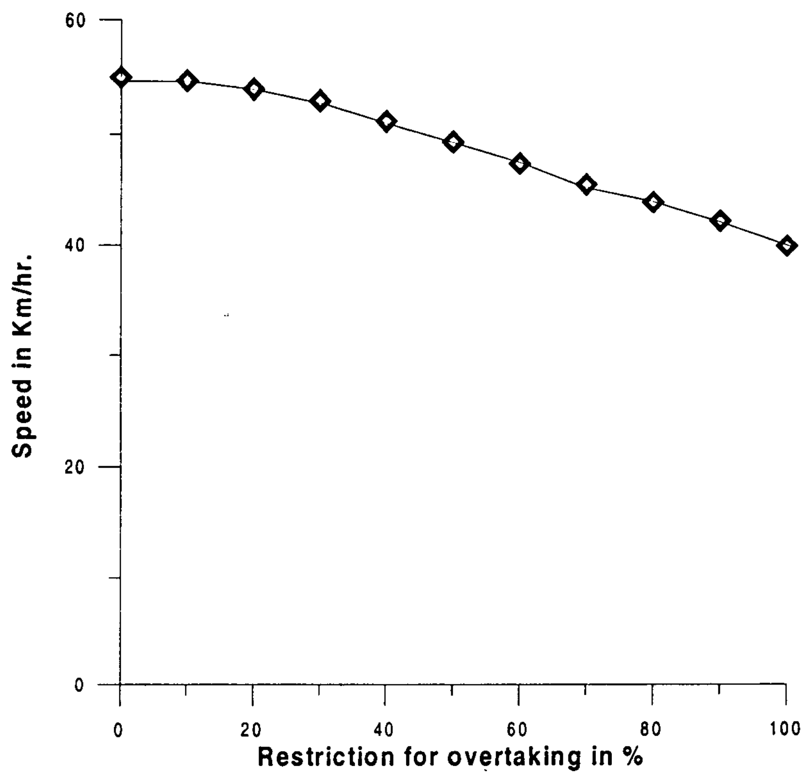

Fig 7.23 (b) Speed v/s partial restriction in overtaking for buses only stream

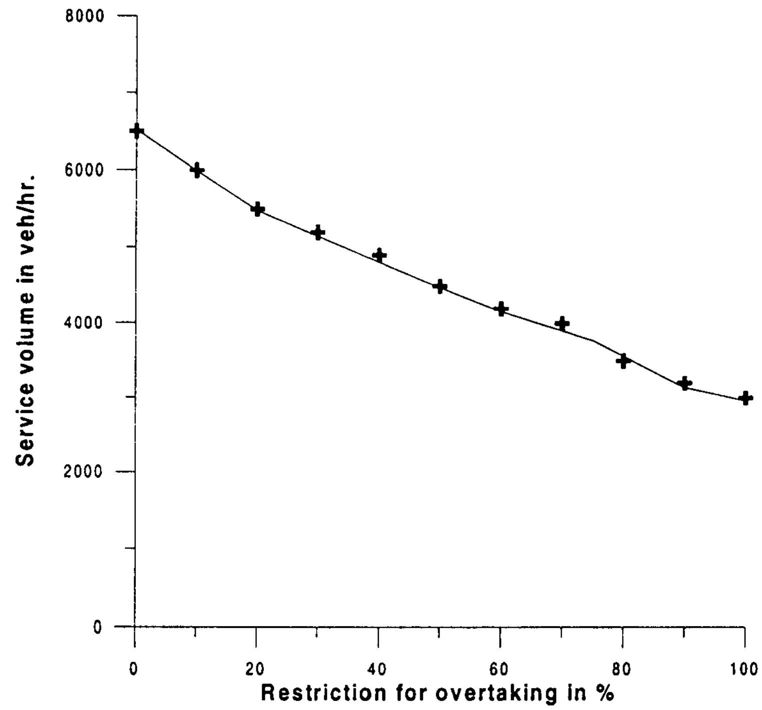

Fig 7.24 (a) Service volume v/s partial restriction in overtaking for T/W only stream

