ANALYSIS OF VEHICULAR INTERACTIONS AT HIGHWAY INTERSECTIONS UNDER MIXED TRAFFIC FLOW

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By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ANALYSIS OF VEHICULAR INTERACTIONS AT HIGHWAY INTERSECTIONS UNDER MIXED TRAFFIC FLOW** in fulfilment of the requirement for the award of the **Degree of Doctor of Philosophy** submitted in the Department of Civil Engineering of the University is an authentic record of my own work carried out during a period from July 1987 to October/November 1990 under the supervision of Dr. A.K. Gupta and Prof. S.K. Khanna.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree.

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ABSTRACT

The major-minor priority intersection is by far the most common intersection layout in current use in India. Intersections are the critical element of road networks and their characteristics determine the efficiency and capacity of the entire road network system.

Consideration of methods of estimating effectiveness and level-of-service of priority intersections shows that despite the considerable amount of research which has already been completed, the possibility of effectively designing and efficiently operating such intersections is still limited, specially under mixed traffic flow as is prevailing in India. The major factors affecting the performance of an semi-urban type uncontrolled (priority) intersection have to be analysed quantitatively, including parameters such as :

- approaching traffic volumes on major and minor roads ,
- composition of the approaching traffic,
- turning flows on minor roads,
- physical and operating characteristics of motorised and non-motorised vehicles,
- approach widths, turning radii, length of turning paths, angle of intersection and
- crossing times and speeds for different type of vehicles.

The above factors get further multiplied when the prevailing traffic is of mixed nature, that is, it is mixture of motorised and non-motorised veicles. As such the cluster of variables is too large to be analysed by any simple intuitive approach. Hence the logical and

ultimate choice is adoption of digital simulation techniques looking to the complexities of mixed traffic behaviour where wide variation in static and dynamic operating characteristics exists, while sharing the same right-of-way.

Therefore the scope of this research work has been :

(i) To analyse the mixed traffic vehicular characteristics of major vehicle types predominantly available on Indian roads with special reference, to size, approaching and clearing speeds at the intersection, composition of traffic and manoeuvring characteristics.

(ii) The analysis has been carried out on 3-leg and 4-leg semi-urban type uncontrolled (priority) intersections with typical Indian urban and rural traffic characteristics. The semi-urban intersections are essentially located at the outskirts of urban areas. However, studies have been done on selected representative sites only.

(iii) Some impoprtant field studies have been designed to be conducted on the selected sites. The data were collected on these sites through manual method and video recording techniques (VRT). This data were utilized for building and validation of the simulation model. Also they were used as a vital input into the simulation model SIMMTRA-345 for analysis of traffic ar uncontrolled 3-leg and 4-leg road intersections.

The digital simulation model SIMMTRA-345 has been developed in FORTRAN-77 language keeping in view its wide acceptability. The event-scanning procedure has been incorporated in the model as it best suits the situation to be simulated.

It has been explained in the experimental programme, that the simulation programme is also divided in sequential steps and then synthesised to obtain logical and reasonable results of practical, as well as, theoretical importance. Summarised programme is :

(i) An initial programme to understand the basic flow process at uncontrolled intersections under mixed traffic flow.

(ii) The flow variables are analysed with special reference to time-headway, intersection clearing timings, approaching and clearing speeds of different type of vehicles, gap acceptance behaviour, approach width and intersection angle.

(iii) Mathematical models and statistical distribution synthesising the above results have been derived and built into a digital simulation model 'SIMMTRA-345'.

(iv) The delays caused to minor road vehicles, are considered to be the measure of performance to establish the level-of-traffic quality at intersection proper.

(v) The concept of vehicular interactions under different traffic and roadway conditions is successfully exploited to obtain the various relationship between input and output parameters.

(vi) The simulation software is run on HP-9600 computer system and the results obtained were validated.

(vii) The simulation programme is dynamic in its behaviour and elastic, responsive, and sensitive towards static and dynamic characteristics of the vehicles considered in the study, approach traffic volumes approach traffic compositions and proportion of turning traffic.

(viii) The composition and conflict factors developed in the present study are based on simulated delays.

(ix) The new equivalent passenger car values developed for the different of vehicles exclusively for uncontrolled intersections under mixed traffic flow vary depending upon the proportion of conflicting traffic and non-motorised vehicles in the approaching traffic volumes.

(x) The established four levels-of-service are based on the simulated average delay to which the minor road vehicles are subjected.

The results of the digital simulation model SIMMTRA-345 provide better and clear insight into the flow variables of mixed traffic flow occuring on uncontrolled priority type semi-urban intersections. The variables are now availeble in terms of :

(i) Vehicular interactions, time headways between successive vehicles, time headway between same type of vehicles, total delay and average delay experienced by all minor road vehicles and the state of length of queue formed on minor road at any instance of simulation time.

(ii) It is possible to have the exact information on the minimum time gap necessary for the different type of vehicles on minor road for clearing an intersection safely.

(iii) The various relationships established between input and output parameters indicate the following results;

- the delays increase with increased approach traffic volumes, which is rather well expected.

- the delays increase with increased proportion of conflicting traffic and non-motorised traffic

- the delays increase with addition of each additional type of vehicles in the traffic stream.

- the delays are affected by approach width and increases as the approach width decreases.

- the delays are marginally affected by angle of intersection and increase as the angle becomes acute.

- left turning vehicles are not subjected to any delay, except pedestrian crossings.

- for the same level-of-service, the delays increase with addition of each type of vehicle in the traffic stream.

- the delay to major road vehicles increases with increased proportion of conflicting traffic in major road traffic stream.

Thus it can be conclusively said, that the developed computer software SIMMTRA-345 is capable of providing an indepth insight into the operational analysis of uncontrolled priority type intersections and the work is geographically transferable in view of parameters incorporated into the model. It may be further added that while the model is applicable to relatively homogeneous traffic also, the work for homogeneous traffic flow is not applicable to the situation analysis herein.

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TABLE OF CONTENTS

PAGE NO.

PAGE NO.

PAGE NO.

PAGE NO.

PAGE NO.

PAGE NO.

LIST OF FIGURES

Page No.

Page No.

Page No.

Page No.

LIST OF TABLES

PAGE NO.

PAGE NO.

CHAPTER I

INTRODUCTION

1.1 GENERAL TRAFFIC SCENERIO AND PROBLEMS

Population growth and distribution and the associated vehicular registration growth are significant factors in the development of transportation demand and the systems that are provided to meet these demands. The road network, as a means of surface transport, is one of the vital components of the infrastructure of transport system of our country. It has a dominant role in over all improvement of the socio-economic conditions, essential movements for employment, cultural and social movement of the masses in both the rural and urban sectors. It is evident from the statistical data that there has been phenomenal growth in road length and vehicle population as presented in Tables 1.1 and 1.2 (1)*. This spectacular increase in vehicle population has given birth to lot of traffic problems, particularly in and around urban areas the traffic picture is quite gloomy (2).

The symptoms of urban and semi-urban traffic problems which are manifest in traffic congestion, delays in journey times, slower speeds, frequent enroute stoppages, the risk of life and vehicular damages, are quite frustrating to the road users. Table 1.3 shows the statistics of accident situation in India which is very alarming (1). These symptoms are to be found in varying degrees in all parts of the world; and hence India is no exception. The problems present themselves wherever there is traffic or likelihood of traffic; which, of course, is omnipresent due to the existance of human population

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* Numbers in parentheses correspond to references listed in the end.

TABLE 1.1 - GROWTH OF ROAD LENGTH IN INDIA

Year	Road length (km)	Percentage increase
1971	917,880	-
1972	1012,399	10.3
1973	1127,943	11.41
1974	1171,318	3.85
1975	1215,262	3.75
1976	1248,795	2.76
1977	1307,798	4.72
1978	1372,140	4.92
1979	1445,873	5.37
1980	1491,873	3.18
1981	1503,994	0.81
1982	1545,891	2.79
1982	1587,000	2.66
1990*	1859,423	2% /annum over 1982
2001*	2266,625	2% /annum over 1990

* In the absence of actual data being available, these are projected figures and are on conservative side.

TABLE 1.2 – NUMBER OF REGISTERED MOTOR VEHICLES IN INDIA

Year	Number of motor vehicles	Percentage increase
1971	1865315	-
1972	2044881	9.63
1973	2109041	3.14
1974	2327064	10.34
1975	2472353	6.24
1976	2699598	9.19
1977	3260118	20.76
1978	3613708	10.84
1979	4058969	12.32
1980	4513986	11.21
1981	5173013	14.60
1982	5844493	12.98
1983	6718539	14.95
1990*	14852549	12%/annum over 1983
2001*	46129763	12%/annum over 1990

* In the absence of actual data being available, these are projected figures and are on conservative side.

TABLE 1.3 - NUMBER OF ROAD ACCIDENTS AND CASUALTIES IN INDIA DURING THE PERIOD 1960-1984

Year	Total No. of accidents	Number of Persons		
		Killed	Injured	Total
1960	55478	5106	37731	42837
1961	59770	5547	36230	41777
1962	62891	6269	39184	45453
1963	65660	6820	36111	42931
1964	68168	7207	42730	49937
1965	71897	8510	45778	53888
1966	74340	8702	48651	57353
1967	100131	9734	51377	61111
1968	102230	10654	58565	69219
1969	97530	8158	46949	55107
1970	114079	14459	70642	75101
1971	120243	15034	70692	85726
1972	122341	16125	76397	92522
1973	121597	17623	79332	96955
1974	114310	17297	76650	93947
1975	116810	16858	77020	93878
1976	124662	17788	82547	100335
1977	135362	20138	95575	115713
1978	146282	21811	99510	121321
1979	144394	22595	102916	125511
1980	152076	25620	108973	135593
1981	160457	27970	114028	141998
1982	167528	30010	126397	156407
1983	170844	30671	131436	161907
1984	191908	53643	153732	187375

and their eternal desire of mobility. Symptoms and warnings abound, traffic and transportation engineers and planners have to look at the problems of the urban and semi-urban traffic in greater depth and analyse them to achieve meaningful alternative solutions.

Marya (3) and Srinivasan (4) have suggested for timely implementation of traffic and transportation operation plans for cities where traffic situation is quite hazardous. Rao (5) very recently suggested an approach for developing integrated action proposals for road transport in metropolitan city of Ahmedabad. The lack of integration within and between the sectors has been found to result in low priority treatment to public transport operations, resulting in increasing congestion and rapid growth of other travel modes in the city, making the overall traffic flow and estimation problems more difficult and complex.

Buchanan (6) suggested tackling the problem without confusion over the aims, without timidity over the means, and above all without delay. Drew (7) further mentioned that these problems shall be with us and they need logical engineering solutions to the engineering problems, which are however very challenging.

Khanna et al. (8, 9, 10) have examined various aspects of the traffic problems in India including flows, trip generation, delays, traffic demand estimation etc. and have suggested some basic solutions.

It is thus seen that there is a rational thinking which has now seriously started to focus the attention on the traffic problems in and around the urban areas.

Efficiency of transport network is interpreted in terms of operating speeds prevailing on the road section and capacities they attain, with optimum level of safety and economy. Of all the elements which combine to form the roadway network, the intersection is one of the most critical in terms of safety, operations and delays (11). At intersection the same right-of-way is assigned to two or more facilities, resulting in a set of unique operational problems and conflicts. The intersections thus become the major bottlenecks in smooth flow of traffic and a major accident spot. Studies in India and abroad have revealed that as many as 25 to 33 percentage of total accidents occur at intersections (12).

One of the most major problems faced by traffic engineers and planners is related to delays at intersections. Cost to the community due to accidents, together with intangible costs of operational delays resulting at these intersections, demand the careful attention of traffic engineers, planners and researchers alike.

A review of the available extensive literature related to this subject revealed that bulk of work has been accomplished towards the intersection analysis and studies. Several models have been developed to analyse the traffic situation at an intersection under different traffic, roadway and control conditions.

In order to reduce the operational problems and conflicts at intersections, different type of controls are introduced depending upon prevailing roadway, traffic and environmental conditions of an intersection. These controls offer varying performance characteristics. There are several methods to control conflicting movements at at-grade intersections. Two of the basic types entail the signalisation and uncontrolled intersections with stop or yield sign. Lot of information is available in literature related to design and analysis of signalised intersections, but very little support is available for the uncontrolled and priority type intersections. Therefore there is a need of an in-depth investigation for the performance of these neglected intersections particularly under mixed vehicular traffic (mixture of motorised and non-motorised vehicles) where same right of way is assigned to them, as could be seen in India and other Asian countries. It is needless to mention that since this problem is a region specific problem, not much global work has gone into it due to obvious reasons.

1.2 SIGNIFICANCE OF THE PRESENT RESEARCH THEME

From location view point the intersections can be classified in to three main categories, viz; urban, rural and semi-urban or semi-rural intersections. The semi-urban intersections are located on the outskirts of urban areas. The traffic characteristics on such intersections is neither purely urban nor purely rural. Most of the semi-urban intersections are priority type intersections. In priority type intersections, the priority is given to major road vehicles over minor road vehicles for crossing an intersection. Whereas the minor road vehicle have to look for the appropriate gap in the major traffic stream. If minor road vehicle does not find the appropriate and safe gap, it has to wait for the same. There is a considerable variety of layouts including three - way "T" or "Y" intersections and crossroads or staggered intersections.

As mentioned earlier, the semi-urban intersections are by far the most common intersection layouts in current use, yet very little is known in an organised manner about their performance, level-of-service and capacity. Although the research work of Aitken (13), Tanner (14), Lewis and Michael (15), Scraggs (16), Salter (17), Ashworth (18), Webster (19) is note worthy in this regard. However these techniques are developed for homogeneous traffic situations and hence can not be applied straight away to heterogeneous traffic situations as are available in India.

Heterogeneous traffic consists of variety of vehicular modes in India as shown in Fig. 1.1 The static and dynamic characteristics of these vehicles vary significantly. The proportion of these vehicles in traffic stream also vary to large extent from city to city as presented in Table 1.4.

The review of literature has revealed that very limited information is available on mixed traffic behaviour at priority type semi-urban intersections (20, 21, 22). Therefore in this context this research work bears lot of significance for the traffic engineers and planners for a detailed and indepth analysis of such intersections.

1.3 MIXED TRAFFIC FLOW CHARACTERISTICS

Mixed traffic flow has been the interest of traffic researchers (23, 24, 25, 26) and some useful studies have been done in different countries around the world to characterise and understand mixed traffic flow behaviour.

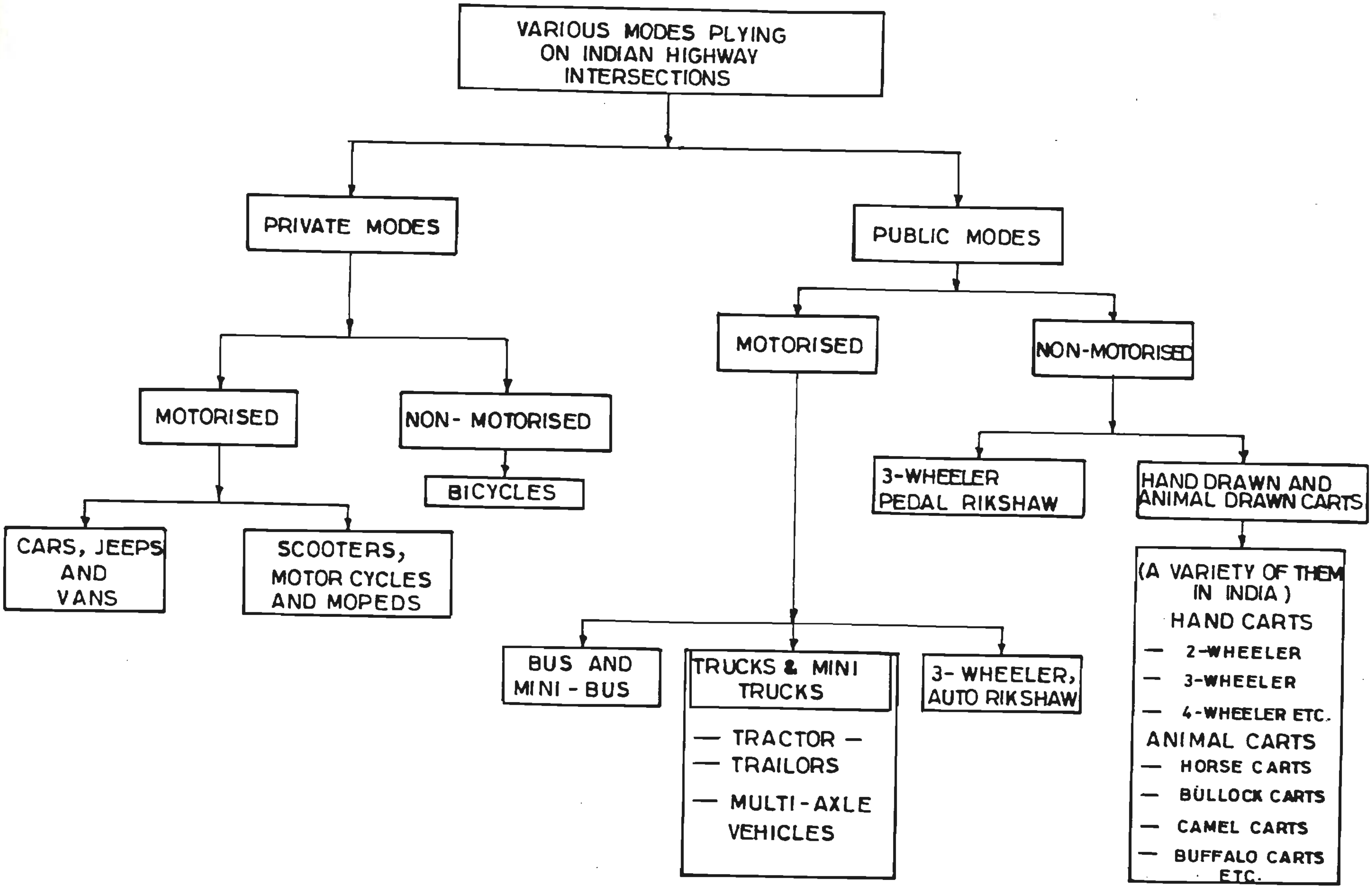


FIG.1.1 DIFFERENT MODES OF ROAD TRANSPORT IN INDIA

TABLE 1.4 – TRAFFIC COMPOSITION IN SELECTED CITIES IN INDIA

City*	Traffic Composition (in percentage of total)				
	Cars, Auto-Rickshaw,etc.	Bus & Truck	Scooters, Motor cycles	Bicycle	Cycle Rickshaw & Other
Ahmedabad	23	2	34	38	3
Chandigarh	15	4	32	37	12
Coimbtore	15	14	22	42	7
Cuttuck	10	17	20	35	18
Lucknow	10	1	17	53	19
Kanpur	10	1	22	48	19
Pune	18	4	27	44	7

* Measurements averaged over four corridors in each city.

Traditionally the term 'mixed' in relation to traffic flow is somewhat analogous to an 'impurity' or a 'foreigner' or, perhaps, may be an 'unwanted guest'. The reason is very simple. Since the entire flow is characterised in terms of passenger cars, any thing other than a 'passenger car' has always created a 'mix' and subsequently its own characteristic problems. Even the highway capacity manual (27, 28, 29), describing these vehicles other than passenger cars, which were primarily commercial vehicles, or trucks as 'capacity reducing vehicles and of course, have to be 'unwelcome', or 'unwanted' or creating a 'mix'. Therefore, mixed traffic flow characteristics may be generalised in very simple terms as a vehicular traffic flow containing vehicles other than passenger cars also, in aggregated traffic flow stream and utilizing same right-of-way or the carriageway (30).

The mixed traffic flow, as characterised in India, is rather peculiar. Though, following the same basic definition of mix, the characteristic mix of the type prevalent in India, is, perhaps not found in any other country except the neighbouring Pakistan and Bangladesh, perhaps to some extent Burma and Sri Lanka. The problems associated with this characteristic mixed traffic flow are many and merit a detailed elaboration.

1.4 PROBLEMS ASSOCIATED WITH MIXED TRAFFIC FLOW

The problems due to mixed traffic flow start from the planning stage and involve themselves through various stages of design, operation and control in a continuous chain action.

The traffic flow of the type prevailing on Indian roads is heterogeneous where passenger cars, may some times, tend to constitute a very marginal proportion, but may have very large variety of other vehicle types. It has been estimated (31, 32, 33) that as many as 13 different incompatible types of vehicles having very different static and dynamic operating characteristics, with as high a speed differential as 5 to 50 kmph; having a total projected area ratio of 1:20 or even more; varying from animal drawn to manually operated and drawn to automobiles, ply on same carriageway in aggregated flows.

In the light of above mixed traffic problems, the analysis of highway intersections becomes complicated in comparison to the homogeneous traffic on account of following reasons :-

1. The heterogeneous modes have considerable variation in their speeds, acceleration and deceleration pattern.

2. Pavement occupancy of each mode is different hence single lane discipline is rather impossible.

3. There are interactions while crossing, turning and merging.

4. Gap acceptance behaviour is a complex phenomenon.

5. The composition of traffic varies to a great extent from time to time and place to place.

6. Delay threshold value for each category of driver is likely to be different.

7. Formation of the mixed queues and their release are quite complicated processes.

1.5 NEED FOR THE RATIONAL APPROACH

The operation of an intersection is greatly influenced by the total volume, type of vehicle and turning movements present in the separate traffic streams approaching an intersection. The general problem facing the traffic engineers is to obtain a level of performance which will qualify to be a safe situation within the overall environment of mobility (34). Very little literature has been reported for the priority type semi-urban intersections so far. Even the control warrants such as two-way stop, three-way stop, four-way stop and signal control are rather based on arbitrary considerations. Though the manual on traffic control (35) provides some guide lines for the choice of intersection control, they do not serve the purpose for mixed traffic flow completely. Thus there is an absolute need for a rational approach in this regard. This further facilitates in finding the level-of-service and delay criteria for evaluation.

1.6 IN SEARCH OF A TECHNIQUE

1.6.1 Possible Techniques

Analysis of mixed traffic at priority intersection is a highly complex phenomenon. There are vehicles and pedestrians that move following physical laws and make their appearances according to the law of probabilities. There are some human decisions that can be explained by psychological laws and there are some other that can not be explained at all.

The theory of traffic flow provides many insights into the working of the road and traffic system and ways of improving it. In some cases the real physical problem can be solved by mathematical techniques. The mathematical models developed to analyse the traffic situation at a priority intersections provide a relatively quick answer to a problem but are often limited in their application due to the assumptions used to develop them. Besides they provide single value on all of the elements of analysis which is most undesirable in discrete traffic situation. On the contrary, the traffic engineer may wish to have the variables represented by a distribution.

Because of a large number of variables involved, the chances of arriving at a rather complicated mathematical model incorporating realism of the traffic problem are high. Hence the analysis of traffic flow at priority intersection through analytical modelling becomes formidable task, which is often beyond practical possibilities. Moreover the analytical approach is a macroscopic in nature and intended to be applicable to a wide range of situations. The individual driver-vehicle unit, is not considered at all in the above modelling approach.

The analysis of traffic by the alternative method of controlled experimentation presents its problems too. It is generally cumbersome, expensive and slow in producing meaningful results.

Knowing the limitations of the analytical and the experimental approaches, many transportation engineers hope to find the solution in simulation technique which is relatively inexpensive and convenient tool to conduct operational analysis of priority type semi-urban intersections under mixed traffic flow. The hope has been inspired by the widespread availability of high speed digital computers which make possible the replication of an incredible number of stochastic variables in a very small time. Further desirable result is the possibility of introducing changes in the variables without traffic safety risks, and any number of times.

1.6.2 Simulation Approach

Simulation can be defined in general terms as the representation of a real system that is to be analysed by a model which the analyst can manipulate. Thus simulation of road traffic by means of digital computers is a useful operation for the analysis of traffic situations where theory does not lead to a formula or other analytical solution which is suitable in practice. The simulation also provides a large amount of data under controlled laboratory conditions which would be difficult, if not impossible, to obtain through field studies (36).

The main purpose for opting simulation approach is its capability to simulate the actions and interactions of the intersection traffic system, so that effectiveness of the system can be determined for any set of designed conditions. The various steps involved in development of simulation model for traffic analysis are shown in Fig. 1.2.

1.7 Definition and Problem Identification

The problem now becomes defined in view of the gap of the existing knowledge and the needed research as outlined in article 1.2.

The specific problem may now be listed as follows, identifying its components :-

1. What is the process, magnitude and type of vehicular interactions at priority type intersections with special reference to the

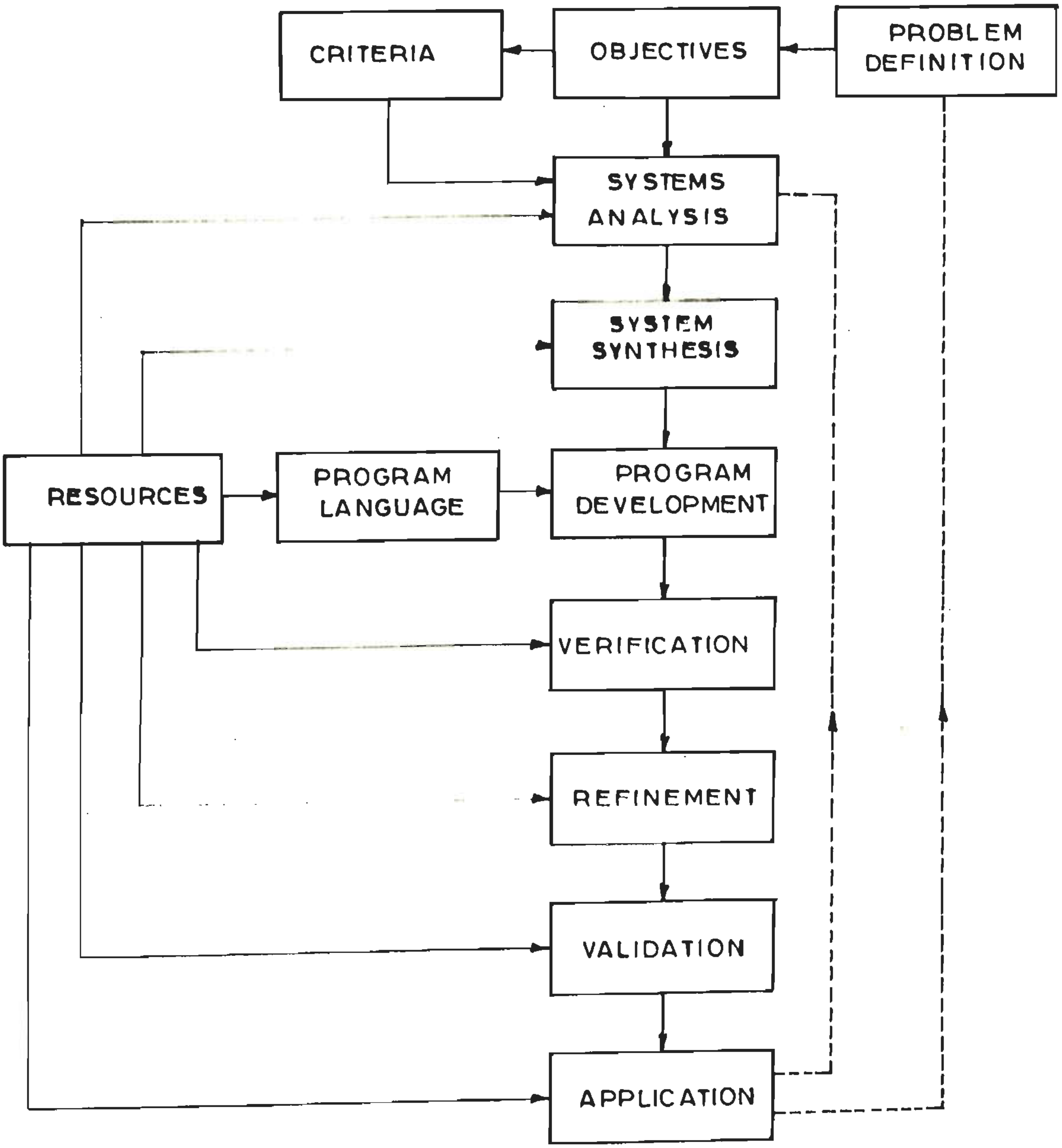


FIG. 1. 2 THE SIMULATION MODEL DEVELOPMENT PROCESS

heterogeneous type of traffic flow prevailing on Indian roads.

2. How to define in terms of the vehicular interactions, the effective volume of the existing traffic flow, which may be represented in terms of passenger car units or as an equivalent passenger car values (EPCV) for developing level-of-service criteria.

3. A special aspect to be included in this work is that no attempt is being made to consider traffic flow as relatively homogeneous, rather all vehicle types are being considered simultaneously in the flow analysis.

It only appears logical that a description of methodology adopted be made to link this problem identification to possible solution techniques.

1.8 Methodology

The method of handling the problem as defined above may be said to be the formulation of an appropriate simulation model and analysis of traffic at priority intersection.

Though the details of the formulation shall be described in detail later, the basic methodology adopted herein is :-

1. To develop a simulation model and analyse the priority intersections in terms of those simple variables and parameters which may be easily measured and analysed. For this purpose the following interactions , variables and parameters are measured-

   - Through crossing speeds

- Through size of the vehicles
- Through total approaching volumes in each approach
- Through composition of traffic in the intersection flows
- Through turning proportions i.e. directional split of flows
- Intersection geometry and relative importance of crossing road.

2. A further subdivision of the work is done by breaking it up in two distinct compartments :

   - Three-legged 'T' or 'Y' intersections with varying intersection angles and approach widths.
   - Four - legged right angled intersections or cross roads or staggered 4 - arm intersections with varying intersection angles and approach widths.

3. A special field study programme to collect the data, for model formulation and validation, through manual and video graphic recording techniques (VRT) has been employed.

4. A simulation model has been developed to compute the total delays, average delay and queue length, that are considered to be the figure of merit for evaluation of intersection performance. Also the relation between level of service and average delay has been established.

5. A simulation model formulated in Fortran-77 language and run on HP-9600, and DEC-2050, high speed digital computers is validated by feeding the observed data into the model.

CHAPTER - II

REVIEW OF WORK RELATED TO VEHICULAR INTERACTION AT - GRADE INTERSECTIONS THROUGH ANALYSIS AND SIMULATION

2.1 GENERAL

Vehicular interactions in a heterogeneous mixed traffic flow at highway intersections present a challenging task (37, 38, 39, 40) to traffic engineers and planners in many ways. Normally the number of variables involved and the affecting parameters are so large that a very complex interaction results from such intersection analysis. Simulation of road traffic by means of digital computers is a useful tool for the analysis of traffic situations where analytical models do not lead to a unique or closed form solutions. It is in such cases that simulation often enables the analyst to finish off the task that theory has enabled them to begin, through analysis of problem in parts.

Sound and tested simulation models can be used to estimate the likely effects of various changes that the traffic engineer or planner may have in mind for a road system. The capabilities of simulation are equally reliable as closed - form analytical models and has many additional advantages.

Traffic simulation models may be stochastic or deterministic. They have been used in the stochastic representation of traffic situation where the random variations can not be analysed theoretically and in deterministic representation of traffic in networks.

6. With simple input data the final desired values may be directly obtained with approximately 1 minute of computer time depending upon the size of the input data.

1.9 OBJECTIVES AND SCOPE OF THE PRESENT RESEARCH

1.9.1 Objectives

In continuation of the discussion of the problem identification and methodology, the broad objectives of the research programme are to study the heterogeneous traffic behaviour at priority type semi-urban intersections with a view to,

* Identify the suitable statistical distributions for headways, speeds and gap acceptance under mixed traffic conditions.

* Estimate the relative vehicular interactions due to change in traffic composition, total approaching traffic and turning traffic in terms of total delay.

* Estimate the vehicular interactions due to physical characteristics of an intersection.

* Develop the composition and conflict factors. These factors essentially incorporate the effect of vehicular compositions and inter-vehicular conflicts.

* Develop the equivalent passenger car values exclusively for priority intersection on the basis of composition and conflict factors.

* Develop the relationship between level-of-service (LOS) and average delays.

1.9.2 Scope of the Present Research

For achieving these objectives, the scope of the present programme has been limited within the realm of completion of the research programme and restraints on time, cost and other variables :

1. Only three categories of approach width are considered.

   (a) 3.5 m (minor road) corresponding to single lane.

   (b) 7.0 m (minor road) corresponding to double lane.

   (c) 7.0 m (major road) corresponding to double lane.

   Actually these conditions cover majority of Indian intersections in operation.

2. Only priority type semi-urban intersections are considered for the study with three or four approaches.

3. Only vehicular analysis is within the scope of the study. Pedestrians are not included in the analysis.

4. Give way or yield type control on the minor road is considered.

5. Only seven vehicle types are considered or all vehicles have been grouped in seven major categories.

The stochastic digital simulation model "SIMMTRA -345" has been developed for the analysis of mixed traffic at priority type intersections.

1.10 THESIS ORGANISATION

Chapter II presents a review of research studies related to analysis of vehicular interactions at at-grade intersections through simulation techniques, carried out for varied traffic, roadway & control conditions in India and abroad. Also some important arterial, network and corridor simulation models have been discussed along with the analytical studies for priority type intersections. Few note worthy studies at road intersections and road sections under mixed traffic conditions have also been highlighted.

Chapter III consists of the details of experimental programme and field studies carried out for the research work. The design of field studies and other salient features of each field study including the type of the data required and method of its measurement is presented. Specially designed video technique of data collection has been presented in this chapter. Finally the problems faced during data collection have been highlighted in this chapter for general usage and for subsequent research studies.

Chapter IV presents the data collection through the programme of the field studies as identified in chapter III and the analysis of data for subsequent usage in development and validation of simulation model 'SIMMTRA-345'. Some of the results of data analysis, such as, crossing times, crossing speeds, approaching speeds etc. have also been presented in this chapter.

Chapter V, first discusses all the variables and parameters that are to be incorporated in building a digital simulation model and subsequently presents the process of developing digital simulation model for analysing mixed traffic flow at priority type intersections. The simulation model SIMMTRA-345 has been written in Fortran-77 language and operated on HP-9600 computer system. The programme was also run on DEC-2050 with slight modification in the simulation model.

Chapter VI highlights the various simulation experiments with 'SIMMTRA-345' on mixed traffic flow at priority type intersection approaches. Experimental results and discussion on various established relationships between volume - delays, volume - queue lengths, composition of traffic - delays, conflicting traffic - delays have been presented. The development of composition and conflict factors for computing new equivalent passenger car values exclusively for priority type intersection have also been presented in this chapter. Homogenising and heterogenising effects and effects due to roadway factors have been studied through SIMMTRA-345. Also the major road conflicting movements have been simulated and the results have been presented. Finally the criteria for level - of - service for priority type intersection has been established.

Chapter VII presents the listing of the summarised conclusions of this research programme and suggestions for further work are also provided.

At the end, the references used in this thesis report and vitae of the author have been included.

The early simulation models were limited in the complexity of the system simulation (41). The physical limitations of contemporary computers in respect of software and hardware did have effect on efficiency of initial models. However in recent years because of the availability of high-speed digital computers, it has been possible to adopt digital simulation more effectively to solve the complex traffic problems at highway at - grade intersections. These solutions have also become cost - effective, safe to perform and accomplish such options which are either impossible or impracticable otherwise.

2.2 TRAFFIC SIMULATION OF AT - GRADE SIGNALISED INTERSECTIONS

Mathewson and Trautman (42) used analog simulator for analysing traffic at intersection way back in 1950. A simulation model was developed by Goode, Pollmar and Wright for a signalised intersection with two lanes in each direction (43). Afterwards in a modified version of the model a dynamic picture of the intersection traffic was displayed.

Probably one of the earliest application of simulation to a traffic situation was its use by Webster (19) in obtaining an expression for average delay to a vehicle passing a fixed time traffic signal when the vehicles arrive according to Poisson process.

Lewis and Michael under a research project have developed a digital simulation model to determine volume warrants at four - legged, right angled street intersections (15). Two types of intersection control were studied, the semi - actuated signal and two - way stop sign. The delays were measured at the intersection and used as criteria for the establishment of warrants for the type of intersection control.

Simulation studies were carried out by Young (44), Francis (20) and Miller (45) on co-ordinate signal systems. The studies were carried out on general purpose computers (GPC's) with memorandum representation of information. However in some cases special purpose simulators (SPS's) have been developed (46).

A simulation model was developed by Pretty (47) to assess the effect of right-turning vehicles on saturation flow at - signalised intersections.

Culshaw (48) simulated the effects of different type of traffic signal controllers on the performance of signalised intersection through digital simulation.

In another simulation study, Robertson used TRANSYT computer programme to find the best timing for coordination of a traffic signal system. The programme uses a simulation model to predict the average number of stopped vehicles within a network and seeks to minimise that number.

A simulation model SIGNET (50) was developed for use in the design of signal systems. The use of the SIGNET model is not restricted to signal timing studies but, infact, the effects of many other traffic engineering measures may be evaluated by varying the programme inputs. Such measures could include turning movements, turn prohibitions parking restrictions, unbalanced lane operations and one - way street operation.

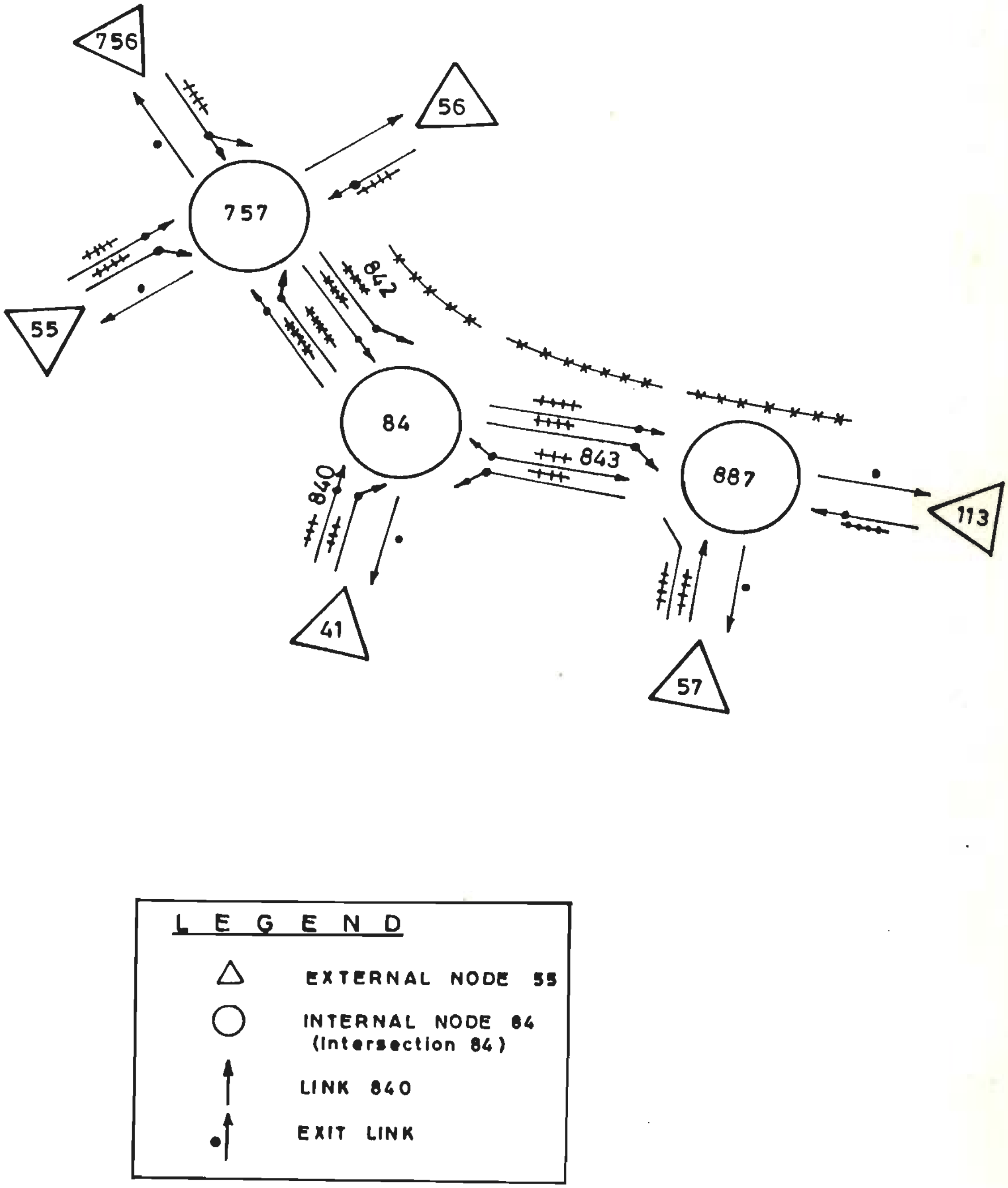
Cohen has applied UTCS - 1 network simulation model, with certain modifications, to analyse the traffic performance of single urban intersection (51). It was found that modified UTCS-15 simulation model is an accurate and flexible model suitable for use in the analysis of the performance of individual intersections.