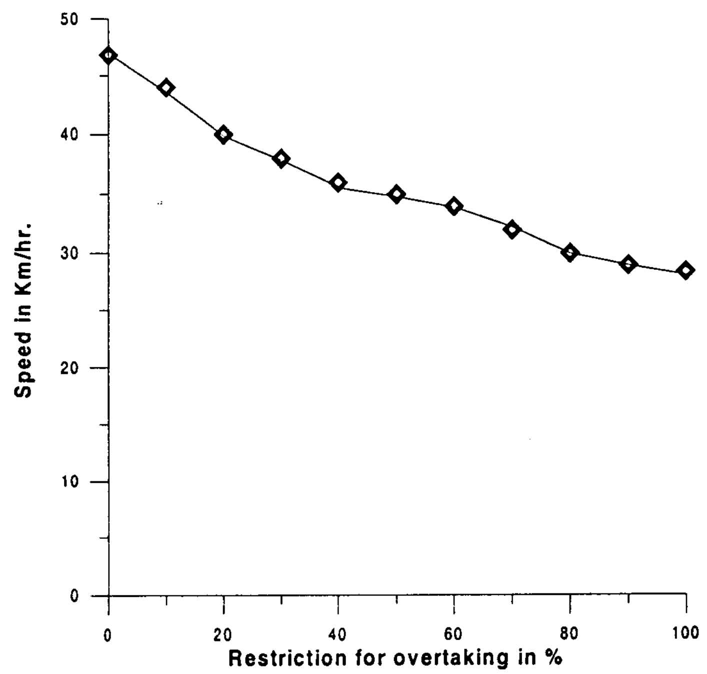

Fig 7.24 (b) Speed v/s partial restriction in overtaking for T/W only stream

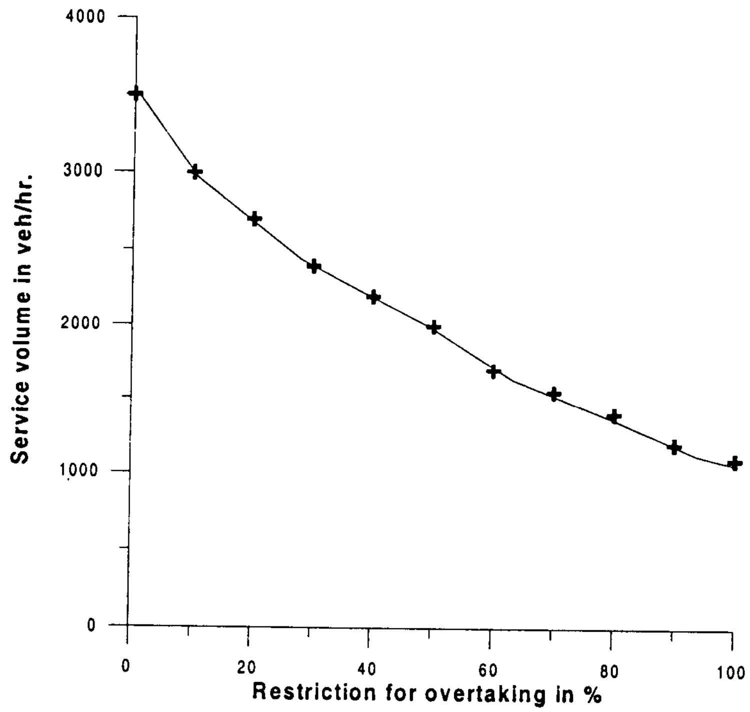

Fig 7.25 (a) Service volume v/s partial restriction in overtaking for Mix-1 only stream

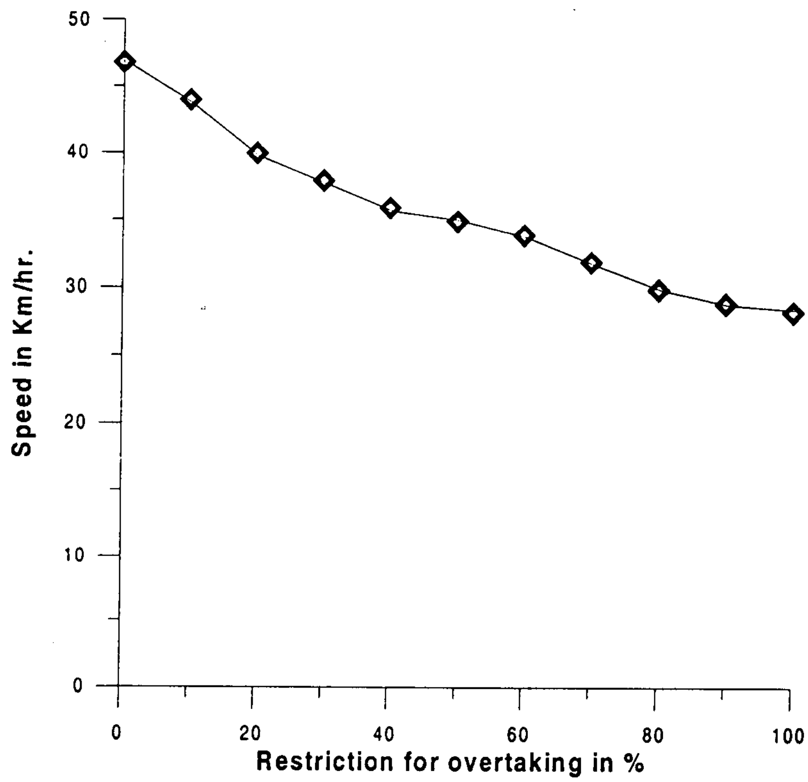

Fig 7.25 (b) Speed v/s partial restriction in overtaking for Mix-1 only stream

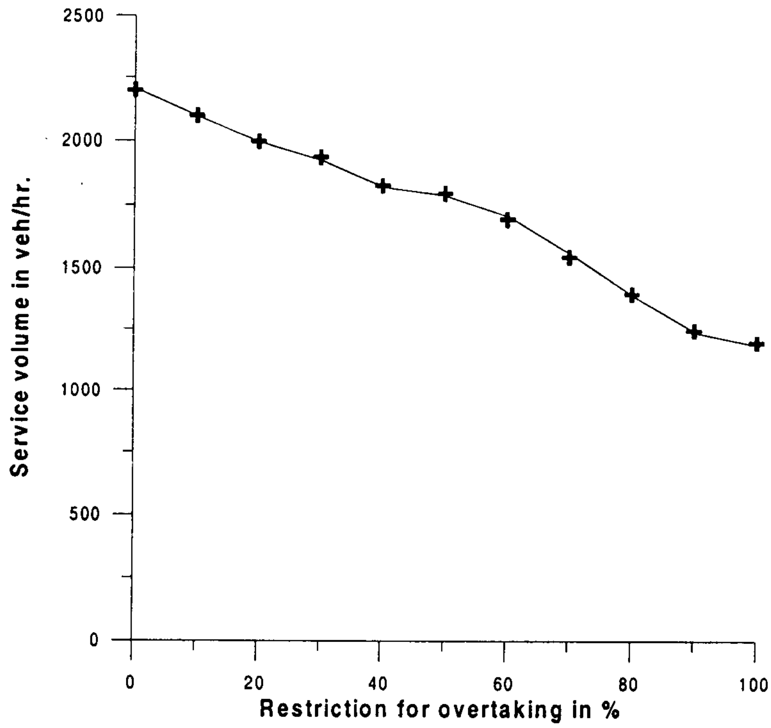

Fig 7.26 (a) Service volume v/s partial restriction in overtaking for Mix-2 only stream