NETSIM/UTCS - 1 is a microscopic simulation model developed by Lieberman and Rosenfield in 1971 for analysis of road networks. Basically, it is an arterial network model but it can treat most major forms of urban traffic controls and was primarily designed as a tool for testing alternative control strategies under conditions of heavy demand.

The modified version of NETSIM (53) is particularly applicable to evaluation of dynamically controlled signal system which uses real-time traffic survillance information. It simulates both fixed time and vehicle actuated signal operations. Detailed driving behaviour such as lane - changing, car following and acceleration/deceleration are simulated (54).

The NETSIM model is capable of simulating variety of geometrical situations such as double right turn movements, T-intersections, one-way streets and diagonal turns (the one that has an obtuse turning angle). These forms are represented in Fig. 2.1.

In one comparison study Devis (55) used the NETSIM model for analysing hypothetical four - legged intersection with single - lane approaches, controlled by a fixed time signal, and for isolated semi-actuated signal at T-intersection. It was found that in case of T-intersection, the average number in each of the queues were more or less matching with field observations. It was also observed that



TRAFFIC MOVEMENTS 842 & 843 REPRESENT DIAGONAL TURNS WITH AN OBTUSE TURNING ANGLE

Fig. 2.1 Representations of various geometric situations considered by NETSIM the queue lengths predicted by NETSIM are generally slightly shorter than those observed.

On the other hand when NETSIM was applied to the hypothetical intersection and the results were compared with Webster technique, it was found that in general, NETSIM predicts about the same or less delay than the Webster method until nearing capacity at which time NETSIM predicts higher average delay.

In one another simulation study the load factor was found for signalised intersections. The load factor is widely accepted as the performance indicator for level-of-service (LOS) of signalised intersections. The highway capacity manual (HCM) (56) has suggested numerical limits of load factors for various levels-of-service as presented in Table 2.1.

TABLE 2.1 – LOAD FACTOR LIMITS FOR VARIOUS LEVELS-OF-SERVICE AS RECOMMENDED BY HCM

Level of Service	Traffic Flow	Load Factor
A	Free	0.0
B	Stable	< 0.1
C	Stable	< 0.3
D	Approaching unstable	< 0.7
E	Unstable	< 1.0
F	Forced	-

May and Pratt (57) and Sutaria and Haynes (58) used the results of simulation study to correlate average delay with level-of-service for signalised intersection. The developed correlations are shown in Table 2.2

TABLE 2.2 - RELATIONSHIP BETWEEN LEVEL-OF-SERVICE AND AVERAGE DELAY

Level of Service	Average Individual Delay (sec/veh) May and Pratt	Sutaria and Haynes
A	< 15	< 12.6
B	< 30	< 30.1
C	< 45	< 47.7
D	< 60	< 65.2
E	> 60	< 82.8

Jacobson (59) developed a computer model SYMSYG which simulates the operation of one approach at a fully actuated traffic signal. The user is permitted to vary any of the large number of inputs to determine the effects of alternative design and timing schemes on queue lengths, delay, cycle lengths stops and fuel consumption. Lee developed a TEXAS model (60) to analyse the intersection traffic for signal warrants and intersection capacity. The level-of-service criteria has been established for signalised intersections based on average stopped delay to vehicles on all approaches.

Ferrara (61) has developed a simulation model to simulate delays at a signalised intersection. The model is capable to determine the service time and delays to motor vehicles and bicycles at signalised intersections. The results offer some quantitative indications on level of delays for various combinations of traffic flows.

A simulation model SIMSET 2 was developed by Nairn (62). The SIMSET 2 model is for isolated traffic signals and currently is in extensive use in Australia for design and optimization of existing signals.

The main objectives of the SIMSET 2 model are :

1. To assess accurately the effects of lane width and lengths and alternative phasing arrangements.

2. To provide a means to readily test a number of design alternatives.

The model SIMSET 2 provides a simple and convenient mechanism for the comparison of alternative treatment for isolated signal operation both in terms of geometric layout and phase sequence.

Keller and Saklas (63) have developed a procedure using a microscopic traffic simulation model on an urban network to derive passenger car equivalent (PCE) estimates for large vehicles as a function of vehicle size, signal timing and traffic volume. It was observed that as the length of vehicle increases and signalisation approaches to optimum, the PCE values also increase.

A simulation model SIGART was developed at University of Bradford (64) for simulating traffic at a signal controlled roundabouts.

Salter (65) divided the model SIGART in two parts. The first part accepts input data and performs necessary calculations where as the second part performs a simulation study using the traffic and signal information supplied. The relationships between average delay and queue length, degree of saturation and average delay and demand flow and inscribed diameter were investigated. It was found that the results of SIGART agree more or less with observed values.

Shawaly, Ashworth and Laurence (66) have compared the observed, estimated and simulated delays and queue lengths at over saturated signalised junctions. Doherty's comprehensive delay formula was made use of, to find out the average delay (67). The simulation programme developed was capable of producing data similar to the actually observed at signal-controlled intersection and the simulated results of both queue length and delay have demonstrated the considerable variability in observed value of these parameters and their sensitivity to change in vehicle arrival and departure profiles.

Rathi and Santiago (68) report that the NETSIM simulation model has been modified to TRAF-NETSIM simulation model. Four new features have been added to this modified version of simulation model; viz; actuated controller logic, identical traffic streams, conditional turning movements and signal transition. Over and above several major modifications have also been incorporated to the simulation logic to resolve the problems encountered during the testing of the simulation programme.

Rathi and Santiago (69) have presented an enhancement of the TRAF - NETSIM simulation model which provides users with the ability to simulate the traffic streams exhibiting identical routeing patterns, driver-vehicle characteristics and other operational characteristics through a series of runs. Thus the user can make a series of simulation runs by retaining a traffic stream of an initial run while employing different traffic controls or operational conditions in the subsequent runs.

A microscopic simulation model that has found application in more than one european countries is the SIGSIM model developed by Hansson (70). Such a model is particularly relevant now that the microprocessor controller has opened the way to a much wider range of vehicle-actuated control strategies than was possible hitherto. One specialised application of vehicle actuated operation of signals is to give priority to buses or trams that are detected selectively by the control apparatus. The consequences of doing so in terms of capacity and delay to the various traffic streams at the junction are difficult to calculate theoretically, and a simulation model for this purpose was developed by Wood (71).

One of the most ambitious applications of microscopic simulation so far is the work of Hubschneider (72) and Mott (73), in which the simulation of traffic in a signal-controlled street network equipped for the selective detection of public transport vehicles was linked with the simulation of operation of an automatic public transport vehicle-location system. This permitted simulation of control strategies in which the giving of priority to public transport vehicles at signals could be influenced by the requirements of the public transport operator.

For signal-controlled networks in which the pattern of traffic is assumed to be known, a great deal of effort has been devoted to methods of calculating good timing plans for the co-ordinated operation of signals in the network. One important tool for this purpose is model TRANSYT (74) which simulates the movement of traffic through successive signal - controlled junctions operating with a common cycle time by means of Cyclic Flow Profiles. This has proved a very useful tool where there are substantial number of traffic signal.

2.3 UNCONTROLLED (PRIORITY) INTERSECTIONS

There are several methods to control conflicting movements at unsignalised intersections. Two of the basic types entail YIELD-Sign and STOP-Sign control. These are regulatory signs which are used to inform the road users of the specific right-of-way requirements at the intersection.

The YIELD sign is a type of regulatory sign which assigns right-of-way to traffic on certain approaches of an intersection. All drivers approaching a YIELD sign are required by law to slow down and 'yield' the right-of-way to vehicles in the intersection in other major stream of flow. Vehicles controlled by a YIELD sign need only stop when necessary to avoid interference with other traffic which has the right-of-way. YIELD signs are usually placed to control minor flow of traffic at intersections.

The STOP-sign, on the other hand, requires every driver to come to a complete stop at the approach stop line before determining whether or not it is safe to enter an intersection. The STOP sign is placed on each approach of the minor road or when the two crossing roads have similar geometric & traffic features.

2.3.1 Simulation Studies for Homogeneous Traffic Conditions

A simulation model was developed by Kell as early as 1962(75,36). The model was applicable to the intersections with 2-lane two-directional streets with one street being controlled by STOP sign. The model was capable to compute acceleration and deceleration for both major and minor roads and slowing, stopping and queueing delays. Finally the relationship between delay and approach volumes was established.

Lawis and Michael (15) have developed a digital simulation model to determine volume warrants for two-way stop sign intersection. The delays were measured at the intersection and used as criteria for establishment of warrants for the type of intersection control.

An uncontrolled T-intersection was simulated by Aitken (13) to analyse the traffic conditions.

A digital simulation model was developed by Wright (76). The performance of an intersection was studied under various volume levels and percentage of turning traffic. Input to the programme were based on field studies at three intersections.

A two-way intersection with stop sign was simulated by Thomasson (77). The traffic was simulated to check the performance of an intersection.

By making use of general purpose model, Tully (78) simulated a T-junction with dual carriageway and a single carriageway.

Pillai used the digital simulation technique to study the traffic behaviour at pedestrian crossings (79, 80). A traffic corridor selected for the study consisted eleven minor road junctions, five pedestrian crossings and two vehicle actuated signal controlled intersections. Through simulation technique it was possible to develop the warrants for pedestrian crossings based on traffic volumes.

Fergusson (81) has presented the results of his conflict simulation programme. The traffic at a T-junction was simulated for conflicting traffic streams.

Ashworth, Goodwin and Cheung (82) reported the simulation studies at a T-junction. Traffic delays were measured with various alternative forms of layout of T-junctions.

Cooper developed a conflict simulation model (83) to study the accident situation at T-intersection with 'GIVE WAY' sign. It has been discovered that the factors such as approaching volumes, turning volumes, intersection geometry, speed, etc. affect the conflict rate. Scraggs (16) reports simulation studies of an uncontrolled Tee intersection to determine the capacity of minor road for any combination of turning movements. An empirical formula has been developed for the capacity of minor road based on the results of his simulation studies.

A simulation model TEXAS was developed by Rioux and Lee (84, 85) way back in 1978. It is a microscopic and time-scan simulation model. The model is designed to perform detailed evaluation of traffic performance at isolated intersection. It has been recommended that the model is useful for developing and evaluating alternative geometric or control improvements for intersections.

Hothersall and Salter (86) have presented a series of design curves for deducing average delays, which have been computed, using the theory of Hawkes (87). The usefulness and accuracy of the Hawkes theory is assessed by comparing its results with those deduced using a computer simulation model of traffic flows at a junction with the necessary restraints. A T-junction, with single lane approach, was considered for the study. It was found that the agreement between two methods is adequate over the range of parameters which have been considered.

Allsop and Charlesworth (88) have combined the two programmes TRANSYT and TRAFFIC and have provided a completely computerised procedure for examining a given road network and finding signal timings that will induce an improved traffic pattern for engineers of planners.

Lee has used TEXAS model (21) to evaluate the capacity and level-of-service of isolated unsignalised intersections through simulation. Lee used queue delays as an indicator for level-of-service of unsignalised intersections. It has been recommended that TEXAS model is best suited to analyse the capacity of unsignalised intersections under different traffic, geometric and volume conditions.

A Tee-junction, with priority control, was simulated by Salter (89) in 1971. A series of digital computer models of traffic flow have been used for investigating the behaviour of vehicular flow at priority intersections.

Ashworth (90) investigated the gap acceptance behaviour and delays to minor road vehicles at priority type intersection by making use of digital computer. Intersection delays were compared with Tanner's delay model for various combinations of major and minor traffic volumes. The intersection considered in the study consisted of crossing by a minor road and dual carriageway of main road.

Darzentas and others (91) have described an event stepping simulation model for investigating the risk of traffic accidents at T-junctions. A version of the traffic-conflict technique was made use of under various traffic and behavioural parameters to simulate the traffic. The vehicular delays and the capacity of intersection were not considered in the study. It was mainly concerned with road safety aspect.

Salter (92), in 1982, has described a computer simulation investigation for an oversaturated priority intersection performance. A simulation model is discussed in which it is possible to input both priority and non-priority route flows which have a flow variation typical of peak hour traffic. The average delay per vehicle and queue length for non-priority route have been found. Finally the comparison of simulated and observed traffic delays is made for an intersection in the city of Bradford.

The traffic flow (93) at temporarily over-saturated priority junction was simulated by making use of microcomputers. The performance of traffic and choice of control devices at intersection through simulation was studied by Lee (94). A TEXAS-II model was used. The performance of traffic control devices was studied in terms of vehicle emissions and fuel consumption at intersections.

Vasarhelyi (95) has studied the traffic at an uncontrolled road intersection through stochastic simulation model. An uncontrolled intersection with poor visibility, where the right-of-way belongs to the driver on the right, were considered. The model deals, with crossing with and without turning movements. Finally volume warrants were proposed for establishing two way stop/yield controls on uncontrolled crossings.

Popat, Gupta and Khanna (96) have analysed the traffic at uncontrolled T-intersection by making use of a simulation model developed at Monash University, Australia (97). The relationship between delay, queue length and approaching volumes.

A more recent and wider - ranging example of the use of simulation to validate intuitive approximate queueing formulae is provided by the work of Kimber and Hollis (98) on expressions for queue-length and delay as a function of time in queues where the arrival rate and departure rate are subject both to random variation and to systematic or uniform variation over time.

Marian TRACZ (99) has reported, in his simulation studies, the capacity reducing factors of priority intersections. The basic characteristics of traffic simulation models have been described for three types of priority intersections. Special attention has been given to the quantification of level-of-service and the service volumes determination measures. The effect of turning movements and adjacent traffic signals on capacity of minor road approaches along with other simulation results have been presented.

The Institute of Roads, Railways and Bridges (warszawa) (100) has carried out the studies to investigate the capacity of unsignalised intersections.

Ashworth and Bottom (101) have simulated the traffic at priority-type intersections. The drivers gap-acceptance behaviour was studied at priority type intersections and results have been presented.

In addition to the simulation studies and models discussed so far, the list of simulation models developed for different transportation and traffic engineering purposes, is presented in Table 2.3.

2.3.2 Studies on Heterogeneous (Mixed) Traffic Situations

Bhattacharya (102) has developed a relationship between clearing speed and clearing volume for signalised intersection under mixed traffic flow. The relationship is given as :

$$Q = \frac{3600}{h} = 590V - 43.5\ V^2 \qquad (2.3.21)$$

where

V = clearing speed (m/sec)

Q = flow (VPH)

h = headway (sec)

It has been stated that initially the flow increases with increased clearing speed, but after a particular speed limit, it tends to decrease.

The effect of bicycle traffic on saturation flow has been estimated by Srinivasan (103). The following relationship between saturation

TABLE 2.3 - BRIEF DETAILS OF INTERSECTION MODELS

Sl.No.	Name of Model	Year of Development	Purpose of Model	Characteristics of Model	Language	Run on
1.	TEXAS	1978	Traffic Performance	Mic, Stoc., TS, Sim.	Fortran-IV	CDC 6600 IBM 370
2.	SOAP	1977	Signal timing (cycle, splits & phasing)	Mac., Det., TS, Opt.	Fortran-IV	IBM 360/370
3.	SPLIT	1976	Signal timing (splits only)	Mac., Det., TS, Opt.	Fortran	IBM 360
4.	CYCLE	1976	Signal timing (cycle only)	Mac., Det., TS, Opt.	Fortran	IBM 360
5.	HARPST	1975	Pedestrian effects	Mac., Det., TS, Sim.	GPSS	IBM
6.	SIGCAP	1975	Signal timing (splits only)	Mac., Det., TS, Opt.	Fortran	
7.	UTCS-15	1973	Traffic performance	Mic., Stoc., TS, Sim.	Fortran-IV	IBM 360
8.	BLY	1973	Bus priority lanes	Mic., Sim.	Fortran	Unknown
9.	SIGSET	1971	Signal timing (cycle & splits).	Mac., Det., TS, Opt.	Fortran	IBM 360
10.	BRADFORD	1968	Gap acceptance	Mic., Stoc., TS, Opt.	ALGOL	ICL 1909
11.	TEC	1968	Traffic performance	Sim	GPSS	IBM 7094 IBM 360
12.	JONES	1968	Left turn storage	Mic., Stoc., TS, Sim.	Fortran	IBM 1130
13.	DARE	1968	Advisory speed signals	Sim.	GPSS	IBM 360
14.	WRIGHT	1967	Stop control delays	Mic., Stoc., TS, Sim.	ALGOL (Ext)	Unknown
15.	BOTTGER	1965	Four way stop	Mic., TS, Sim.	Unknown	Unknown
16.	NCIRP	1964	Traffic performance	Mic., Stoc., TS, Sim.	Fortran-III FAP	IBM 1094
17.	MILLER	1965	Effect of Turns	Mic., Stoc., Sim.	Unknown	Unknown

(Contd....)

(Contd....) Table 2.3

18.	AUSTRALIAN	1964	Capacity and controls	Mic., Stoc., TS, Sim.	Fortran	IBM 7090
19.	BLEYL	1964	Traffic performance	Mic., Stoc., TS, Sim.	Fortran-II	IBM 7094
20.	EVANS	1963	Queueing at stop signs	Mic., Stoc., TS, Sim.		IBM 7090
21.	AITEN	1963	Queueing at "Tee" junction	Sim.	Unknown	Ferrenti sirius
22.	KELL	1962	Vehicular delay	Mic., Stoc., TS, Sim.	FAP	IBM 701 & 7094
23.	LEWIS	1962	Traffic control	Mic., Stoc., TS, Sim.	Fortran-II/ FAP	IBM 7094
24.	NPL	1962	Traffic performance	Mac., Det., Sim.	Unknown	Ferrenti pegasus
25.	CHEUNG		Delay	Mac., Det., TS, Sim.	Fortran	ICL 1907
26.	GOODE	1956	Delay	Mic., Det., TS, Sim.	Unknown	MIOAC IBM 704

Abbreviations :

Mic.	-	Microscopic	Det.	-	Deterministic
TS.	-	Time scan	Sim.	-	Simulation
Mac.	-	Macroscopic	Stoc.	-	Stochastic
ES.	-	Event scan	Opt.	-	Optimization

flow and percentage of bicycle flow in traffic stream has been developed.

$$Y = 0.12X^2 - 17.27X + 2053 \quad (2.3.22)$$

where

Y = saturation flow in passenger car units (PCU's) per hour of green time per lane.

X = percentage of bicycle in traffic stream.

Gupta (104) has analysed the vehicular interactions under heterogeneous traffic flow. A mathematical model has been developed to estimate traffic demand of a mixed traffic flow stream in terms of passenger car volume or Effective Equivalent Passenger Car Volume along with other flow conditions.

Traffic was analysed at intersection under mixed traffic flow by Jain (105). Level of service criteria for intersections under mixed traffic flow was studied. The left and right turning factors have also been suggested.

Khanna and Gupta (106) have examined various aspects of mixed traffic flow problems in India including traffic flow, trip generation, delay, traffic demand estimations etc. and have suggested some basic solutions.

Katti, Shastri and Pathak (107) have determined the degree of constraints for the mixed traffic on Indian urban arterials against varied traffic volume levels. Bunching and pre and post bunching behaviour has been considered in developing the regression models for the proportion of free and constrained vehicles. It has been claimed that the model is applicable to simulation studies and qualitative evaluation of prevailing traffic.

2.3.3 Simulation Studies for Heterogeneous (Mixed) Traffic Situations

The various simulation studies discussed above, to simulate the traffic at at-grade intersections, have normally been carried out for homogeneous traffic only. The traffic consisted of very low percentage of commercial vehicles. Thus mode wise they belong to only powered (motorised) vehicle group. Two wheeler motor cycle/scooters, three wheeler auto rickshaws and other non-motorised vehicles like bicycles, pedal rickshaw and animal and hand drawn carts were almost absent in the traffic streams or were not considered in the simulation to simplify the work.

But the traffic scene in developing countries like India, Nepal, Ceylon, Bangladesh & Pakistan, is entirely different. It consists both motorised, as well as, non-motorised vehicles, more or less in equal proportions. The physical and operating characteristics of motorised and non-motorised vehicles vary to a great extent.

Rather limited work has been reported on simulation studies on uncontrolled at - grade intersections under mixed traffic flow of the type obtaining on Indian roads.

Ferrara (108) has developed a simulation model to study the performance of an intersection controlled by stop signs. The model is applicable to 4-legged intersections with simple geometry. On each approach one lane is provided for motor vehicles whereas the remaining space is assigned to bicycle traffic. It was discovered that the model gives a fairly good representation of delays to bicycles and motor vehicles at intersection under stop-sign control.

Katti (109) has developed a digital simulation technique to study the mixed traffic behaviour at the priority approaches as well as the intersection proper. Two models, MITISS and SIMPRI, have been developed to study the mixed traffic behaviour and traffic performance at priority intersections respectively.

Narasimha Rao (110) simulated rural road intersection and suggested warrants for the same.

Bhanu Murthy (111) has introduced the pedestrian component into an idealised road intersection. The delays were developed through simulation on uncontrolled urban intersection.

A simulation model STUPTRI, in fortran language, has been developed by Chari and others (112) specifically for the mixed traffic conditions as are available on Indian roads. The model is applicable to uncontrolled priority type three - legged rural intersections. Finally the relationships between volume, number of vehicles delayed, total delay to various approaches and intersection angle are established. However only four categories of vehicles have been considered in simulation.

Gupta and Jain (113) have developed two simulation programmes to analyse the behaviour of intersection flows at 'T' and 4 - arm intersections. Working under the research scheme R-13, sponsored by

Ministry of Surface Transport, Government of India, they have developed a simulation programme which truly represents the intersections under mixed traffic flow.

The traffic simulation model was developed by Sushil Kumar (114). The model is used to study the traffic flow behaviour on a Delhi metropolitan road corridor of two-way and four lane.

2.4 SOME OTHER IMPORTANT TRAFFIC SIMULATION MODELS

Wallman (115) has illustrated a simulation model in his Ph.D. work. In his simulation model he has studied the influence of geometric design and traffic composition on individual drivers and vehicles for the presentation of the traffic consequences of a certain design to politicians, decision - makers and other laymen involved, before the road is constructed. Furthermore, by making use of magnetovision technique, it has been made possible to display the traffic flow on CRT screen. The model is applicable to grade-separated intersections and would prove useful in obtaining optimum design of interchanges.

Rathi and Nemeth (116) have described a simulation model to simulate the traffic operations at freeway lane closure. The model logic is based on a rational description of the behaviour of the driver in a freeway lane closure situation and the programme is written in simscript 11.5. An application of the model is illustrated with evaluation of potential safety impacts of reduced speed zones in freeway lane closures at different levels of assumed driver compliance.

Perchonok (117) has studied a digital computer application to the problem of freeway-on-ramp operations, giving design answers to that knotty problems at a small fraction of cost involved in actual construction methods. With the technique described it is possible to determine the effects of changes in traffic volume, velocity, geometric design, etc.

The 'SUB' (118) model is a special purpose programme for simulating bus operations on arterials. It provides a number of performance measures. Vehicular traffic is treated macroscopically, while buses are treated microscopically. Twenty arterial blocks may be modelled with either protected or unprotected bus stops.

A simulation model PRIFRE (119) was developed by minister Ovaici and May way back in 1973. It is a macroscopic, deterministic, time scan simulation model. It simulates the operation of a directional freeway section with a concurrent-flow priority lane for high occupancy vehicles (HOV). In operation, PRIFRE calculates the total travel time spent under normal freeway operations and total travel time spent under any number of different priority operation strategies, and compare the two.

Large number of corridor models (118) have been developed at the University of California at Berkeley. The simulation models DAFT, CORQ and SCCT are the microscopic deterministic and time scan models developed in 1970, 1974 and 1975 respectively. They are used to evaluate the traffic control strategies within the corridors. A simulation model 'LIEW' is meant for evaluation of optimal ramp control strategies. The main purpose of simulation model STAR is to evaluate survelliance and control strategies for route diversions.

2.5 SOME IMPORTANT ANALYTICAL STUDIES FOR AT - GRADE INTERSECTIONS

Macroscopic, deterministic, time scan optimisation model SOAP was developed by Courage and Landmann (120) in 1977. The model SOAP is used to design the signalisation for three to four - legged intersections. Either fixed or actuated control and multiple phasing may be specified. SOAP uses a search and optimisation procedure to find the optimum cycle length , splits and dial assignments. Measures of effectiveness are delays, stops, fuel consumption due to stops and delays, degree of saturation and left turn conflicts. SOAP may be used to analyse existing or pre-determined timing. The SOAP is also capable to consider coordination of the signal with an adjacent intersection and the effect of platoon arrivals.

Hansson presents (121) a method for calculating capacity, queue length and delay at unsignalised intersections that was developed for the new Swedish capacity manual. The method is based on a queueing model that considers each lane in the approaches controlled by YIELD or STOP sign as a service discipline. Service time is calculated for each stream of vehicles in the lane, as a function of primary road flow rates and gap acceptance parameters. The lane capacity is assumed to be the actual flow-to-capacity ratio. The queueing model estimates queue length distribution and mean delay. The most important parameter in the model is critical headway. The model is applicable to the intersections with stop and yield sign.

Karl - Lennart, Bang (122) has developed a method for calculating signal timing, capacity, queue length, proportion of stopped vehicles and delay, working under the Swedish National Road Administration. The method is based on calculating saturation flows separately for each lane.

The highway capacity manual (123) has suggested a methodology to determine the capacity and level-of-service of signalised and unsignalised intersections.

The capacity of each lane of signalised intersection is given by

$$C_i = S_i \times \left(\frac{g}{C}\right)_i \tag{2.51}$$

Where

C_i = capacity of i^{th} lane

S_i = saturation flow rate of i^{th} lane

g = effective green time (sec)

C = cycle length (sec)

The (V/C) ratio is found out for the lane,

$$\text{ratio} = X_i = (V/C) \tag{2.52}$$

$$= \frac{V_i}{[S_i \times (\frac{g}{C})_i]}$$

Where

V = adjusted flow for i^{th} lane

The critical (V/C) ratio is calculated for an intersection as

$$X_c = \sum_i \left(\frac{V}{S}\right) C_i \left[\frac{C}{(C - L)}\right] \qquad (2.53)$$

Where

C = lost time (sec)

The capacity of the permitted phase is computed as the maximum of;

$$C_{LT} = (1400 - V_o)\,(g/C)_{PLT} \qquad (2.54)$$

or

C_{LT} = 2 vehicles per signal cycle

Where

C_{LT} = capacity of left turn permitted phase, in VPH

V_o = opposing through plus right - turn flow rate in VPH

$(g/C)_{PLT}$ = effective green ratio for the permitted left turn in sec.

The level of service of signalised intersection is based on average stopped delay experienced by each vehicle in seconds.

Highway capacity manual (HCM) also has developed the methodology to compute the capacity of two-way STOP and YIELD controlled intersections. The capacity is computed on the basis of prevailing geometric and volume conditions, conflicting traffic, gap acceptance behaviour and impedance factors.

When several movements share the same lane, the HCM has developed a mathematical model to calculate the capacity and level of service of shared lane.

$$C_{SH} = \frac{V_l + V_t + V_r}{[\frac{V_l}{C_{ml}}] + [\frac{V_t}{C_{mt}}] + [\frac{V_r}{C_{mr}}]} \quad (2.55)$$

Where

V_l, V_t and V_r are volumes or flow rates of left turn, through and right - turn in pcph (Passenger cars per hour).

C_{ml}, C_{mt} and C_{mr} are the movement capacities in shared lane in pcph.

C_{SH} = capacity of shared lane in pcph.

Level of service (C_R) of shared lane can be given by

$$C_R = C_{SH} - V \quad (2.56)$$

Where

V = total volume or flow rate using the lane in pcph.

The TRRL has recently developed the new strategy for signal control at isolated intersection known as 'MOVA' (Micro-processor optimised vehicle actuation) (124). In this approach the data from vehicle detectors on the junction approaches are analysed by an on-line microprocessor implementing the MOVA programme. The duration of the green signals are controlled by a 'delay and stops minimising' logic, or, if any approaches become oversaturated, by a 'capacity maximising process'.

Popat, Gupta, Khanna and Chandrasekhar have tried to design the isolated traffic signals for Indian traffic (125). A signal is designed for Warangal city by Webster method but with two different approaches. In the first approach, the usual EPCU were made use of where as in the second approach EDVU (126) (Equivalent design vehicle units) were used. The EDVU for different type of vehicles vary depending upon the proportion of the slow moving vehicles (SMV) available in the traffic stream as shown in Table 2.4 and 2.5. By comparing the two approaches it was found that the optimum cycle length in second approach is about 30% more than the first approach. It is believed that this additional cycle time facilitates the SMV to cross the intersection comfortably.

Popat, Gupta and Khanna (127) have studied the 4-leg uncontrolled intersections under mixed traffic flow. The equivalent passenger car units, especially for intersection, have been developed. The homogenising and heterogenising effects in terms of speed have been graphically presented. It was found that the approaching and crossing behaviour of motorised and non-motorised vehicles are altogether different.

Wright (128) has attempted a definitive classification and enumeration of conflict types at a junction with an arbitrary number of approaches The analysis is based on topological principles rather than geometric ones to avoid the problems associated with non-standard junction layouts. In addition, a notation is proposed which would allow each individual interaction to be represented uniquely in term of a 'string' of characters which is common for left and right drive rule.

TABLE 2.4 : EQUIVALENT DESIGN VEHICLE UNITS (EDVU) FOR DIFFERENT PROPORTION OF SMV AND LEVEL-OF-SERVICE (TWO-LANE, TWO-WAY)

Level of service	Any	A			B			C		
Type of vehicle	0% of SMV	%age SMV			%age SMV			%age SMV		
		10	30	50	10	30	50	10	30	50
Car	1	2.91	6.66	15.00	1.74	4.08	9.52	0.98	2.27	5.19
Bus	-	2.79	5.71	10.90	1.67	3.33	6.58	0.88	1.68	3.33
Truck	-	2.18	4.62	10.00	1.44	3.08	6.49	0.96	2.02	4.29
Auto	-	3.53	7.50	15.00	2.00	4.08	8.33	1.07	2.20	4.49
M/C	-	4.29	10.00	24.00	1.58	4.44	10.00	0.61	1.46	3.70

TABLE 2.5 : EXTRAPOLATION OF EDVU FOR LEVEL OF SERVICE 'C' FOR HIGHER PERCENTAGE OF SMV

Vehicle type	60%	67%	73%	76%	85%	87%	89%	90%	92%
Car	7.1	8.9	10.6	11.5	14.8	15.6	16.5	17.1	17.8
Bus	4.4	5.2	5.8	-	-	-	-	-	-
Truck	5.4	6.5	7.3	7.8	9.4	-	10.0	10.2	-
Auto Rickshaw	5.7	6.7	7.8	8.3	10.3	10.7	11.2	11.6	-
M/C	5.1	6.8	7.7	8.5	11.5	12.8	13.5	14.3	15.4

2.6 SUMMARY

The review of vehicular interactions through simulation in this chapter provides an insight to the studies carried out and presently underway in various parts of the world in recognition of the need of understanding the basic mechanism of flow more accurately at priority-type at - grade intersections. However, a striking feature of the review presented here is, that while there is a concentration of work being carried out in countries where interactions amongst the vehicles at highway at - grade intersections are much less complicated, beginning only seems to have been made to understand and analyse the grossly heterogeneous flow of the type prevalent in India.

CHAPTER III

EXPERIMENTAL PROGRAMME AND FIELD STUDIES

3.1 INTRODUCTION AND GENERAL

Application of digital simulation for the analysis of various complicated traffic situations at highway intersection has been presented in the previous chapters. But it is not an easy task unless the real system is seen in the correct perspective. Even todate the mixed traffic behaviour is not well understood in totality and only little segmental advancements have been made.

The major-minor priority intersection is by far the most common intersection layout in current practice in India. There is a considerable variety of layouts including three-way T-intersections, three-way non-right angled intersections with varying intersection angles, right angled cross roads, right angled four-way staggered intersections and four-way intersections with different intersection angles. These all types have already been presented in earlier chapters. The joining roads can cover virtually all combinations of one-or-two-way traffic, turn restrictions and the size of these intersections can range from unmarked minor intersections in housing estates to complex channelized intersections on high speed dual-carriageway highways and arterials.

In the present study the semi-urban, uncontrolled (priority) 3-leg and 4-leg intersections with varying geometric conditions have been considered, as already identified in the scope of the present study in detail in article 1.9.2.

3.2 SEMI-URBAN INTERSECTIONS

These intersections are essentially located at the outskirts of urban areas. The traffic situation at such intersections consist of the accent of both rural as well as urban traffic characteristics. Thus the traffic situation being neither purely urban nor purely rural, these intersections pose more complex problems specially under heterogeneous traffic flow conditions.

The programme of field studies for a complex heterogeneous flow presents many problems in contrast to various well known and established practices for homogeneous traffic flows, specially automobile flows.

The problem, basically, centres round the following points :

1. Each vehicle of the heterogeneous flow, of the type attempted here in, has different static and dynamic operating characteristics.
2. The vehicular interactions vary significantly between different groups of vehicles within the total composition of traffic flow.
3. The measurements of vehicular speeds and volumes can not be carried out in normal manner; as well as; the other interaction parameters have to be recorded simultaneously to have a meaningful data set.

3.3 FACTORS AFFECTING THE CHOICE OF INPUT DATA

The choice of input data for simulation model are constrained by a number of considerations; such as;

3.3.1 Computer Facilities

Many computer installations do not have a large variety of periferals or the software to fully exploit their existing periferals. The input data is therefore limited to those facilities.

3.3.2 Cost of Development of Input Data

The development of appropriate input data procedure is important since it will influence the acceptance of the model. However, the cost of developing the input data must be compared with the benifits to be gained.

3.4 FIELD DATA REQUIREMENTS FOR THE STUDY

The requirements of the basic field data which guided the design of the experimental programme have been divided in two distinct groups, in accordance with the objective and scope of the present research programme.

1. Three-legged semi-urban type uncontrolled (priority) intersections.

2. Four-legged semi-urban type uncontrolled (priority) intersections.

Typical three legged and four legged intersections are located at the outskirts of the urban areas. They vary in their geometric standards with regard to the approach widths or the total right-of-way, which varies normally from single lane width of 3.5 m to two lane width of 7.0 m. The angle of intersection varies from 30 degrees to 150 degrees. Most of the approaches are undivided roads without any pavement markings as can be seen in Fig. 3.1.

These intersections carry urban as well as rural traffic which is highly heterogeneous in character as presented in Table 3.1.

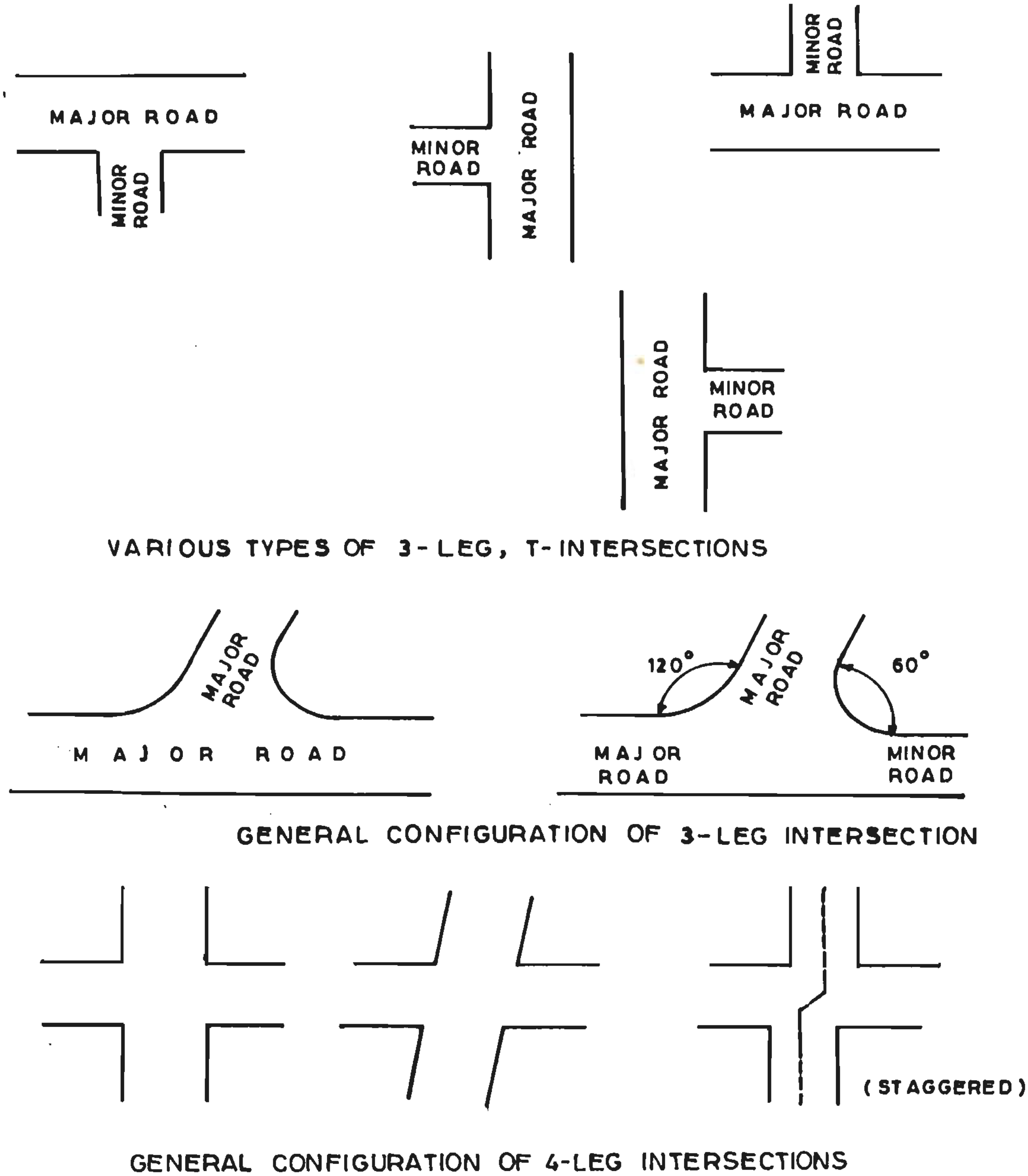
TABLE 3.1 – TYPICAL TRAFFIC COMPOSITION AS OBSERVED ON MAJOR ROAD AND MINOR ROAD AT KM : 11.400 (LUCKNOW DIVISION), NH .25, SEMI-URBAN, UNCONTROLLED T-INTERSECTION

Sr. No.	Type of Vehicle	% On major Road	% On minor Road	% Motorised / Non-motorised	Remarks
1.	Car	24.70	34.15	53.64	Motorised
2.	Bus	02.90	01.83		
3.	Truck	08.35	02.44	(On major road)	
4.	Scooter/ motorcycle	17.69	17.07	55.49	
				(On minor road)	
5.	Bicycles	43.03	40.24	46.36	Non-motorised
6.	Pedal rickshaw	01.42	03.66	(On major road)	
7.	Others*	01.91	00.61	44.51 (On minor road)	
Total	Percent volume (vph)	100% 1413	100% 164		

* It consists all other non-motorised vehicles including animal and hand drawn carts.

Thus five features become significantly important.

1. The approach width available for vehicles desiring to clear the intersection.



(NOT TO SCALE)

Fig. 3.1 General types of at-grade intersections found on INDIAN ROADS

2. The composition of traffic stream and nature of flow during critical or peak periods.

3. The amount and consequences of the vehicular interactions due to conflicting traffic and heterogenity of traffic.

4. Angle of intersection which ultimately determines the distance to be covered while crossing the intersection, and

5. Approaching and crossing speeds of different type of vehicles.

The above information has been sought to be collected through the field studies as detailed in article 3.5.

3.5 DESIGN OF FIELD STUDIES

The first step in any modelling exercise is to obtain a precise statement of the objectives. These objectives should enable a modeller to determine the level of details required as the inputs to an analytical or a simulation model. In view of this, the following traffic studies were carried out in the states of Uttar Pradesh and Himachal Pradesh on the identified locations so that the findings could supplement the subsequent model building process.

Two types of input data was collected on the identified intersections; viz.,

1. Data on physical characteristics of an intersection; such as; a detailed intersection layout and locational details, angle of intersection, type of intersection, number of approaches, width

of approaches, location of actual crossing paths and measuring their lengths from stop line to stop line, etc.

2. Data on traffic conditions; such as; mixed traffic composition and vehicular speeds, time headway data, crossing or intersection clearing speed for different type of vehicles under mixed traffic flow and classified straight and turning traffic volumes.

The data collection programme was designed in two distinct ways, viz;

1. Manual data collection programme.
2. Data collection through video recording techniques (VRT).

3.5.1 Manual Data Collection Programme

As mentioned earlier, manual data collection is many a times considered essential, when requirement of data is such that either the mechanical or other means can not provide the data in the required format or the exact instrumentation is not available for recording the data in the way it is required. In the present research programme the requirement of data is so diverse that manual data collection programme was considered effective, efficient and essential.