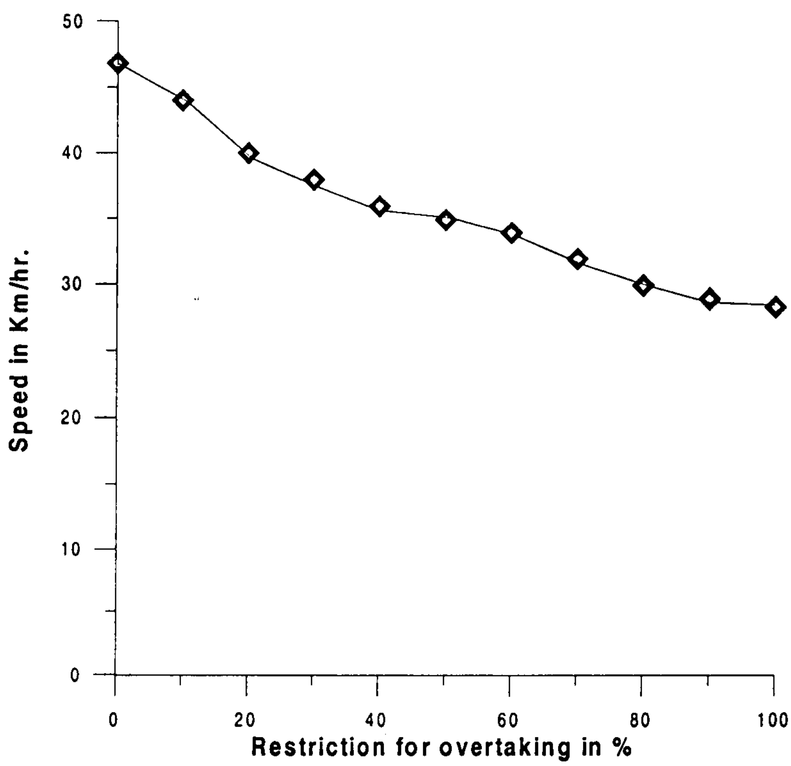

Fig 7.26 (b) Speed v/s partial restriction in overtaking for Mix-2 only stream

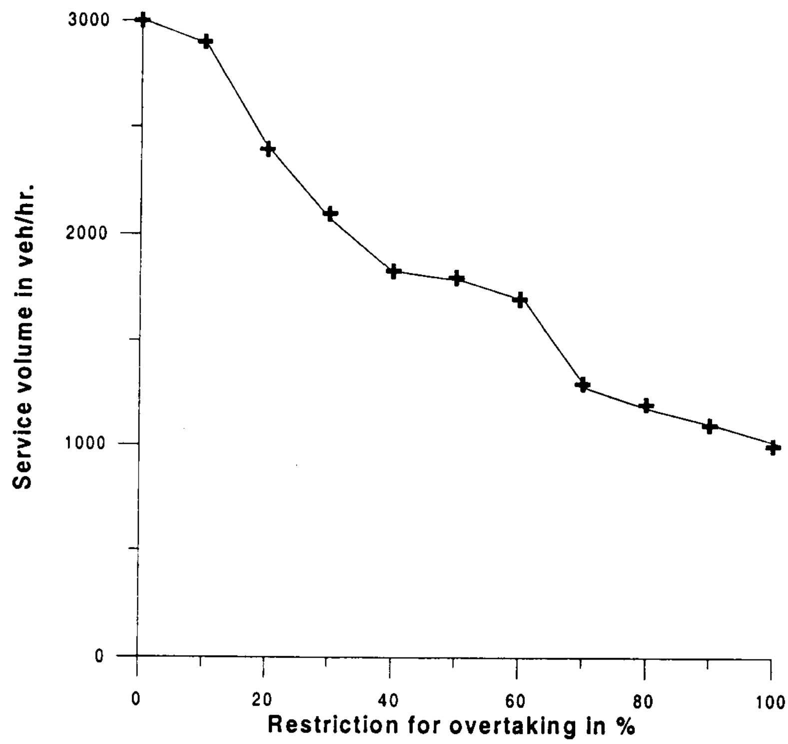

Fig 7.27 (a) Service volume v/s partial restriction in overtaking for Mix-3 only stream

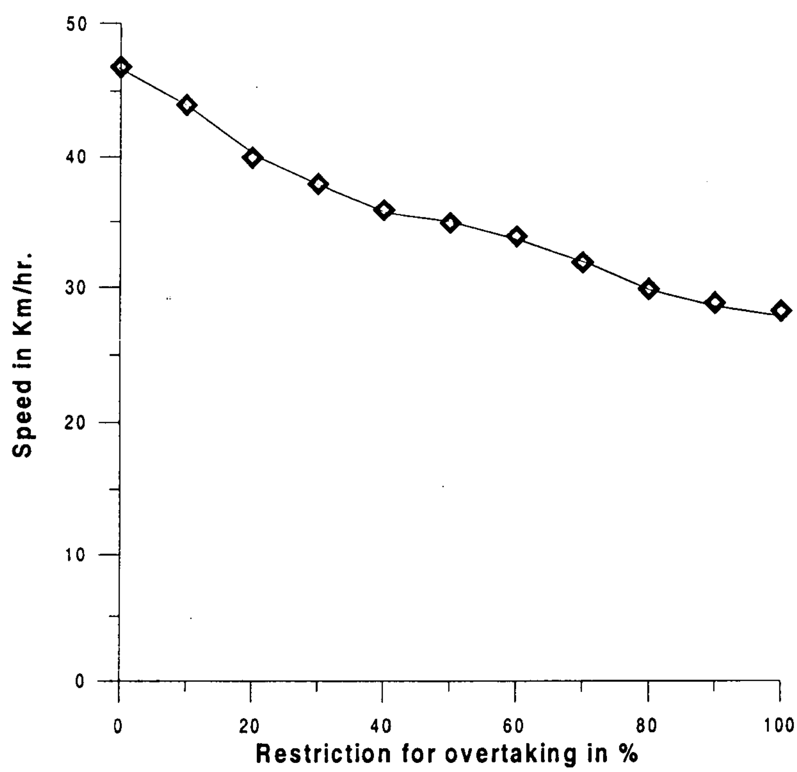

Fig 7.27 (b) Speed v/s partial restriction in overtaking for Mix-3 only stream

speed and its desired speed. As the percentage in the restriction of the overtaking operation increased, the flow was observed to be decreasing. Trial and error method was used to get the same flow. To do this, experiments were repeated by increasing the input flow, until the chosen flow was obtained.

From these experiments, it was observed that, the speed of the stream was less when the number of vehicles permitted to overtake was less, but the speed was observed to increase rapidly with the increase in percentage overtaking and after certain percentage number of vehicles was restricted (around 30 percent), there was practically very little increase in the speed of the traffic stream.