3.5.2 Data Collection Through Video Recording Techniques

Video recording technique is a very useful tool to collect the traffic data specially at intersections. The video recording was performed on all the identified intersections during the peak hours. In the video recording technique the actual mixed flow of traffic in the intersection area is recorded in video cassette in real time. The same traffic can be analysed in the traffic laboratory by replaying the cassette and projecting the film through a video-rame on a wider screen. The movement of traffic on the ground is truely replicated on the screen in the laboratory. Moreover it can be checked through electronic counter attached with video and is free from any manual recording errors in the field.

3.6 SITE SELECTION AND DATA COLLECTION

Looking at the availability of the limited literature on semi-urban, uncontrolled intersections under mixed traffic conditions, it was decided to carry out the field studies for time headways, crossing speeds, approaching and turning volumes to provide the appropriate model and input for the intersection simulation model.

3.6.1 Site Selection

Within the scope and objectives of the work the following aspects were considered in the selection of sites for collecting the required data.

Typical 3-leg and 4-leg uncontrolled, priority type semi-urban intersections were selected in the states of Uttar Pradesh and Himachal Pradesh. The details of various sites identified for the data collection have been incorporated appropriately elsewhere.

3.6.2 Data Collection

As discussed in article 3.5, the required data was collected by two methods. This article discusses the details of data collection by these two methods. It may be mentioned here that the selected sites have provided data base representing extreme heterogenity of traffic stream in Indian context.

3.6.2.1 Data collection through manual method

In general the present research work needed the following parameters of traffic stream characteristics that were collected through manual methods.

1. Identification of peak-periods or critical periods :

   The traffic was recorded on all the identified sites round the clock from 6 a.m. to 6.00 a.m. the next day, in number of vehicles per hour for 24 hours and one hour peak-period was identified on all the sites for detailed data collection.

2. Intersection crossing times were measured for all type of vehicles for through and turning movements. Time taken by different type of vehicles to clear the intersection from stop line to stop line were recorded. Also approaching speeds of different types of vehicles were measured on all sites. The average observed crossing timing for three movements and observed average approaching speeds for different type of vehicles are presented in Table 3.2.

3. Approach widths of all the legs and stopline to stopline distances for left, straight and right turns were measured on all the sites. The actual turning paths were located for all manoeuvres and

the distances were measured along these paths.

4. The angle of intersection was measured on all the sites.

5. On some indentified locations, classified approaching and turning traffic, as well as, composition of traffic of all the traffic streams were recorded.

TABLE 3.2 – OBSERVED AVERAGE CROSSING TIMING FOR LEFT, STRAIGHT, AND RIGHT AND OBSERVED AVERAGE APPROACHING SPEEDS

Sr. No.	Vehicle Type	OBSERVED AVERAGE CROSSING TIMINGS			Observed Average Approach Speed (kph)
		Left Turn (Sec.)	Straight (Sec.)	Right Turn (Sec.)	
1.	Car	4.2	4.0	5.6	36.5
2.	Bus	5.2	4.4	5.9	34.3
3.	Truck	8.2	6.1	11.0	32.4
4.	Scooter/ Motor Cycle	4.1	4.4	6.5	29.4
5.	Bicycle	6.4	7.7	7.7	11.0
6.	Pedal Rickshaw	7.0	9.1	8.2	9.5
7.	Others	24.0	24.0	28.0	4.0

3.6.2.2 Data collection through video recording techniques (VRT)

The following data was collected in the traffic laboratory through a specially designed system at the centre of Transportation Engineering (COTE), by replaying the video cassettes.

1. Classified approaching traffic volumes on all the legs. One enumerator per approach was appointed to record the classified approaching traffic. Traffic was divided into seven modes; viz; cars, buses, trucks, scooters or motor cycles, bicycles, pedal rickshaws and others. The proforms used to record the traffic is shown in Appendix - A .

2. Classified traffic turning to various legs from a leg under consideration. Each enumerator was assigned about two turning manoeuvres depending upon the total turning traffic. So for each approach 4 to 5 enumerators will be required for 4-leg intersections and 3 to 4 enumerators for 3-leg intersections. In order to record the traffic for all approaches, the cassette is replayed for the required number of times.

3. Composition of traffic streams : The percentage of each vehicle type in traffic stream on each approach are calculated and recorded. Also the percentage of each vehicle type in all turning traffic is determined and recorded. These two variables are direct input in the simulation model.

4. Time headways on minor road and major road : The time headway are recorded for the type of vehicles in the laboratory. The reference point is located on each approach. Then the type of vehicle and the time, when its front axle touches the reference point, are recorded. From the recorded arrival times, the headways are calculated.

3.7 ADDITIONAL DETAILS OF THE STUDIES

The additional details of the studies are discussed in the following article.

3.7.1 Headway Distribution Studies

An important variable that describes the mechanism of traffic flow is the spacing and headway between individual vehicle in a traffic stream. Actually headways and gaps are called the building blocks of traffic stream. In a simple way it can be defined as a time measured from head to head or tail to tail of successive vehicles. The minimum value of headway is considered to be of the order of 1.5 to 2 seconds (129). In urban areas the distribution of headways is largely influenced by upstream conditions, such as; traffic signals, where as under semi-urban or rural traffic condition, random headways result since traffic is not constrained upstream.

3.7.1.1 Headway distribution models for homogeneous traffic

Road traffic may be represented on a two dimensional network of space & time. However the most significant aspect is that while time & space are both continuous variables, the occurences of vehicles are discrete occurences. The term headway refers to time headway which is the time difference between the arrival of the successive vehicles at a reference point. Distribution may take or approximate to various mathematical forms. The random nature of traffic distribution in the stochastic sense was realised late in the mid 1930s by Kinzer (130) and Adams (131). Many other researchers (132, 133) adopted different type of continuous distributions for fitting the headway data. The negative exponential model has the form

$$P\ (h \geq t) \quad = \quad e^{-\lambda t} \qquad (3.1)$$

where $P(h \geq t)$ = probability of headway being equal to or greater than time 't' seconds.

and λ = average flow rate.

It was observed that in a reasonable large flow of traffic the negative exponential distribution tends to overestimate the small headways between 0 and 2 seconds. To overcome this problem a displaced exponential model was used by Gerlough and Capelle (134). The priobability of a headway greater then 't' seconds is given by

$$P(h \geq t) \quad = \quad e^{-\frac{(t - \tau)}{(\bar{t} - \tau)}} \qquad (3.2)$$

where

τ = minimum separation headway or shift that varies from 0.5 to 2.25 seconds.

$\bar{t}$ = mean headway in seconds

Validity of the traffic randomness and its limitations was the subject matter of Pakpoy's (135) study. He observed that the use of Poisson's distribution is applicable up to critical volume range. This volume range he considered as the practical capacity of highway facility. In one another study (136) Greenshield observed that random behaviour could be assumed up to 400 vph in both directions on a two lane roadway.

Headway studies on 2-lane roads posed the problem of restrained overtaking and few headways were observed as clustered around one second gap. Schuhl (137) analysed this issue in terms of two driver populations, one for the restrained vehicles and other to consider the free movers. He proposed the composite model for the two populations as

$$P(h \geqslant t) \quad = \quad e^{-\frac{(t - \tau)}{(\bar{t}_1 - \tau)}} + (1 - \gamma)\, e^{-\frac{t}{\bar{t}_2}} \qquad (3.3)$$

where

γ = proportion of restrained vehicles

$\bar{t}_1$ = mean headway of restrained vehicles

$\bar{t}_2$ = mean headway of free flowing vehicles

τ = minimum headway for the restrained vehicles

e = base of natural logarithms

Extensive surveys by Grecco and Sword (138) did assist in predicting the Schuhl parameters in terms of traffic volume. The proportion of restrained vehicles was given as

$$\gamma \quad = \quad 0.00115\ Q \qquad (3.4)$$

where

Q = lane volume in vph

Schuhl's composite model was made use of by Sinha (139) in his freeway simulation model and by Dawson (140) and Hodgson (141) in their study on non-passing zones. However Oliver and Thibault (142) used a continuous distribution based on Schuhl's model for medium to high traffic volumes.

When vehicles are arriving in a bunch, Gamma and Erlang distributions (143) were considered as better models. However Hyper-erlang model was adopted by Sinha (139), Dawson and Chimini (144) for the arrivals of ramp vehicles.

Later for certain traffic data, lognormal headway model was found to be more promising by Daou (145), Greenberg (146) and Tolle (147). Tolle shifted the gap slightly in his lognormal model to account-for platoon effect. Truncated Guassian and exponential models were the part of the composite model proposed by Ovuworie, Darzentas and Mcdowell (148). They argued for three population groups in the traffic stream, namely restrained vehicles, free moving vehicles and decelerating vehicles to join the platoons.

But all the models discussed above are applicable only to homogeneous traffic conditions. Further, it must be very well noted that all the above works are not general theories, but are efforts to fit distributions to the observed data. Hence, no general guidance can be drawn.

3.7.1.2 Headway distribution models for heterogeneous (mixed) traffic flow

Very limited information is available on headway distribution for mixed traffic situations. Earlier simulation studies on mixed traffic by Marwah (149) and Reddy (150) assumed negative exponential model for the vehicular arrivals. Pillai and Ramanayya (151) found specified exponential, shifted exponential and lognormal distribution models better suited to the mixed traffic range of 500 vph, 650 vph and 900 vph respectively. Ferrara (61) prefered shifted exponential model for the mixture of motorized vehicles and non-motorised bicycles at intersections and crossings. He assumed the value of shift as 1.3 seconds for motorised vehicles and zero for bicycles. Working along the same line, Groth (152) suggested that exponential model better fits to bicycle arrivals up to 500 bicycles per hour.

Katti (109) recommended negative exponential distribution and shifted exponential with shift of one second for approach traffic up to 500 vph and 500 to 1200 vph respectively for mixed traffic conditions. He also suggested that no separate headway distribution models need be used for motorised and non-motorised traffic unless there is clear seggregation of these streams.

In another simulation study on uncontrolled intersections, Chari and Badarinath (112) recommended exponential distribution for vehicular volumes up to 600 vph and for pedestrian volume up to 600 ped/hr.

Gupta et al. (113) in an R & D project have done extensive work on uncontrolled semi-urban intersections in northern-India and have suggested values for headways and gaps based on highway capacity manual criteria (123) and other approaches to suit Indian conditions. The values of critical gap size under various operating speeds for minor and major roads have been suggested. Gupta (104) has critically examined the space headway data collected through time lapse photographic techniques on undivided busy city roads and divided highways.

He developed the relationship for space headway for undivided city road which explains the spacing behaviour in the best fashion. The relationship is

$$S = (0.065 + 0.082\ V)\ L$$

Where

S = space headway (m)

V = speed (kmph)

L = length of vehicle (m)

In case of divided highways it was observed that 2-degree and a 3-degree polynomial curves are best - fit for the space - headway data. It was also found that the analysis of non-motorised vehicles did not yield any significant result.

3.7.2 Speed Studies

The speed with which vehicles cross the intersection is one of the most important input parameters to the simulation model. The overall performance and capacity of an intersection are considerably influenced by speed of travel, crossing and turning manoeuvers.

3.7.2.1 Speed distribution models for homogeneous traffic flow

Around the intersection the speed can be divided in to three categories; viz; normal driving speed, approach speed and crossing speed. Had there not been an intersection, most of the vehicles would have been moving with normal driving speed which is associated with design speed under normal operations. It has been shown that the normal driving speeds can be better represented by normal distribution. Richard, Baker and Sheldon (153) considered the distribution of observed speeds for medium traffic volumes as best reflected normal driving speeds. They considered standard deviation as 20% of average normal driving speed.

3.7.2.2 Speed distribution models for heterogeneous (mixed) traffic flow

In two separate studies Pillai and Ramanayya (151) and Reddy (150) observed that the mixed traffic speed phenomenon was better explained by normal distribution.

In 1981, Kadiyali, Viswanath and Gupta (154) carried out apeed studies under 'Road User Cost Study' project. It was found that the speed of various modes followed the normal distribution. However, these findings were applicable to straight stretches of road and not to uncontrolled intersections.

Gupta (104) has analysed the vehicular interactions in terms of speed interruptions under mixed traffic conditions. The speed interruptions were studied for undivided roads and divided arterials. An equation for speed reduction due to the presence of various vehicle types has been worked out for divided arterials as under

$$VV = (VFV - a_o) - \Sigma a_i N_j \tag{3.5}$$

where

VV = speed of given vehicle type, kmph

VFV = Free-flow speed of the vehicle type, kmph

a_o = intercept constt. of linear regression

a_i = interaction coefficient of different vehicle categories, kmph

N_j = number of vehicles present causing interaction, of a given group

Here

i = 1 to 6 and j = 0, 1, 2, 3, 4, 5

In one another speed study, Kadiyali and Viswanath (155) reported that bicycles differed from the linear trend than other modes.

Katti (109) carried out speed studies at intersection under mixed traffic flow. The turning speeds for left, right and straight have been found. Also the behaviour of speeds of different type of vehicles in the intersection area was observed. It was concluded that the speeds of all the fast moving modes follow normal distribution whereas for the slow moving modes like bicycles and pedal rickshaw, lognormal distribution has been recommended.

Chari and Badarinath (112) determined the mean free speeds of different type of vehicles under mixed traffic flow. They have considered the average of the mean free speeds as average intersection speeds to simulate the traffic at uncontrolled intersections.

3.7.3 Gap Acceptance Behaviour

One of the most common situations of traffic operations occurs at uncontrolled intersections when vehicles of minor road either cross or merge with the major traffic stream. The minor road users are required to assess the suitability of gaps available to them. They may accept the gaps or reject the gaps depending upon the size of the gap. This scenario is frequently considered and described as gap acceptance behaviour.

Gap acceptance phenomenon is very important in any intersection performance study. The delay to the vehicles and ultimately the capacity of an intersection are highly influenced by gap acceptance phenomenon.

Acceptable gaps are subjective and stochastic in nature and may differ even for the same driver under different traffic conditions. The value of gap acceptance is affected by total volume, traffic composition, crossing speeds, moving or stopped positions of the gap seeking vehicles, speed of major road vehicles, etc. so it is normal practice to assign an acceptable gap to a particular vehicle by adopting certain gap acceptance distribution.

Under the mixed traffic flow at an uncontrolled intersection, it was observed that, whenever driver realises that he can clear the conflict zone well before the conflicting vehicle arrives, he ignores the cross flow and enters the intersection for clearing. Otherwise he slows down and depending upon the estimated time difference between the arrival times of both the vehicles at the conflict point, and there after he takes a decision.

It is evident from the above arguments that speed is the main criteria that enables the drivers to decide whether to cross or to wait. Keeping this in view, it was decided not to adopt any gap acceptance distribution in the present study. Instead the crossing speeds and the crossing distances have been used that ultimately decide the gap to be accepted. The effect of the gap acceptance phenomenon, therefore has been indirectly incorporated.

Further, due to difference in vehicular sizes and the absence of lane-discipline in movement; the process of gap-acceptance losses its usual significance, hence the above mechanism of incorporating crossing speed and crossing distances has been employed.

3.8 EXPERIENCES THROUGH MANUAL DATA COLLECTION METHOD

In the begining of the manual data collection programme limited manpower was appointed. But soon it was realised that the required data could not be collected with the limited manpower. Keeping in view the type of data collection, amount of data collection and the availability of funds the following decisions were taken.

3.8.1 Man Power Requirements

The details of minimum manpower that could collect the necessary data of better and required quality are as under -

	Type of Data Collection	Man power	Hours	Man hours
1.	Crossing timing data (12 movements for 4 leg intersection)	6	2	12
2.	Approaching speeds by radar speedometer.	1	2	2
3.	Classified approaching and turning traffic (12 movements)	6	2	12
4.	Geometrics of an intersection. (approach widths shoulder widths, length of all 3 turning movements from stopline to stopline with the help of measuring wheel and angle of intersection).	3	2	6
	TOTAL	16	8	32

3.8.2 Cost of the Data Collection

As skilled labour is required for this type of data collection minimum INR 6/-(1.USA $ = INR 17.0) are to be paid per hour. Therefore the cost of the data collection for 4-leg intersection comes out to be about INR 200/- whereas it is about IRN 150/- in case of 3-leg intersection for the peak period alone.

In order to identify the peak hour on all the finally identified intersections, the traffic data were collected for 24 hours round the clock. Three groups (each of 6) of enumerators were assigned the job. The total cost incurred for each site for this job was about INR 900/- for 4-leg intersections and about INR 700/- for 3-leg intersections.

From the above figures it is evident that if a large number of intersections are to be covered under the study, large sums of funds should be available. Therefore this particular process of manual data collection is very expensive.

3.8.3 Training of Personnel

It was realised that it is very advantageous to extend the necessary training to the enumerators prior to proceeding to the site of data collection. This will enable them to collect the required data of better quality. If the enumerators are briefed about the type of intersection, type of data requirement, way to record it, proforma details etc., it will save lot of time in the field and avoid all kinds of doubts.

Some times the training can be imparted by showing the site of data collection through video cassette in the office. The enumerators can be familiarised with the type of intersection, its geometric features, obstacles on site and even the exact position of enumerators can be fixed in advance. This type of training will avoid starting delays at site and the data collection programme can be carried out smoothly and satisfactorly.

3.9 SUMMARY

This chapter presents the philosophy behind the design of the experimental programme of the present study. It has been elaborated that for the objectives of achieving a comprehensive record of vehicular interactions under mixed traffic flow at uncontrolled semi-urban intersections, a very well laid-out programme of field study is required. The physical and traffic details have been collected by manual methods and vedio recording techniques (VRT).

The procedure of data collection, the data required from field studies for development of simulation model, the background of some of the important field studies and the experiences during the data collection have been highlighted herein.

The details of data processing and analysis in the format required as an input to the simulation model are presented in the succeeding chapter.

CHAPTER IV

DATA PROCESSING AND ANALYSIS

4.1 INTRODUCTION

In the preceding chapter, the experimental programme and the design of field studies have been discussed in relation to the requirements of the field data for this research programme. The parameters on which data are required in the analysis of vehicular interactions for mixed traffic flow, are so large and varied that the data obtained from the field and its processing becomes the backbone of the efficacy, or otherwise, of the application of simulation modelling. This chapter is devoted to presenting the summarised and processed data and its preliminary analysis for subsequent use in the next chapter which deals with the process of model development.

As explained earlier in article 3.5.2 the data have been obtained through specially designed field studies, involving manual data collection and video recording technique (VRT). Other additional data, as required at the subsequent stages of model formulation, were also collected and processed, and, are presented in this chapter for providing an overview of the total problem and a comprehensive coverage. It may however, be mentioned that during the course of this research programme, a lot of data on initial planning of the field studies and other subsidiary data required in - between, to check the completeness of the data, which were collected, have not been included herein. The data presented herein is directly linked to the requirement of the vehicular interactions in the simulation model. Data here in this chapter are a basic requirement of the simulation model input and serves as an essential guide to establish the trend and the extent of the requirement of input and feedback to the simulation model for the practical field applications presented in Chapter VI.

4.2 IDENTIFICATION OF FIELD STUDY LOCATIONS

The problem of analysing the traffic at priority intersection under mixed traffic conditions has many parameters such as -

- Intersection geometry
- Terrain
- Composition of traffic
- Proportion of conflicting traffic
- Approaching and crossing speeds of various vehicles
- Static and dynamic characteristics of various vehicles
- Total volume of traffic flow
- Time - headway amongst vehicles on different-approaches, etc.

Keeping the above interacting parameters in view, the data were collected on number of intersections in plain terrain of the state of Uttar Pradesh and hilly terrain of the state of Himachal Pradesh. The details of the intersections, identified for data collection in the above two states, are given in Table 4.1.

However, after detailed preliminary studies the following

TABLE 4.1 - DETAILS OF IDENTIFIED INTERSECTIONS FOR PRESENT RESEARCH WORK

STATE : UTTAR PRADESH

Sl. No.	Name of Division	Locational Details		Type of Intersection	Type of Intersecting Roads	Remarks
		Highway* system NH/SH/MDR/ODR	Kilometrage			
1.	Lucknow	NH25	11.400	T	NH/MDR*	Semi-urban
2.	BCD, Div.,Kanpur	NH25	59.000	Y	NH/MDR	Semi-urban
3.	BCD. Div.,Kanpur	NH25	63.000	4-leg Right Angled	NH/SH	Rural
4.	NHRC, Div., Kanpur	NH2	17.000	4-leg Right Angled	NH/SH	Semi-urban
5.	NHRC. Div., Kanpur	NH2	12.000	4-leg Right Angled	NH/SH	Semi-urban
6.	Agra	NH2	222.000	4-leg Right Angled	NH/MDR	Semi-urban
7.	Agra	NH2	201.000	4-leg Right Angled	NH/SH	Semi-urban
8.	Mathura	NH2	193.000	Y	NH/SH	Semi-urban
9.	Mathura	NH2	148.000	4-leg Right Angled	NH/SH	Semi-urban
10.	Ghaziabad	NH24	20.000	T	NH/Link road	Semi-urban
11.	Ghaziabad	NH24	28.000	T	NH/SH	Semi-urban
12.	Ghaziabad	NH24	86.000	4-leg Right Angled	NH/SH	Rural
13.	Moradabad	NH24	157.000	T	NH/SH	Semi-urban
14.	Moradabad	NH24	164.000	Y	NH/SH	Semi-urban
15.	Bareilly	NH24	185.000	T	NH/MDR	Semi-urban
16.	Dehradun	121W, MDR	173.000	4-leg Staggered	MDR/Link road	Semi-urban
17.	Hardwar	SH-45	170.000	4-leg Right Angled	SH*/Link road	Semi-urban

(Contd....)

(Contd....) Table 4.1

STATE : HIMACHAL PRADESH

1.	Solan	NH22	64.200	Skewed	NH/ODR	Semi-urban
2.	Solan	NH22	102.600	Skewed	NH/SH	Semi-urban
3.	Solan	NH22	117.465	Skewed offset	NH/ODR*	Semi-urban
4.	Bilaspur-II	NH21	127.000	Y	NH/SH	Rural
5.	Bilaspur-I	NH21	145.850	Skewed	NH/SH	Rural
6.	Mandi	NH21	184.600	T	NH/SH	Rural
7.	Kulu	NH21	291.000	Y	NH/ODR	Semi-urban

* NH = National Highway   MDR = Major District Road
SH = State Highway   ODR = Other District Road

ten intersections were choosen for detailed microscopic study. Details of these ten intersections, situated in the state of Uttar Pradesh are presented in Table 4.2.

Since the entire study data collected on finally selected ten intersections, are rather massive, some typical values/tables/figures have been incorporated in the present work to present the typical data type and format.

In the following article, the various types of data collected on the above ten sites and the methods adopted are discussed in detail.

4.3 DATA FROM MANUAL COUNTS AND RECORDINGS

As has been discussed in article 3.6.2.1 the manual data collection programme is an effective, efficient and economic proposition for extremely heterogeneous composition of traffic flow. The entire extent of raw - data collected for this programme have not been found necessary to be included as such; mainly because of the constraint of the total volume of this work presentation and secondly, because it does not serve any useful purpose. The traffic volume data were recorded round the clock for 24 hours and the peak hour was identified. Typical 24 hours volume count and identification of peak hour is presented in Figs. 4.1 and 4.2 for three leg and four leg intersections respectively. To give an insight into the typical data sets which may be used as an input in to the analytical programme and simulation modelling, the

TABLE 4.2 - DETAILS OF FINALLY SELECTED INTERSECTIONS FOR THE STUDY

Sl. No.	Name of Division	Locational Details: Highway system N.H./S.H./MDR/ODR	Locational Details: Kilometrage	Type of intersection	Type of intersecting roads	Remarks
1.	Ghaziabad	NH24	20.000	T	NH/Link road	Semi-urban
2.	Agra	NH2	201.000	4-leg Right Angled	NH/SH	"
3.	Mathura	NH2	193.000	Y	NH/SH	"
4.	Mathura	NH2	148.000	4-leg Right Angled	NH/SH	"
5.	NHRC Div., Kanpur	NH2	12.000	4-leg Right Angled	NH/SH	"
6.	Lucknow	NH25	11.400	T	NH/MDR	"
7.	Hardwar	SH45	170.000	4-leg Right Angled	SH/Link road	"
8.	Dehradun	121W-MDR	173.000	4-leg Right Angled Staggered	MDR/Link road	"
9.	Ghaziabad	NH24	28.000	T	NH/SH	"
10.	BCD, Kanpur	NH25	59.000	Y	NH/MDR	"

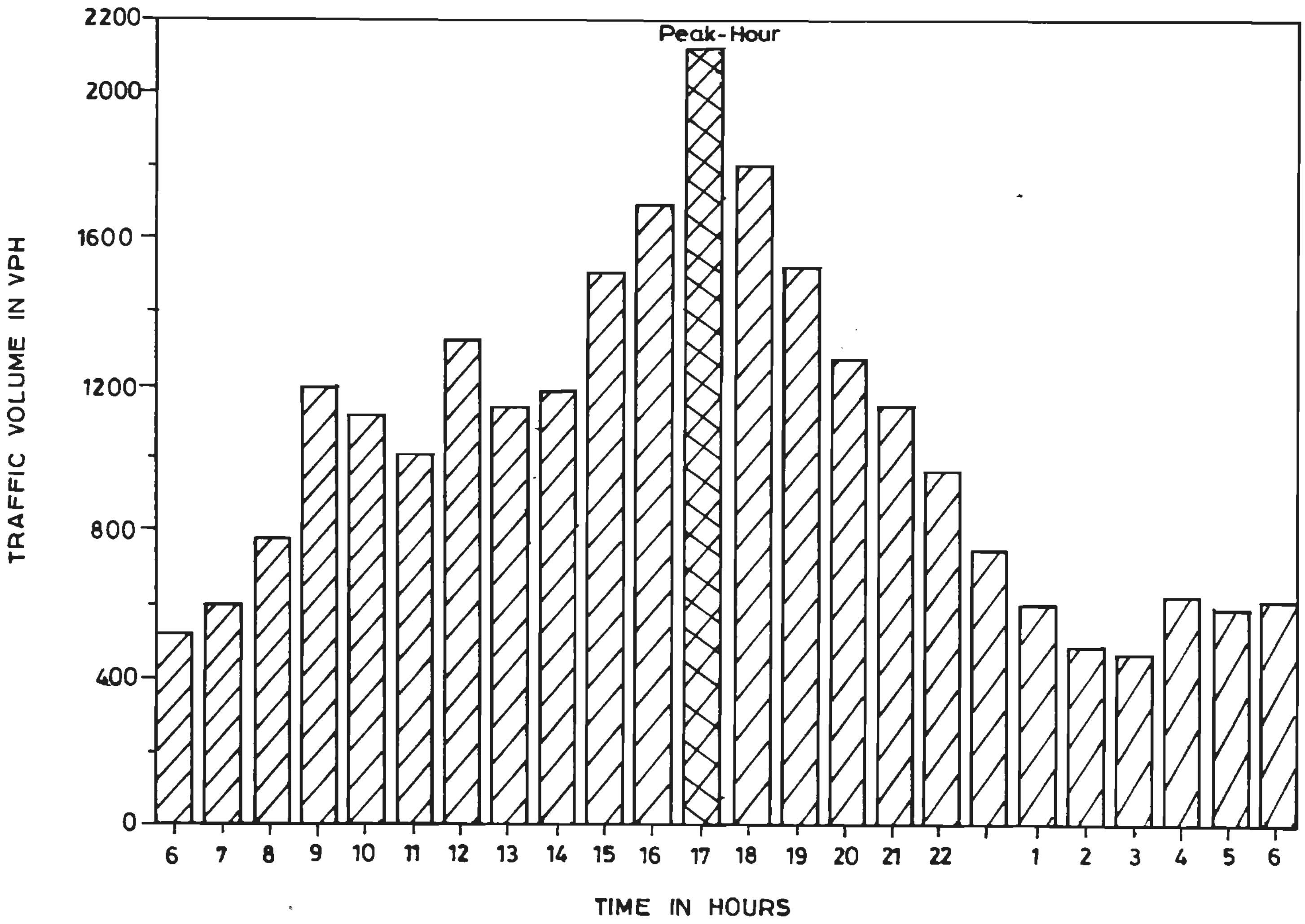


Fig. 4.1 Volume count for 24 Hours

(Km. 18.000, NH 24 Ghaziabad division, 3-Leg intersection)

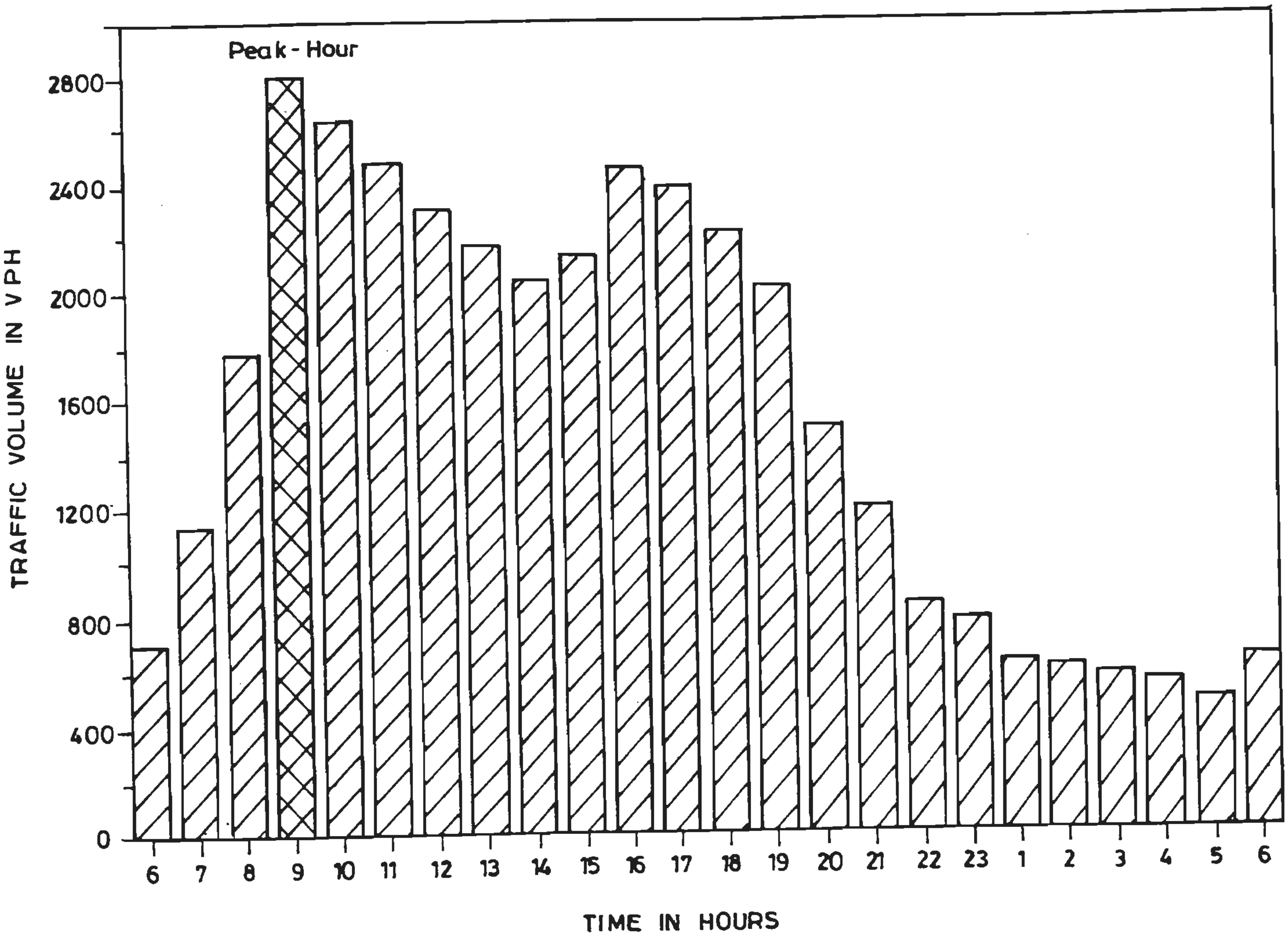


Fig. 4.2 Volume count for 24 Hours
(Km. 201.000, NH2 Ghaziabad division, 4-Leg intersection)

discussions on the data base is presented herein, in the following articles.

4.3.1 Composition of Traffic Stream Approaching Intersection

There are about 13 different types of vehicles plying on Indian roads and most of these categories have been found at different locations. Practically it is very difficult to incorporate all these vehicles in any analytical process or simulation modelling. Keeping this in view, the whole traffic has been categorised in to seven modes as presented in Tables 4.3 and 4.4 for three-leg and four-leg intersections respectively. The classified traffic volume was recorded during the peak hour on all the approaches simultaneously. The number of enumerators appointed depended upon the number of approaches, total approaching volumes and number of vehicle modes available in the traffic stream.

4.3.2 Classified Directional Distribution and Turning Pattern

The classified turning traffic counts were recorded on all the approaches simultaneously during the peak hour. This data is of great importance in the analysis of over all performance of intersection in terms of delay and queue length. The typical data for classified directional distribution of traffic on major roads and minor roads for three-leg and four-leg intersections are presented in Table 4.5 and 4.6 respectively.

TABLE 4.3 - TYPICAL TRAFFIC COMPOSITION AS OBSERVED ON MAJOR ROAD AND MINOR ROAD AT Km 11.400 (LUCKNOW DIVISION), NH25, SEMI-URBAN PRIORITY INTERSECTION(3-leg) MANUALLY RECORDED

TYPICAL COMPOSITION DURING PEAK HOUR

Vehicle Category	Vehicle Type	Observed Percentage (%)			
		Major Road	Minor Road	Major Road	Minor Road
Fast Moving or Motorised (FMV)	1. Car, Jeep, Three Wheeler, Light Vans, Tractor	24.70	34.15		
	2. Bus & Mini bus	2.90	1.83	53.64	55.49
	3. Truck & Mini trucks	8.35	2.44		
	4. Scooters, Motor cycles and Mopeds	17.69	17.07		
Slow Moving or Non-motorised (SMV)	1. Bicycles	43.03	40.24		
	2. Pedal rickshaws	1.42	3.66	46.36	44.51
	3. Others*	1.91	0.61		
			TOTAL	100.00	100.00

* It consists all other non-motorised vehicles including variety of animal and hand drawn carts.

TABLE 4.4. TYPICAL TRAFFIC COMPOSITION AS OBSERVED ON MAJOR AND MINOR ROADS AT Km 12.000 (N HRC, KANPUR DIVISION), NH2 SEMI-URBAN PRIORITY INTERSECTION (4-leg) MANUALLY RECORDED

TYPICAL COMPOSITION DURING PEAK HOUR

Vehicle Category	Vehicle Type		Observed Percentage (%)			
			Major Road	Minor Road	Major Road	Minor Road
Fast Moving or Motorised Vehicles (FMV)	1.	Car, Jeep, Three wheeler, Light vans, Tractor	3.19	3.89		
	2.	Bus & Mini bus	0.65	1.20	17.69	47.31
	3.	Truck & Mini truck	3.31	15.87		
	4.	Scooters, Motor cycles & Mopeds	10.54	26.35		
Slow Moving or Non-motorised Vehicles (SMV)	1.	Bicycles	67.35	42.81		
	2.	Pedal Rickshaws	11.65	8.38		
	3.	Others	3.31	1.50	82.31	52.69
			TOTAL		100.00	100.00

TABLE 4.5. TYPICAL CLASSIFIED DIRECTIONAL DISTRIBUTION OF TRAFFIC ON MAJOR AND MINOR ROAD Km. 28.000 (3-Leg INTERSECTION) <u>MANUALLY RECORDED</u>

Link	Turning Movement	Percentage of Vehicle Type in Turning Traffic							
		Car	Bus	Truck	Scooter/ Motor Cycle	Bicycle	Pedal Rickshaw	Others	Total
Major road	Left	5.21	1.94	2.78	4.99	0.83	-	0.11	15.86
	Straight	18.14	8.76	5.55	32.72	14.48	2.61	0.89	83.15
	Right	0.22	-	0.22	0.22	0.33	-	-	0.99
	TOTAL	23.57	10.70	8.55	37.93	15.64	2.61	1.00	100.00
Minor road	Left	0.62	-	0.93	1.86	2.80	0.31	0.31	6.83
	Right	37.89	9.32	12.42	27.33	5.90	0.31	-	93.17
	TOTAL	38.51	9.32	13.35	29.19	8.70	0.62	0.31	100.00

TABLE 4.6. TYPICAL CLASSIFIED DIRECTIONAL DISTRIBUTION OF TRAFFIC ON MAJOR & MINOR ROAD Km. 12.000 (4-Leg INTERSECTION) <u>MANUALLY RECORDED</u>

Link	Turning movement	Percentage of Vehicle Type in Turning Traffic							
		Cars	Buses	Trucks	Scooter/ Motor Cycles	Bicycles	Pedal Rickshaw	Others	Total
Major Road	Left	1.05	0.60	4.94	6.74	17.22	5.08	0.75	36.38
	Straight	2.53	0.30	8.83	14.97	14.52	1.50	0.15	42.80
	Right	0.60	0.60	2.10	5.39	9.58	1.95	0.60	20.82
	TOTAL	4.18	1.50	15.87	27.10	41.32	8.53	1.50	100.00
Minor Road	Left	0.25	-	0.69	1.27	4.83	1.06	0.12	8.22
	Straight	2.78	0.45	2.25	7.65	59.54	9.89	3.06	85.62
	Right	0.16	0.20	0.38	1.63	2.98	0.69	0.12	6.16
	TOTAL	3.19	0.65	3.32	10.55	67.35	11.64	3.30	100.00

4.3.3 Approach Speed

The approach speed is that speed measured at some point upstream from intersection. The approach speeds were measured on all the approaches for all the vehicle modes. The speeds were measured with the help of radar speedometer with least count of 2 kmph and giving instantaneous speed of the vehicle. The details of approach speed data and its analysis are given in Tables 4.7 and 4.8.

TABLE 4.7 – FREQUENCY DISTRIBUTION FOR SPOT SPEED DATA KM 170.00 (FOR MOTORCYCLES) (RECORDED BY RADAR SPEEDOMETER)

Class boundaries	Class mid-point (X_i)	Class frequency (f_i)	Cummulative freq. (CF)	Cummulative % $CF \times \frac{100}{n}$	Mean freq. (f_i X_i)	Mean square f_i $(X_i)^2$	Remarks
10	19	1	1	1	19	361	Mean = X =
20	21	4	5	5	84	1764	35.46kph
22	23	0	0	0	0	0	Std. Devia-
24	25	7	12	12	175	4375	tion = s = 9.2
26	27	3	15	19	81	2187	Variance= S^2 =
28	29	4	19	19	116	3364	84.8 kph
30	31	9	28	28	279	8649	Std. error
32	33	21	49	49	693	22869	of mean =
34	35	5	54	54	222	6125	0.92
36	37	6	60	60	468	8214	
38	39	12	72	72	164	18252	
40	41	4	76	76	559	6724	
42	43	13	89	89	0	0	
44	45	0	0	0	0	0	
46	47	0	0	0	0	0	
48	49	9	98	98	441	21609	
50	51	0	0	0	0	0	
52	53	2	100	100	106	5618	

TABLE 4.8 – ANALYSIS OF APPROACH SPEED FOR VARIOUS TYPES OF VEHICLES CONSIDERED IN THE STUDY

		DATE SET I				DATA SET II			
Code	Veh. type	Ave. speed (kmph) ($\bar{X}$)	Std. dev. (S)	Vari ance (S^2)	Std. error of mean (Sx)	Ave. speed (kmph) ($\bar{X}$)	Std. dev. (S)	Vari- ance (S^2)	Std. error of mean (Sx)
1.	Car	40.35	7.24	52.4	0.767	35.63	5.20	27.13	1.43
2.	Bus	37.49	6.82	46.55	1.06	29.50	1.92	3.67	0.92
3.	Truck	36.80	8.28	68.59	1.85	25.22	9.42	88.83	1.035
4.	Scooter/ motorcycle	35.46	9.20	84.82	0.92	28.33	5.29	28.05	0.97
5.	Bicycle	14.60	2.73	7.43	0.272	14.73	2.77	7.68	0.256
6.	Pedal richskaw	11.88	1.97	3.88	0.170	10.63	2.09	4.36	0.161
7.	Others*	-	-	-	-	-	-	-	-
All vehicles		30.24	12.28	150.89	0.63	24.83	10.58	119.93	0.46

* The volume of 'other' vehicles was very low and their average speed was found to be 4.0 kmph.

4.3.4 Vehicle Crossing and Turning Timings and Speeds

Vehicle crossing and turning timings at intersection are very important. The reason being, timing determine the speed with which the vehicles clear the intersection area. This also dictates the gap acceptance behaviour. Relative speeds on intersection determine the type of control to be adopted.