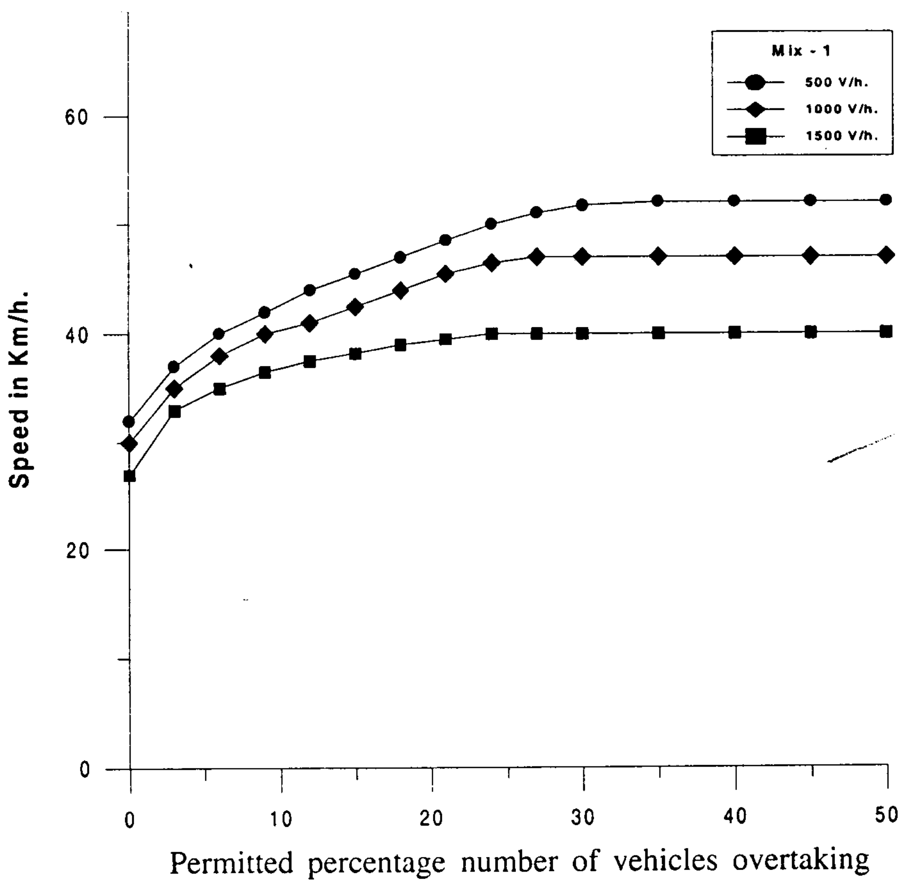

Fig 7.28 Speed variation due to restriction in overtaking for Mix-1 at different flow levels.

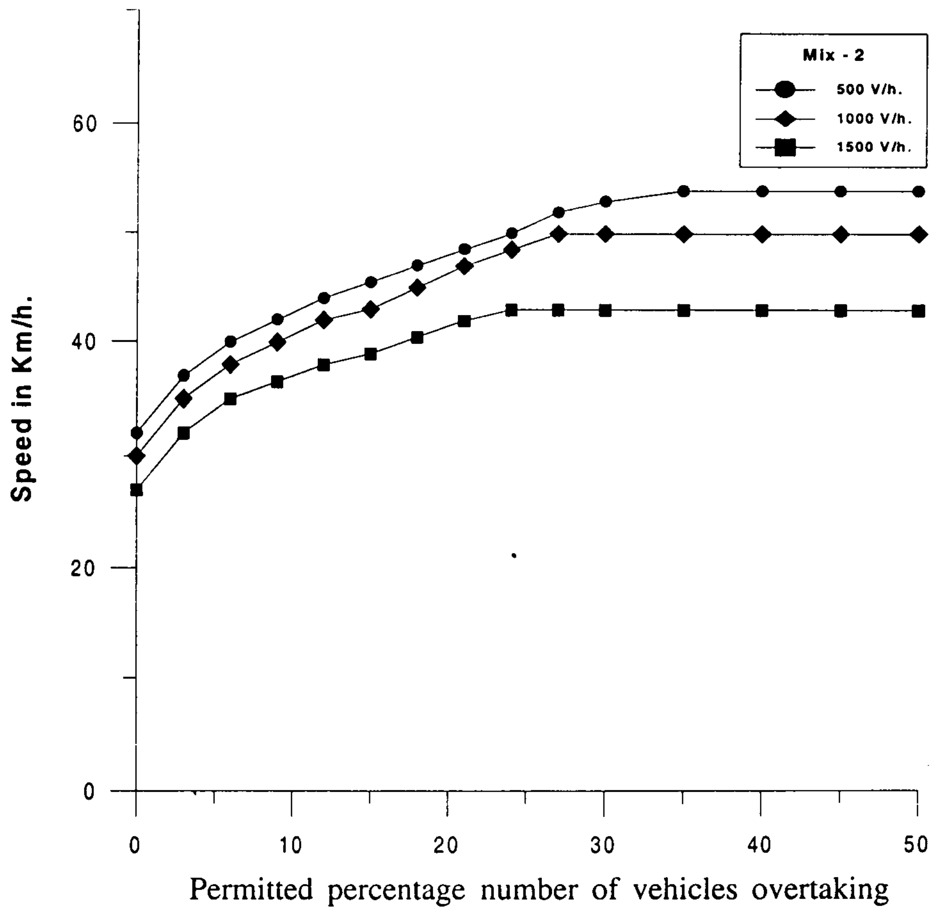

Fig 7.29 Speed variation due to restriction in overtaking for Mix-2 at different flow levels.

7.7 EXPERIMENTS WITH RESTRICTION TO CHOSEN TYPE OF VEHICLE

Experiments were conducted to observe service volumes when the overtakings were restricted to different types of vehicles. To conduct these experiments five different classes of vehicles were used as shown in Table 7.2.

Table 7.2 Different category of vehicles

No.	Code	Vehicle category	vehicles
1.	PC	Passenger cars	Cars, Jeeps and Truckers
2.	MV	Medium Vehicles	MiniTrucks,Mini.Buses and Vans
3.	HV	Heavy Vehicles	Buses and Trucks
4.	A	Autos	Autorikshaws
5.	TW	Two wheelers	Scooters and motor cycles

The observed service volumes for mix-1 and mix-2 are presented in Tables 7.3 and 7.4 for restrictions in different types of vehicles. There is a considerable decrease in the service volumes when the passenger cars are restricted for overtaking. Autorickshaws and Two wheelers are also observed to have similar behaviour, through, the loss in service volume is found to be much lesser for these vehicles. But, when the medium and heavy vehicles are restricted, the service volume is found to increase. This implicates that, if a rule is imposed on heavy and medium vehicles not to overtake, the service volume will increase considerably. But there is some practical difficulty in the imposition of such restrictions, particularly when the vehicles are allowed to run on the sections.

Table 7.3 Observed service volumes for different types of vehicles under different overtaking restrictions for mix-1.

		Overtaking restricted for				
Vehicle	Normal	PC	MV	HV	A	TW
PC	560	320	600	580	500	480
MV	280	300	150	310	220	210
HV	420	400	460	390	380	380
A	420	310	570	510	380	350
TW	320	390	440	410	340	140
Total	2000	1720	2220	2200	1740	1560

Table 7.4 Observed service volumes for different types of vehicles under different overtaking restrictions for mix-2.