In order to measure the crossing and turning timings of different type of vehicles, initially the turning and crossing paths of vehicles were identified in the intersection area on all the approaches. The distances were then measured of these turning and crossing paths from stop line to stop line. This means that these paths start from a stop line and end at a stop line. Once the paths were measured, the timings were recorded for different types of vehicles to cross these paths. The stop watches were used to determine these timings. The average time taken by different type of vehicles for left, straight and right paths were then calculated. Here it would be worth mentioning that the timings were calculated for 26 meters constant path distance. As for instance, if the distance of the right path at a particular intersection is 39 meters and the time taken by a particular vehicle to cover the right path is 7 seconds, then the time to cover 26 meters is calculated, which comes out to be 4.67 seconds. Accordingly, all the crossing and turning timings calculated for constant path length of 26 meters. Now as the distance and time are known the average crossing speeds of all modes for left, straight and right movements were calculated. The typical values of crossing and turning timings and speeds for two intersections are presented in Table 4.9.

Moving along the same line, the similar data were collected on all the finally selected intersections. The average crossing and turning timings and speeds were then determined considering all the intersections. These final values are given in Table 4.10.

It is evident from the table 4.10 that for large size of vehicles (Sl. No. 1 to 3 and 7) the left turning timings are more than straight timings and for small size vehicles (Sl. No. 4 to 6), it is other way round. The possible reason for this rationally may be the size of vehicles and turning radius which is very limited.

TABLE 4.9. TYPICAL AVERAGE CROSSING TIME AND CROSSING SPEED FOR VARIOUS TYPE OF VEHICLES AT TWO SITES

Area (Sqm.)	Vehicle type	Date Set I				Date Set II			
		Average crossing time in (Sec.)	Percentage composition	Proportion of slow & fast moving vehicles	Average crossing speed (kmph)	Average crossing time in (Sec.)	Percentage composition	Proportion of slow & fast moving vehicles	Average crossing speed (kmph)
6.88	Car	4.30	15.61		21.76	2.75	17.78		34.00
22.2	Bus	5.19	4.18		18.03	3.10	20.95		30.20
22.2	Turck	6.62	7.82	59.61	14.14	2.68	16.20	76.80	34.00
1.37	Scooter/ Motor cycle	4.56	32.00		20.52	4.88	21.83		19.20
0.92	Bicycle	7.20	27.73		13.00	6.72	16.20		14.00
2.44	Pedal Rickshaw	9.40	10.95	40.39	9.96	8.53	6.21	23.20	11.00
2 - 12*	Others	21.57	1.71		4.34	17.60	0.79		5.31

* Under other category comes variety of animal and hand drawn carts and their sizes vary to a great extent.

TABLE 4.10 - AVERAGE CROSSING AND TURNING TIMINGS (AVERAGE OF ALL DATA SETS), THE TIME RATIOS OF TURNING AND STRAIGHT AND CORRESPONDING AVERAGE SPEEDS

Vehicle	Left turning time (Sec.)	Straight going time (Sec.)	Right turning time (Sec.)	Ratio LT/ST	Ratio RT/ST	Left speed (kmph)	Straight speed (kmph)	Right speed (kmph)
Car	4.2	4.0	5.6	1.05	1.40	22.3	23.40	16.70
Bus	5.2	4.4	5.9	1.32	1.11	18.0	21.20	15.90
Truck	8.2	6.1	11.00	1.35	1.80	11.50	15.40	8.50
Scooter/ Motor cycle	4.1	4.4	6.5	0.93	1.48	22.80	21.30	14.40
Bicycle	6.4	7.7	7.7	0.83	1.00	14.60	12.10	12.10
Pedal Rickshaw	7.0	9.1	8.2	0.76	0.90	13.30	10.30	11.40
Other	24.0	24.0	28.0	1.00	1.16	3.90	3.90	3.34

As a result the large vehicles have to take slow turn, whereas the small size vehicles occupying very small pavement width can complete the left much faster because there is no conflicting man-oeuvre and there is no Psychological obstruction. It was further found that for all the motorised vehicles the right turning timings are more than non-motorised vehicles.

All the above data have been collected manually as it was not possible to get this data either by mechanical or any other means in the required format.

Examining the behaviour of motorised and non-motorized vehicles while approaching and clearing an intersection, it was found that the approach speeds in case of motorised traffic are higher than the crossing speeds. This is for the simple reason that the motori-sed vehicles are approaching the intersection with relatively higher speeds (about 35 kmph) and in order to avoid any possible conflict while clearing the intersection, they reduce the speed of their vehicles and keep it within safe negotiable limits.

On the other hand, the slow moving vehicles (non-motorised) were found to approach the intersection at their normal speeds (about 10 kmph) and as soon as, they reached at the approach of the intersection, in order to avoid any conflict and reduction in speed, they wanted to clear an intersection as fast as possible. As they approach an intersection with relatively slow speed, they have enough time to perceive the traffic situation in intersection area and decide accordingly. But they would always be intending to clear an intersection as quickly as possible in order to avoid the reduction in speed and ultimately to save their energy or power. It is because of this psychology of drivers of slow moving vehicles, that the crossing speeds of non-motorised vehicles are bit on the higher side (12 kmph) than the approaching speeds. This peculiar behaviour has been presented in the Table 4.11.

4.3.5 Traffic Volumes

Traffic volume information is utilised in almost every aspect of transportation engineering. Accurate and complete volume data are essential in evaluating the quality of flow through an intersection. In the present study the data of traffic volumes approaching intersection from different arms were recorded for peak hour. These approaching traffic volumes were directly used as an input in the simulation model 'SIMMTRA - 345'.

4.3.6 Number of Approaches

Number of approaches of an intersection were recorded and have been used as a direct input into the model. It is worth mentioning here that the simulation model SIMMTRA-345 is applicable to 3-leg, 4-leg and 5-leg priority type road intersections. However it has been tried successfully for 3-leg and 4-leg intersections only in the present study, but can be similarly applied to other types as well.

4.3.7 Approach Widths

The width available for approaching traffic is critical to inter-

TABLE 4.11. TYPICAL APPROACHING & CLEARING BEHAVIOUR OF FMV & SMV

Vehicle Type	Average clearing time in (Sec.)	Average observed approach speed (KPH)	Average clearing speed (KPH)	Speed difference (KPH)
		INTERSECTION 1		
Car	4.30	32.70	21.76	-10.94
Bus	5.19	30.26	18.03	-12.23
Truck	6.62	26.50	14.14	-12.36
Scooter/ Motor cycle	4.56	24.90	20.52	- 4.38
Bicycle	7.20	13.60	13.00	+ 0.60
Pedal Rickshaw	9.40	11.10	9.96	+ 1.14
Others	21.57	4.00	4.34	+ 0.34
		INTERSECTION 2		
Car	2.75	44.40	34.00	-10.40
Bus	3.10	41.50	30.20	-11.30
Truck	2.68	42.20	34.00	- 8.20
SC/MC	4.88	36.90	19.20	-18.00
Bicycle	6.72	12.19	14.00	+ 1.81
Pedal Rickshaw	8.53	10.50	11.00	+ 0.50
Others	17.60	4.00	5.31	+ 1.31

section capacity; it may be considered either as total approach width or by number of lane and lane width. American and British practices favour the former, but Australian methods are developed around the latter (156). In the present research work the total approach width has been considered. The approach widths have been recorded under following three categories :

3.5 m (single lane) on minor road.

7.0 m (two lane) on minor road.

7.0 m (two lane) on major road.

Approach width of all the legs meeting at an intersection is a direct input in the simulation model SIMMTRA-345.

4.3.8 Angle of Intersection (Angle of Turn)

Angle of intersection decides the turning movements which have an advance effect on intersection capacity. Depending upon the turning angle. The turning distance to the covered and the speed with which it is to be negotiated, are decided. For the sharper angle of turn the distance will be less and also the speed to negotiate the curve would be low. Similarly incase of turning angle greater than 90 degrees, the relative distance and speed would increase.

The turning angle data was recorded for all the approaches and at all the sites. These angles are direct input in the simulation model SIMMTRA-345. The model calculates the lengths of various movements depending upon these angles.

Apart from the above basic data collected on semi-urban type uncontrolled at-grade intersections, some additional manual data was also collected for the following reasons :

1. Either to check the completeness and the accuracy of a given data set or for the supplementing of data derived from video recording technique, and,

2. For generating and collecting the supplementary or secondary data for input into process of building the simulation model and analysis it, as and when the need for the same arose.

4.4 DATA FROM VIDEO RECORDING FIELD STUDIES

The manual data collection for different required parameters of traffic flow as discussed earlier is slightly tedious and tends to be a bit lacking in accuracy when total flow is higher at intersection. Therefore the data collection on most of the intersections has been carried out by using video recording. Simultaneous , comprehensive and permanent record of different traffic parameters recorded through video recording technique was studied in traffic laboratory.

4.4.1 Data Recording

The video recording unit was set up on some elevated point at identified intersection, overlooking the intersection. The angle of the camera was adjusted in such a way so that all the approaches of the intersection and the traffic entering and leaving the intersection were well covered within the range of video camera. Care was needed to ensure that no obstacle or vehicle blocks the camera view. The angle of inclination of camera should be such that it also records these consecutive cube reflectors fixed at known distance along both edges of the carriageway. This is important to measure the distances in the laboratory.

On ten selected intersections the data were recorded during the peak hour period. In order to identify the peak hour traffic, the traffic was recorded for 24 hours on each selected intersection. The data were recorded for exactly one peak hour on all sites.

4.4.2 Data Extraction in Traffic Laboratory

There are two methods to extract numerical data from the video recordings, one of which involved the use of Australian road research board (ARRB) (157, 158) equipment and the other used simple manual analysis. As ARRB equipments were not available, manual method of analysis was used.

The inclusion of stop watch timing on the video record was critical for the success of this method. The starting point of the recording tape for each intersection is cyncronised with stop-watch. An arbitrary mark was assumed on the screen (Say a corner cube reflector) on each approach. Each time a vehicle passed the mark, the time was noted down. This was done with different observers watching separate approaches. Incase of heavy traffic on approaches, the cassette was replayed several times to maintain the quality of the data. The whole process took about 5 to 6 times the time of video recording. At the end of each replay the data were entered in the fixed proforma. The following data were recorded.

1. Time headway and arrival time data
2. Total traffic volume data on each intersection.
3. Composition of traffic
4. Classified directional distribution of traffic
5. Conflicting traffic at intersection

4.4.3 Time-Headway Data and Arrival Times

The arrival of vehicles at a queueing system can best the described in terms of interarrival times; i.e., in terms of times that elapsed between successive vehicle arrivals. These times are often called 'headways' in traffic problems.

In the present study the headway data were collected in traffic laboratory by replaying the video cassette. As explained in article 4.4.2, some point was assumed on the T.V. screen and the time between successive vehicles was recorded with the help of stopwatch when they cross the point. The details of recording headway data from video cassette and calculation of arrival times are presented in Table 4.12.

Headway data was grouped in to three traffic volumes in the ranges of 200 vph, 500 vph and 1000 vph respectively. Different distribution models were tried for the above volume ranges. The final results of these trials are given in Table 4.13. Also the expo-

TABLE 4.12 - TYPICAL HEADWAY AND ARRIVAL TIME DATA
Km. 20.000, Approach N. 3 (From Delhi)

Video Cassette Starting Time : 00.03.52 (Recorded from video cassette)

Vehicle Type*	Arrival time as per the stop watch	Headway (Sec.)	Arrival time	Vehicle Type	Arrival time as per the stop watch	Headway (Sec.)	Arrival time
T	03.53	1	1	SC	05.25	33	93
C	04.01	8	9	T	06.09	44	137
C	04.03	2	11	SC	06.22	13	150
C	04.06	3	14	B	06.26	4	154
C	04.08	2	16	C	06.28	2	156
T	04.15	7	23	T	06.33	5	161
C	04.23	8	31	B	06.48	15	176
C	04.30	7	38	B	06.53	5	181
SC	04.35	5	43	B	06.58	5	186
B	04.40	5	48	SC	07.04	6	192
B	04.43	3	51	CY	07.34	30	222
SC	04.48	5	56	CY	07.39	5	227
SC	04.52	4	60	C	07.53	14	241

* Where C = Car; B = Bus; T = Truck; SC = Scooter or Motor cycle; CY = Bicycle; PR = Pedal Rickshaw and O = Others.

nential distribution for time headway for one of the volume ranges is shown in Fig. 4.3.

TABLE 4.13 – GOODNESS OF FIT TEST ON MIXED TRAFFIC HEADWAY DATA

Sl. No.	Distribution Tried	Volume up to VPH	Actual volume VPH	X_o^2	X_c^2 At Significance level 0.05	Degree of freedom	Remarks
1.	Poisson	200	152	7.81	8.15	3	Good fit
2.	Exponential	500	443	56.13	14.07	7	Bad fit
3.	Shifted Exponential	500	443	16.82	18.31	10	Good fit
4.	Shifted Exponential	1000	883	27.08	15.51	8	Bad fit

4.4.4 Total Traffic Volumes at Each Intersection

The total traffic entering an intersection from all the approaches was recorded. As mentioned in article 4.3.1 the same data were collected manually too. Thus the total traffic volumes collected by two different methods were compared as shown in Table 4.14. It can be seen that there is marginal variation between two traffic volumes. However for all practical purposes the data collected by video recording technique were considered accurate and valid.

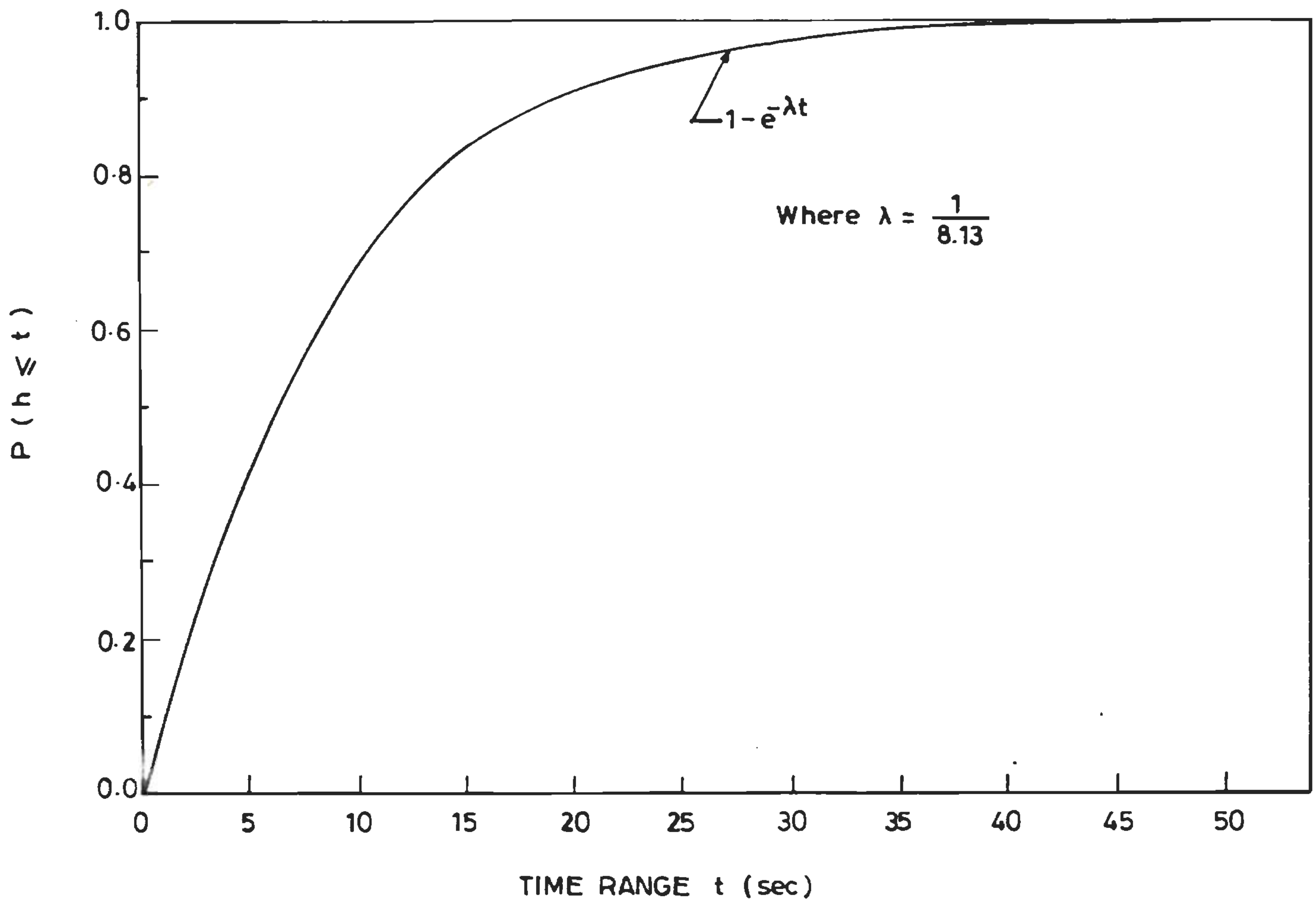


Fig. 4.3 Exponential distribution for time headway

TABLE 4.14 - COMPARISON OF TRAFFIC VOLUME DATA COLLECTED BY TWO METHODS

Sl. No.	Identification of an inter-section	Type of inter - section	Observed Traffic Volumes (Vph)		Variation Vph	Remarks
			Manual method	Video recording		
1.	NH.24, Km. 20.000 (Ghaziabad Div.)	T	939	942	3	
2.	NH.2, KM. 201.000 (Agra Div.)	4-leg Right angle	2792	2811	19	
3.	NH.2, Km. 193.000 (Mathura Div.)	Y	693	691	2	
4.	NH.2, Km. 148.000 (Mathura Div.)	4-leg Right angle	460	464	4	
5.	NH.2, Km. 12.000 (NHRC Div., Kanpur)	4-leg Right angle	3115	3115	0	
6.	NH.25, Km. 11.400 (Lucknow Div.)	T	1577	1577	0	
7.	SH.45, Km. 170.000 (Hardwar)	4-leg Right angle	398	399	1	
8.	121-W MDR, Km. 173.000 (Dehradun)	Staggered Right angle	429	429	0	
9.	NH.24, Km. 28.000 (Ghaziabad Div.)	T	2089	2125	36	
10.	NH.25, Km. 59.000 (BCD Div., Kanpur)	Y	986	1000	14	

4.4.5 Composition of Traffic

Classified traffic data were collected for all the approaches by replaying the video cassette in traffic laboratory. The data were collected for all the finally selected intersections. Total volume generated by each approach during peak hour and its composition in percentage are the direct input in simulation model SIMMTRA-345, were recorded as shown in Table 4.15 and 4.16 and Figs. 4.4 to 4.7 for three leg and four leg intersections respectively.

4.4.6 Classified Directional Distribution of Traffic

For each approach classified directional distribution of traffic was recorded that is, classified traffic going in different directions from an approach. This data is presented in Table 4.17 for four leg intersection.

4.4.7 Conflicting Traffic at Intersection

As per Indian traffic environment, the traffic conflicts at - intersection can be categorised as right - turn conflicts, cross-traffic conflicts or rear - end conflicts. In some of the traffic conflict studies (159, 160, 161), the technique has been developed to relate the projected accident hazard to the frequency of observed intersectional vehicular conflicts of various types.

Proportions of conflicting traffic entering the intersection from different approaches have been recorded and presented in Table 4.18. These data are direct input into the simulation model.