		Overtaking restricted for				
Vehicle	Normal	PC	MV	HV	A	TW
PC	940	530	1130	1250	950	940
MV	380	420	210	420	380	380
HV	560	570	590	420	560	560
A	60	60	70	70	20	60
TW	60	60	60	70	50	30
Total	2000	1640	2060	2230	1960	1970

7.8 DEVELOPMENT OF DYNAMIC PCUs OF VEHICLES UNDER RESTRICTION IMPOSED FOR DIFFERENT VEHICLES

Quite often it is of interest to know the effect of imposition of certain restrictions to some chosen vehicles on the speeds of other vehicles in the traffic stream. TSM (Transport System Management) action plans often recommend priority for bus operation or restriction to light and heavy commercial vehicles on certain roads to bring about certain orderliness in the traffic stream. Such decisions are often taken without the support form scientific experiments.

AutoTRAFFIC simulation model developed has an advantage of imposing restriction on any of the chosen vehicle and to study the effect of this restriction on the speeds of different vehicles. Making use of this package, experiments were conducted at four different flow levels namely 500, 1000, 1500 and 2000 vehicles per hour and by imposing total removal of different types of vehicles. Table 7.5 to 7.8 show the speeds of different types of vehicles obtained by the removal of the different types of vehicles as enlisted on the top of these tables.

In order to understand the effect of this restriction on different types of vehicles, Dynamic PCU values were also calculated taking the speed obtained for passenger car at 500 vehicles per hour flow as the norm for comparison. The Dynamic PCU value is obtained by:

Dynamic PCU of any vehicle i = $(V_c/L_c) / (V_i/L_i)$

where V_c is the speed of car at 500 vehicles per hour

V_i is the speed of any vehicle at chosen flow level

L_c is the diagonal length of passenger car

L_i is the diagonal length of i^{th} vehicle

Table 7.9 to 7.12 show the Dynamic PCU values of different vehicles. It can be seen from these tables, that the lower flow levels (less than 1000 vehicles per hour), restrictions imposed on the movements of two wheelers and autorikshaws, will increase the speeds of other vehicles in the traffic stream, especially the speed of buses. But at higher flow levels (greater than 1000 vehicles per hour) it is the restriction imposed to the truck movement which will improve the speed of buses. Thus, these tables will be useful to the transportation system managers who are contemplating to impose certain restrictions to the flow of vehicles as one of the management options to improve the level of service.

Another important observation from the Tables 7.9 to 7.12 is that the passenger car units of different vehicles vary considerably depending up on the flow levels. Table 7.13 shows the variations in the passenger car units of different vehicles as observed in the study.

Table 7.5 Speeds of vehicles due to the restriction of other vehicles (flow level 500 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	49.35	-	49.65	52.47	54.55	49.39	51.83	50.97	52.43
Bus	43.83	46.74	-	49.46	48.56	51.96	45.46	51.04	49.56
Auto	41.52	41.65	42.03	-	41.84	41.39	42.67	42.63	42.53
Truck	40.25	40.64	40.55	45.85	-	42.84	44.94	41.45	43.82
T/W	40.15	44.47	43.88	43.09	44.83	-	42.78	43.67	45.74
M.Bus	42.74	43.02	42.48	42.75	44.03	46.84	-	41.68	49.46
M.Trk	34.74	38.58	39.15	41.55	41.37	40.83	41.66	-	37.67
Jeep	47.16	47.89	47.95	48.84	49.02	48.62	47.93	49.10	-

Table 7.6 Speeds of vehicles due to the restriction of other vehicles (flow level 1000 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	45.42	-	48.91	47.81	48.53	45.69	47.61	47.63	48.65
Bus	43.64	45.92	-	45.71	46.83	44.87	45.34	45.08	46.42
Auto	39.91	40.90	41.23	-	40.31	40.82	41.56	41.65	41.31
Truck	39.41	40.22	42.93	40.71	-	39.24	42.44	42.23	43.76
T/W	39.52	40.12	41.66	41.05	40.84	-	41.32	41.21	40.63
M.Bus	41.84	42.21	42.43	43.62	45.09	41.64	-	43.76	44.84
M.Trk	33.53	37.73	35.65	37.02	40.21	34.72	34.33	-	37.72
Jeep	42.32	44.21	43.81	44.84	43.62	43.06	44.93	43.40	-

Table 7.7 Speeds of vehicles due to the restriction of other vehicles (flow level 1500 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	41.43	-	43.84	42.59	42.08	41.93	42.84	42.61	43.72
Bus	39.82	42.29	-	40.93	41.73	39.49	40.76	40.03	40.74
Auto	35.79	37.84	36.35	-	36.81	36.61	36.98	36.57	36.45
Truck	34.05	34.43	35.88	35.92	-	34.79	35.76	35.75	35.30
T/W	37.63	38.77	38.03	38.43	37.83	-	38.86	37.62	38.52
M.Bus	39.34	41.05	40.76	41.79	40.80	39.74	-	39.84	40.78
M.Trk	33.92	36.74	35.82	37.05	35.62	33.05	37.77	-	36.67
Jeep	40.87	41.65	41.74	41.40	42.38	40.84	41.34	41.70	-

Table 7.8 Speeds of vehicles due to the restriction of other vehicles (flow level 2000 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	32.48	-	35.72	33.93	33.61	33.82	32.76	33.72	33.83
Bus	31.60	32.98	-	31.92	32.92	32.61	31.73	32.03	32.71
Auto	27.52	28.02	30.33	-	26.03	30.87	27.81	27.91	28.25
Truck	30.73	31.64	31.83	31.48	-	30.83	30.66	30.84	31.83
T/W	32.81	33.83	33.81	32.02	33.81	-	32.72	33.34	32.90
M.Bus	31.03	32.15	32.04	32.72	32.85	31.93	-	32.65	32.02
M.Trk	30.75	31.37	32.98	31.93	32.71	31.78	30.88	-	31.40
Jeep	30.09	31.75	32.04	32.53	32.07	31.64	31.84	30.80	-

Table 7.9 Dynamic PCU values due to the restriction of other vehicles (Flow level 500 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	1.00	-	0.99	0.94	0.90	0.99	0.95	0.97	0.94
Bus	2.56	2.40	-	2.27	2.31	2.16	2.47	2.20	2.27
Auto	0.81	0.80	0.79	-	0.80	0.78	0.78	0.78	0.78
Truck	2.15	2.13	2.14	1.89	-	2.02	1.93	2.09	1.98
T/W	0.60	0.55	0.55	0.57	0.55	-	0.57	0.56	0.53
M.Bus	1.77	1.76	1.78	1.77	1.72	1.61	-	1.82	2.01
M.Trk	1.93	1.74	1.71	1.61	1.61	1.64	1.61	-	1.77
Jeep	1.03	1.02	1.01	0.99	0.99	1.00	1.02	0.99	-

Table 7.10 Dynamic PCU values due to the restriction of other vehicles
(Flow level 1000 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	1.09	-	1.00	1.03	1.02	1.08	1.04	1.04	1.01
Bus	2.57	2.44	-	2.45	2.40	2.50	2.47	2.49	2.42
Auto	0.84	0.82	0. 81	-	0.83	0.82	0.81	0.80	0.81
Truck	2.20	2.16	2.02	2.13	-	2.21	2.04	2.05	1.98
T/W	0.62	0.61	0.59	0.60	0.60	-	0.60	0.60	0.61
M.Bus	1.81	1.79	1.78	1.73	1.68	1.82	-	1.73	1.69
M.Trk	1.99	1.77	1.88	1.81	1.66	1.93	1.95	-	1.77
Jeep	1.15	1.10	1.11	1.09	1.12	1.13	1.09	1.12	-

Table 7.11 Dynamic PCU values due to the restriction of other vehicles (Flow level 1500 vph)

	No restriction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	1.19	-	1.13	1.16	1.17	1.18	1.16	1.16	1.13
Bus	2.82	2.65	-	2.74	2.69	2.84	2.75	2.80	2.75
Auto	0.94	0.89	0.93	-	0.91	0.91	0.91	0.91	0.93
Truck	2.55	2.52	2.42	2.41	-	2.49	2.42	2.43	2.46
T/W	0.65	0.63	0.64	0.64	0.64	-	0.63	0.65	0.64
M.Bus	1.92	1.84	1.86	1.81	1.85	1.90	-	1.90	1.85
M.Trk	1.97	1.82	1.87	1.80	1.88	2.02	1.77	-	1.82
Jeep	1.19	1.17	1.17	1.18	1.15	1.19	1.18	1.17	-

Table 7.12 Dynamic PCU values due to the restriction of other vehicles
(Flow level 2000 vph)

	No res- triction	Restricted for							
		Car	Bus	Auto	Truck	T/W	M.Bus	M.Truck	Jeep
Car	1.52	-	1.38	1.45	1.46	1.46	1.51	1.46	1.46
Bus	3.55	3.40	-	3.52	3.41	3.44	3.54	3.50	3.43
Auto	1.22	1.20	1.10	-	1.29	1.09	1.20	1.20	1.19
Truck	2.82	2.74	2.72	2.75	-	2.81	2.83	2.81	2.72
T/W	0.75	0.72	0.72	0.76	0.72	-	0.75	0.73	0.74
M.Bus	2.44	2.35	2.35	2.30	2.30	2.37	-	2.32	2.36
M.Trk	2.17	2.13	2.03	2.09	2.04	2.10	2.17	-	2.13
Jeep	1.62	1.53	1.52	1.50	1.52	1.54	1.52	1.58	-

Table 7.13 Passenger Car Units observed in this study

Sl.No.	Vehicle	PCU
1.	Car	0.94 to 1.52
2.	Bus	2.16 to 3.55
3.	Auto	0.78 to 1.29
4.	Truck	1.98 to 2.82
5.	T/W	0.53 to 0.75
6.	M.Bus	1.61 to 2.44
7.	M.Trk	1.61 to 2.17
8.	Jeep	0.99 to 1.62

7.9 DETERMINATION OF OVERTAKING SIGHT DISTANCE AND OVERTAKING ZONE LENGTH

Simulation model AutoTRAFFIC was run nearly for 30 hours to record the various types of overtaking operations that can possibly occur on our roads. The experiments were conducted at four different flow levels, namely, 500, 1000, 1500 and 2000 vehicles per hour. The vehicle system were grouped in to three sets for the purpose of the experiment. While, the first group form the light and the medium category (Car, Jeep, Mini bus and Mini truck), the last group consisted of vehicles of the two and three wheeler group of vehicles (Scooters, Motor cycles and Autorikshaws). The middle group consisted of heavy vehicles like buses and trucks.

Overtaking sight distances were recorded for all combinations of vehicle groups for four different flow level as shown in Table 7.14. The values indicated in the table is the maximum observed overtaking sight distance for the combination of overtaking and overtaken vehicle groups.

It can be observed from the table that the maximum overtaking sight distance observed in the simulation experiment is 853.97m for the flow level of 500 vehicles per hour for the two and three wheeler group of vehicle overtaking the light and medium groups of vehicles. Even though this combination of overtaking and overtaken groups of vehicles is not very common, but such overtakings also are quite prevalent on our road system. Hence, the maximum overtaking sight distance for the mixed traffic flow conditions can be safely taken as around 900m.

Since the flow is bi-directional, it appears reasonable to provide double the overtaking sight distance as the safe minimum overtaking zone length. Hence, the overtaking zone length recommended in this study for the rural road conditions is 1800m.

The procedure adopted for getting the overtaking sight distance and overtaking zone length in this study is completely different from the one adopted by the Indian Roads Congress. In calculating the overtaking sight distance, IRC makes an assumption

Table 7.14 Overtaking sight distances

Overtaking vehicle	Overtaken vehicle	Flow vph	Sight distance(m)	Overtaking zone length
L & MV (L&MV: Light and Medium Vehicles)	L&MV	500	620.56	1241.12
		1000	511.36	1022.72
		1500	412.96	825.92
		2000	234.57	469.14
	HV	500	486.46	972.92
		1000	286.46	572.92
		1500	214.38	428.76
		2000	167.67	335.34
	2&3W	500	534.78	1069.56
		1000	387.58	775.56
		1500	284.93	569.86
		2000	167.58	335.16
HV (HV: Heavy Vehicles)	L&MV	500	830.65	1661.30
		1000	740.38	1480.76
		1500	536.73	1073.46
		2000	395.68	791.36
	HV	500	464.46	928.92
		1000	396.56	793.12
		1500	312.34	624.68
		2000	219.66	439.32
	2&3W	500	573.64	1147.28
		1000	485.95	971.90
		1500	295.96	591.92
		2000	195.30	390.60
2&3W (2&3W: Two and Three Wheelers)	L&MV	500	**853.97**	**1707.94**
		1000	573.09	1146.18
		1500	402.74	805.48
		2000	248.03	496.06
	HV	500	493.56	987.12
		1000	397.30	974.60
		1500	276.94	553.88
		2000	146.43	292.86
	2&3W	500	305.68	611.36
		1000	295.67	591.34
		1500	215.39	430.72
		2000	112.30	224.60

Overtaking zone length recommended is twice the maximum overtaking sight distance observed in this study that the differential speed between the overtaken and overtaking vehicles is 16kmph. But in the present simulation studies no such assumption is made. Instead, the vehicles are driven as per the desired speed and as per the speeds that are possibly to be obtained on the road system in the declared traffic environment. The maximum overtaking sight distance that is recorded in the simulation model, after running the model for substantial amount of time, is recorded as the overtaking sight distance requirement. Hence this approach is devoid of any a priori assumptions.

The overtaking zone length recommended from the study is comparable to the IRC recommended value at the design speed of 100kmph. At this design speed safe overtaking distance worked out by IRC is 640m. If we assume the overtaking zone length is three times the overtaking sight distance, then the overtaking zone length required will be equal to 3x640 = 1920m. This length is comparable to 1800m recommended by the simulation experiment.

7.10 CONCLUSIONS

The following are the major conclusions drawn from the real time experiments conducted using simulation package AutoTRAFFIC:

1) The speed flow density relationships even for mixed traffic flow conditions would be by and large similar to that for homogenous traffic. Many researchers working on mixed traffic flow have not been able to simulate the traffic movement over the entire flow ranges because of lack of appropriate theory to describe the vehicular movement in mixed traffic conditions. The Car Following Model introduced in this study, with the vehicles being governed by Desired Speed Concept has been able to bring about an orderliness which is absent in the many of the research work on a mixed traffic flow. Many types of overtaking phenomena that are observed in real life are incorporated in the simulation model developed and because of this almost all vehicles are manoeuvred on the simulation study sections at or near their desired

speeds. Because of this, most of the vehicle manoeuvres atmost tend towards the traffic manoeuvres at homogenised traffic conditions. This results in the speed-flow-density relationships model approching the theoretical relationships.

2) Experiments conducted with varying widths of roadway have established that the nature of the Capacity vs Width of Roadways depend on the Mix Composition. For an idealised stream consisting of only two wheelers, this relationship is more or less linear, whereas for idealised car only stream, this relationship appears to be rather uneven or cascading type. This only illustrate the point that in a mix predominated by two wheelers, any addition to the width of the roadway increases the capacity as a direct function of the increase in width. But for buses, trucks, and other heavy vehicles additional capacity could be obtained only when the widths of the roads are increased in terms of standard lane widths.

The above observation has got yet another implications as regards the non standard lane widths adopted in our Indian roads. Perhaps the intermediate lane of 5.5m seen on our roads may have its own advantage in a road having predominatly two or three wheeler traffic in increasing the capacity. But the same road may have very little effect in increasing the capacity when the traffic consists of mix of vehicles such as cars, buses and trucks.

3) It has been observed in this study that the number of overtakings per kilometer per min increases with respect to the flow of vehicles upto a certain flow level and then decreases. The shape of these relationships are different for different types of vehicles and for different mix of propotions. It is difficult model to those relationships and the nature of these relationships can only be established by a simulation experiment only.

4) The experiments conducted by restricting the overtakings of vehicle have brought about some interesting observations. Table 7.15 shows the reduction in flow and percentage reduction in flow observed by fully restricting the overtaking operations. It is seen from this table that the reduction in capacity in percentage terms will be very much higher in traffic streams predominated by two wheeler population. For mix-1 type of flow, predominated by two and three wheeler, as much as 70 per cent reduction in capacity has been observed in this study. This only calls for careful introspection on the part of traffic engineers while imposing restrictions for overtaking in traffic stream operation. It has also been demonstrated in the study that there could be considerable increase in the capacities of roads by restricting heavy and medium vehicles and at the same time there could be considerable reduction in capacities of roads if overtakings are restricted to passenger cars.

Table 7.15 Reduction in Speeds and Flows due to complete ban on overtaking

Sl.No.	Composition of vehicles	Speed at no restriction in kmph	Speed reduction in kmph at total ban condition	Flow at no restriction in vph	Reduction in flow at total ban condition in vph	Percentage red uction in flow
1.	Cars only	58	17	1950	600	30.70
2.	Buses only	55	16	1350	330	24.44
3.	T/W only	47	20	6500	3500	53.85
4.	Mix-1	48	18	3500	2450	70.07
5.	Mix-2	47	17	2200	900	40.40
6.	Mix-3	46	18	3000	2000	66.67

5) The Dynamic PCU values calculated in this study have shown that considerable improvement in the speed of buses could be obtained by restricting the two wheeler and autorikshaw movements at low and medium flow levels of 500 to 1000 vph. But in higher flow levels of 1500 vph or above, improvement to the speeds of buses could be brought about only by imposing restriction to the movement of trucks and minitrucks on the roadway. The Dynamic PCU values obtained in this study have shown that the passenger car itself can have the PCU values varying from 0.94 to 1.52 depending on the flow levels. Similarly, the Dynamic PCU value of buses could vary between 2.16 to 3.55. It is also noticed in this study that the PCU values recommeded by IRC for buses and trucks are very nearly equal to the Dynamic PCU values obtained in this study at or near the Capacity Conditions. But for all other vehicles, the PCU values recommended by IRC, are very much on the conservative side.

6) The experiments conducted in this study for calculation of Overtaking Sight Distances have showed that the maximum Overtaking Sight Distance in this study has been observed to be 853.97m (approximately 900m), when a two or three wheeler overtakes a light or medium vehicle in the traffic stream. Using this as the extreme value, on Overtaking Zone Length of 1800m has been suggested for a two lane two way operation with a road width of 7.5m. Unlike in the IRC method, the Overtaking Sight Distance has been calculated, not based on any assumed speed differential of 16kmph between the Overtaking and the Overtaken vehicles, but based on all possible Sight Distance values recorded in a simulation experiment which has been run for considerable amount of time. Thus the recommendation appears to be nearer to the reality.

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CHAPTER - 8

SUMMARY, CONCLUSIONS AND SCOPE FOR FURTHER STUDIES

8.1 SUMMARY

In the present work, an attempt has been made to study the overtaking behaviour of vehicles in the mixed traffic two way flow environment and to develop a simulation model called "AutoTRAFFIC" for simulation of traffic on highway mid blocks. The different stages in the present study were:

i) Collection of traffic data from the field and analysis.

ii) Development of "Video Frame Analysis Method" for the collection of overtaking data along a stretch of road.

iii) Development of "Direct Port Read Method" for accurate speed measurements.

iv) Identification of different types of overtaking operation and development of sub models.

v) Development of the simulation package "AutoTRAFFIC"

vi) Validation of the simulation model.

vii) Experimentation with the simulation model.

8.2 CONCLUSIONS

Major conclusions drawn from field data studies, model building and real time experiments conducted using the simulation model AutoTRAFFIC are listed below:

1) Video frame analysis procedure advanced in this study and direct port read method developed for computing the speeds of vehicles are highly cost effective techniques which are helpful for measurement of speeds of vehicles and study of linear and lateral placement of vehicles. The advantage of these methods is bringing the field conditions directly to the laboratory and hence, they are highly efficient methods for data collection. These methods dispense with the need for marking the pavements and at the same time reduce the required man power for collection of data.

2) The method for determination of density of the traffic stream using instentaneous time mean speeds of vehicles advanced in this study is a very efficient method for collection of spatial data.. The conventional methods of obtaining density suffer from serious limitations of the field of view provided by the video camera and limitations of accurate synchronisation of the timings for the inlet and outlet sections.

3) Unlike the one and only one type of overtaking manoeuvre suggested by Indian Roads Congress for calculation of safe overtaking sight distance, this study has recorded five different types of overtaking manoeuvres that are seen on mixed traffic environment and these have been captioned as: Free Passing, Normal Overtaking, Forced Overtaking, Parallel Overtaking and Streamlined Overtaking. Equation systems have been developed for safe overtaking distances for all the above vehicle manoeuvres. The hypothesis of this work is that the overtaking sight distances will have to be worked out based on all the above types of vehicle manoeuvres seen on our roads system.

4) Some of the major conclusions that have been arrived at the development of the micro simulation package are:

i) Irrespective of the initial headway distribution, the headways stabilise to an exponential model within a distance of 400 to 500m from the inital position. Hence, if the headway distribution are observed after a warm up zone length of 1km, it will be safe to assume exponential headway distribution. It is therefore suggested to have 1km warm up zone length on either side of the study section.

ii) It is possible to reduce the simulation time by adopting the STATE number approach as advanced in this study. By this approach, highly improbable vehicle manoeuvres are filtered out, there by reducing the simulation time.

iii) The timer function available in the Visual Basic can be used to generate a parallel processing system. Each vehicle will be associated with a timer function and thus capable of being processed independently, unlike the vehicle by vehicle processing in ordinary digital simulation. The parallel processing architecture of the modern computer is effectively made use of this purpose.

iv) The simulation package AutoTRAFFIC is capable of simulating the behaviour of mixed traffic flow admirably well as evidence by the Figures of Merit viz, the observed and simulated flow of vehicles in a unit period of time, number of overtaking/km/m and the passenger cars of vehicles computed by the model and compared with the values observed by other researchers.

5) Conclusions drawn from the real time experiments conducted using the simulation package AutoTRAFFIC are:

i) The speed-flow-density relationships even for mixed traffic flow conditions could be by and large explained by same type of relationships as applicable to homogeneous traffic condition. The car following model introduced in this study, with the vehicles being governed by Desired Speed Concept is able to bring about an orderliness in the scatter of points which is very rarely seen in the reported literature.

ii) For a mix of vehicle predominated by two wheelers, any addition to the width of the roadway increases the capacity as a direct function of the increasing width. But, for buses, trucks and other heavy vehicles, additional capacities could be obtained only when the widths of the roads are increased in terms of standard lane width.

iii) Experiments conducted by restricting the overtaking of vehicles have indicated that there could be considerable reduction in capacities of roads predominated by two wheeler population. For one specific vehicular mix in this study, as much as 70 per cent reduction in the capacity of road has been observed. This only calls for careful introspection on the part of traffic

Engineers while imposing restrictions for overtaking in traffic stream operation.

iv) The Dynamic PCU values calculated in the study have shown that considerable improvement in the speed of buses could be obtained by banning the movement of two wheelers and autorikshaws when the flow levels are between 500 to 1000 vph. But in higher flow levels of 1500 or above, the speeds of buses could be improved only by imposing the ban on the movement of trucks and minitrucks on the roadway. The study has demonstrated that even for passenger cars, the PCU values can be vary from 0.94 to 1.52 and for buses the variation could be between 2.16 and 3.55.

v) The simulation experiments conducted in this study for calculation of overtaking sight distances have shown that the maximum overtaking sight distance for a two lane two way traffic condition could be around 900m and therefore the minimum overtaking zone length can be of the order of 1800m. This overtaking sight distance has been arrived based on the extensive simulation of vehicle manoeuvres and is not based on any a priori assumption of certain fixed speed differential between the overtaking and the overtaken vehicles as in the case of IRC method.

8.3 CONTRIBUTIONS

The major contributions of the study are:

i) Development of a simple proceedure for obtaining densities of traffic streams by the use of time mean speed data of vehicles.

ii) Development of a simple procedure for video frame analysis and obtaining speed data using computer port read method

iii) Advancement of a car following theory even for mixed traffic flow operation using the concept of Desired Speeds of vehicles.

iv) Development of mathematical models for overtaking sight distance calculations for different types of overtakings that are seen on mixed traffic flow environment.

v) Introduction of a Dynamic Sign Function for describing the lateral shift of vehicles in overtaking operations.

vi) Development of a comprehensive simulation package called AutoTRAFFIC for simulating all types of vehicle manoeuvres that are seen on mixed traffic conditions. This simulation package has graphic display capability to see and observe the complicated vehicle manoeuvres in mixed traffic flow condition. It has other features such as facility for development of speed-flow-density relationship models and to record the number of overtakings automatically. Thus, the developed package is a very useful tool for conducting many real life experiments.

8.4 LIMITATIONS OF THE STUDY

The developed simulation model is useful for study of mixed traffic flow at two way mid blocks only. The effect of gradient and curvature are not considered in the present study. Similarly, the acceleration and deceleration capabilities of different vehicles have been modelled for only for a very simplistic situation and perhaps these models have to be further refined. Merging, diverging and crossing manoeuvres that are normally seen on road intersections have not been included in the study. The effect of very slow vehicles such as cycles, cycle rickshaws and human and animal driven vehicles have not been studied in this work.

8.5 SCOPE FOR FURTHER STUDIES

The limitations of the study provide the food for thought for further research in this topic. It is of interest to build a simulation package which could possibly take in to account the effect of slow moving vehicles, like cycle, cyclerickshaw and also pedestrians on the road system. Further the simulation package the AutoTRAFFIC, itself could be refined to output the number of conflicts or near conflicts while performing the vehicle manoeuvres and these could perhaps be regressed against the number of accidents that are actually seen on our road system. Such a refinement would be able to predict accidents. Depending on the reality of the accidents predicted by the simulated model, the theory for vehicle manoeuvres may itself have to modified.

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