TABLE 4.15 - TYPICAL TRAFFIC COMPOSITION AS OBSERVED ON MAJOR AND MINOR ROADS AT Km. 28.000 (GHAZIABAD DIVISION) (3-Leg Intersection), NH-24

(Recorded from Video Cassette)

Vehicle Category	Vehicle Type		OBSERVED	PERCENTAGE	OF MIXED	TRAFFIC
		TYPICAL COMPOSITION DURING PEAK HOUR				
		Type of Road	Major	Minor	Major	Minor
		Approach No.	2 3	1	2 3	1
		FMV/SMV	571 201 867 164	291 31	571 201 867 164	291 31
		Vph	772 1031	322	772 1031	322
		Total Vph	1803		1803	
Fast-Moving or Motorised Vehicles (FMV)	1.	Car, Jeep, Three wheeler, Light-vans, Tractor	23.57	38.51		
	2.	Bus & Mini bus	10.70	9.32	80.75	90.37
	3.	Truck & Mini-truck	8.54	13.35		
	4.	Scooters, Motorcycles & Mopeds	37.94	29.19		
Slo-Moving or Non-motorised Vehicles (SMV)	1.	Bicycle	15.64	8.70		
	2.	Pedal Rickshaw	2.61	0.62	19.25	9.63
	3.	Others	1.00	0.31		
		TOTAL			100.00	100.00

TABLE 4.16 – TYPICAL TRAFFIC COMPOSITION AS OBSERVED ON MAJOR AND MINOR ROADS AT Km. 201.000 AGRA DIVISION NH.2 Semi-urban Priority Intersection (4-Leg)

(Recorded from Video Cassette)

Vehicle Category	Vehicle Type		TYPICAL COMPOSITION DURING PEAK HOUR: OBSERVED PERCENTAGE OF MIXED TRAFFIC			
		Type of Road	Major	Minor	Major	Minor
		Approach No./FMV-SMV	1 3	2 4	FMV SMV	FMV SMV
		Vph	869 683	693 566	832 720	442 817
		Total Vph	1552	1259	1552	1259
Fast-moving or Motorised Vehicles (FMV)	1.	Car, Jeep, Three wheeler, Light-vans, Tractor	13.02	5.00		
	2.	Bus & Mini-bus	4.06	1.35	53.61	35.10
	3.	Truck & Mini-truck	9.79	4.29		
	4.	Scooters, Motorcycle & Mopeds	26.74	24.46		
Slow-moving or Non-motorised Vehicles (SMV)	1.	Bicycles	38.08	53.54		
	2.	Pedal Rickshaw	5.86	7.70	46.39	64.90
	3.	Others	2.45	3.65		
		TOTAL			100.00	100.00

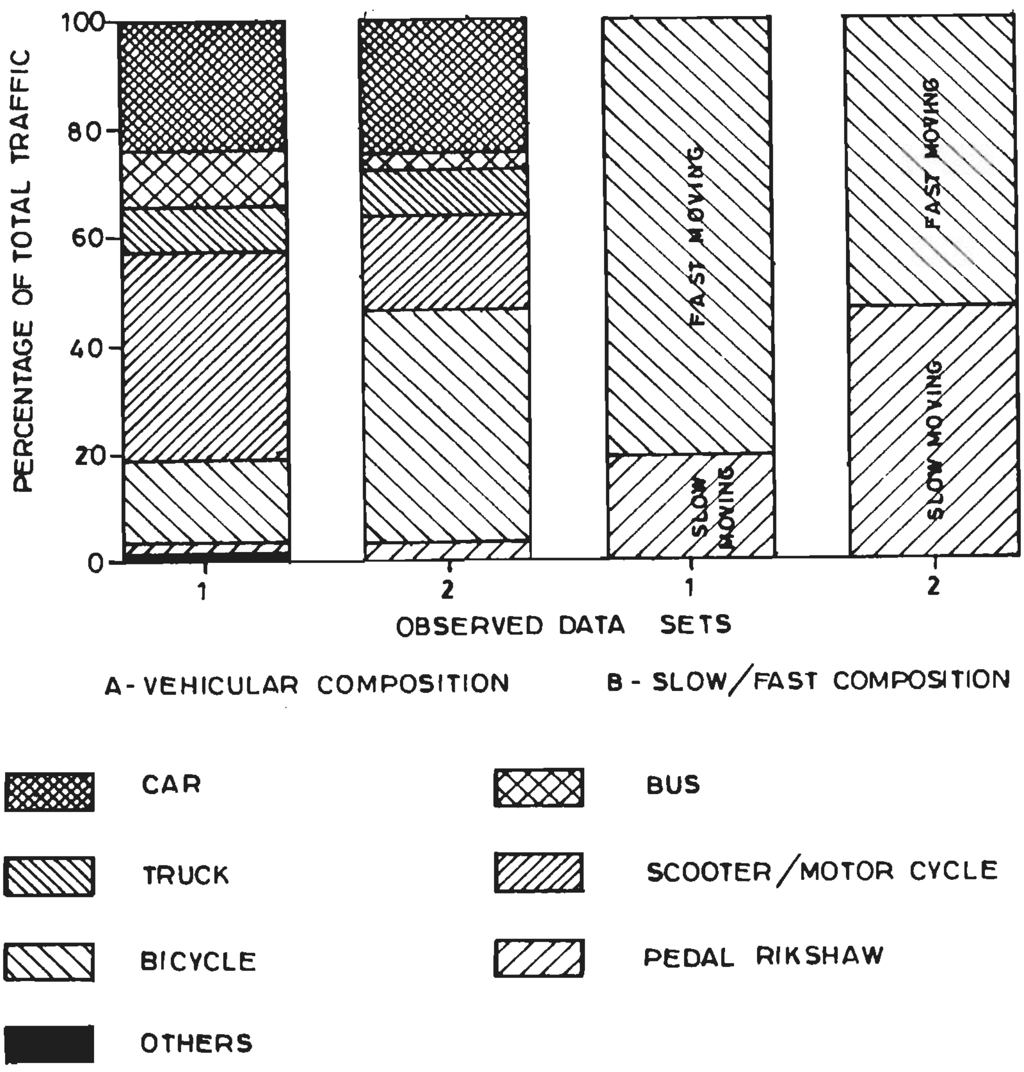


Fig. 4.4 Typical observed traffic composition at intersections Km. 28.000 & Km. 11.400 (3- Leg) major road

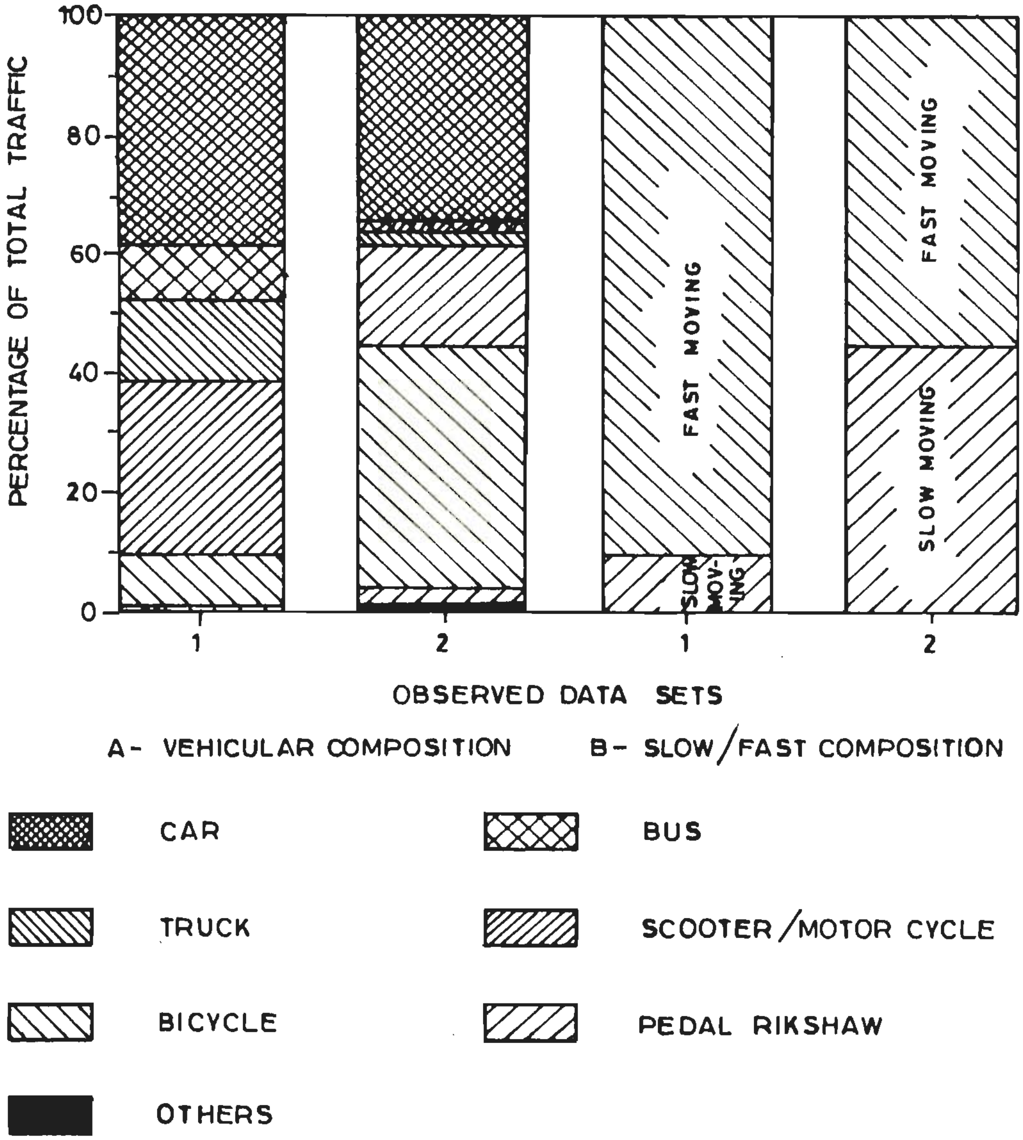


Fig. 4.5 Typical observed traffic composition at intersections Km. 28.000 & Km. 11.400 (3-Leg) minor road

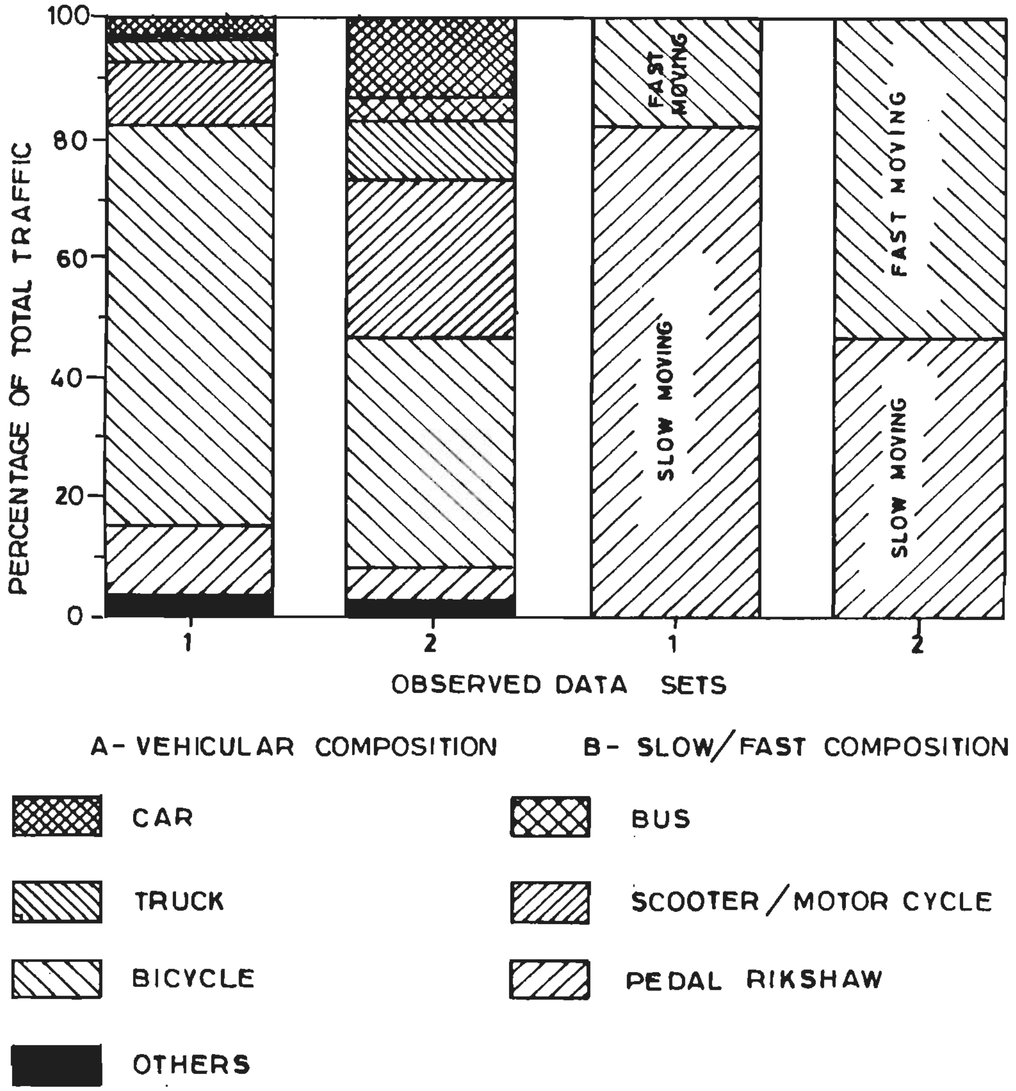


Fig. 4. 6 Typical observed traffic composition at intersections Km. 12.000 & Km. 201.000 (4-Leg) major road

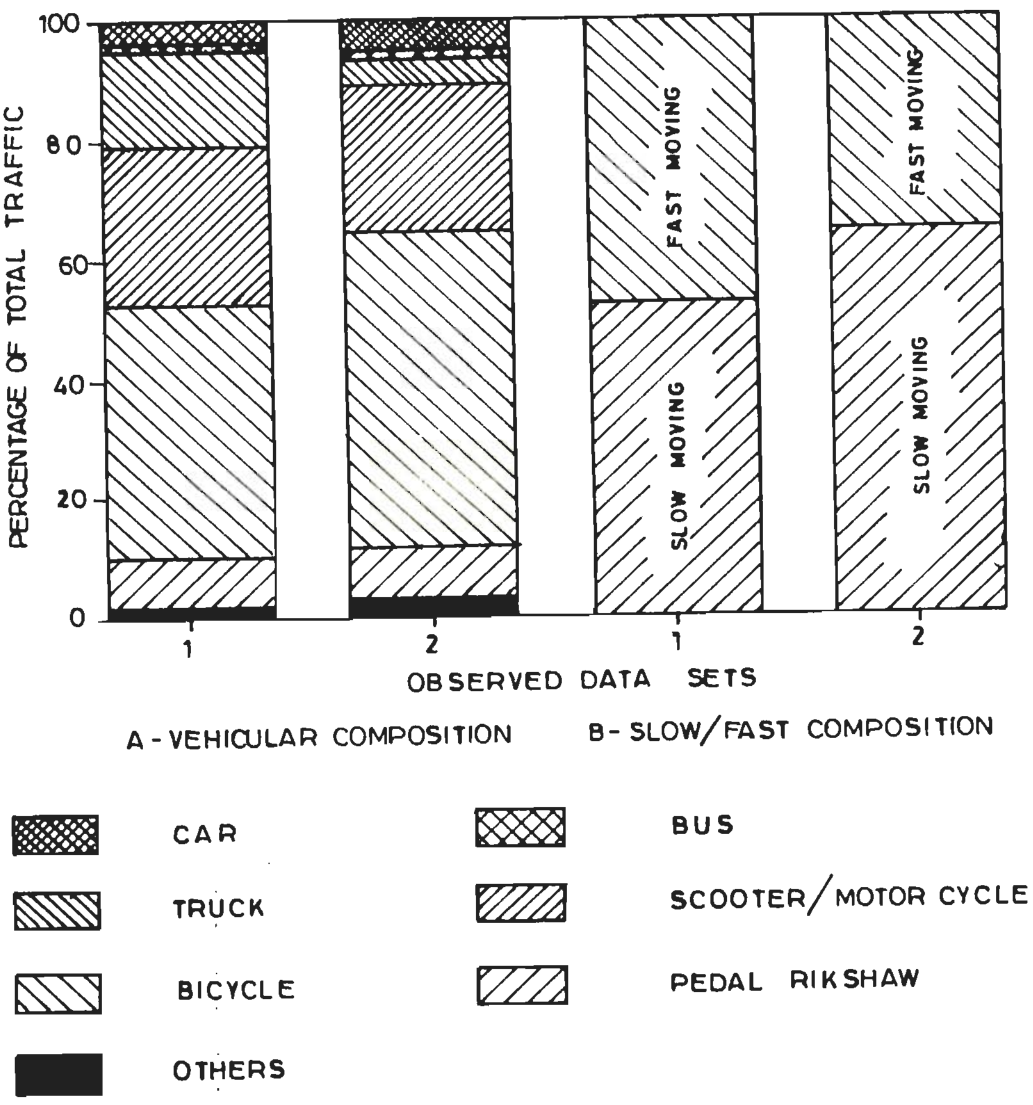


Fig. 4.7 Typical observed traffic composition at intersections Km. 12.000 & Km. 201.000 (4-Leg) minor road

TABLE 4.17. TYPICAL CLASSIFIED DIRECTIONAL DISTRIBUTION OF TRAFFIC Km. 201.000 (4-Leg)

Approach Number and Link	Turning Movement	PERCENTAGE OF VEHICLE TYPE IN TURNING TRAFFIC						
		Car	Bus	Truck	Scooter/ Motorcycle	Bicycle	Pedal Rickshaw	Other
1	Left	7.61	5.37	7.38	29.53	43.40	4.03	2.68
Major	Straight	15.63	3.91	10.80	34.02	29.89	4.83	0.92
	Right	14.94	0.0	2.30	39.08	39.08	4.60	0.00
2	Left	0.0	0.0	5.88	35.29	58.83	0.0	0.0
Minor	Straight	5.50	0.0	1.38	32.11	44.49	11.93	4.56
	Right	2.72	0.0	3.62	17.52	61.03	9.37	5.74
3	Left	6.10	0.0	1.41	24.41	47.42	13.62	7.04
Major	Straight	17.42	5.56	13.64	30.05	28.28	4.29	0.76
	Right	6.76	0.0	17.57	40.54	27.03	2.70	5.40
4	Left	6.25	0.0	31.25	43.75	18.75	0.0	0.0
Minor	Straight	2.22	0.0	1.90	21.20	62.34	9.81	2.53
	Right	9.42	4.71	7.48	27.70	45.71	2.49	2.49

TABLE 4.18 - DETAILS OF CONFLICTING TRAFFIC AT INTERSECTION (4-leg intersection), Km. 201.000

From Approach No.	Percentage of mixed traffic vehicles				Remarks
	Left	Straight	Right	Total	
1.	46.13	44.89	8.98	100.00	Major road
2.	3.0	38.52	58.48	100.00	Minor road
3.	31.19	57.98	10.83	100.00	Major road
4.	2.31	45.60	52.09	100.00	Minor road

4.5 SUMMARY

This chapter covers in depth the various field studies carried by the author on mixed traffic behaviour at priority type semi-urban intersections. The data so collected were analysed and put in the format so that it can be utilised as an input in the simulation model SIMMTRA-345. The various aspects considered in developing a digital simulation model SIMMTRA-345 for traffic analysis at priority type intersections under mixed traffic conditions have been discussed in following chapter.

CHAPTER V

DEVELOPMENT OF DIGITAL SIMULATION MODEL -'SIMMTRA-345'

5.1 GENERAL AND INTRODUCTION

Various field studies on the mixed traffic behaviour, conducted at the finally selected ten intersections in the state of Uttar Pradedh, have revealed some important operational features, as already discussed in the previous chapter. This chapter includes the various stages of simulation model development for priority type intersections; such as; development of simulation logic for individual component and implementation in to computer language in the wake of the scope and objectives of the present research work.

One of the tasks frequently faced by the traffic engineers is the evaluation of intersection performance. Is a particular intersection operating as efficiently as possible under the prevailing roadway, traffic and control conditions? can the performance of intersection be improved by introducing the change in control? In the contemplation of these and similar questions, intersection delay comes to mind as a figure of merit used to evaluate the performance of an intersection. It is practically very difficult to measure the delay at priority intersection through field surveys. So one has to opt for either mathematical modelling or simulation experiments to evolve an operational model.

A model either directly solves problems arising in a real situation or indirectly determines how the real situation would be affected by a possible change in operating policy. If it is possible to get the solution of the set of equations mathematically, it is called an analytical model. But when one has to choose one solution among a lot, it is called optimum model. The model which represents the real situation of the scene is known as simulation model.

Almost any complex traffic situation is capable of simulation and be easily programmed. Variables or controls can be changed and their effects analysed. Before and after studies can be performed in short time without disturbing the traffic in the field.

5.2 DISCRETE EVENT SIMULATION

Simulation is "to assume the appearance of scene without the reality". Simulation model may be deterministic or stochastic. The deterministic simulation model is usually required only for rather complicated analysis of traffic system. The stochastic simulation model, by contrast, are often required for analysis of even quite simple traffic situations. The digital computer models are well suited to stochastic simulation as they enable to represent any particular random element in the situation being simulated.

By its very nature, a stochastic simulation model produces, in general, a different result each time it is used to represent any particular situation. This reflects the fact that the quantities to be estimated are themselves random variables. The only real limitations to such modelling, whether deterministic or stochastic, are understanding of the real system, computing resources and the availability of data for validation of the models.

5.3 SIMULATING THE BEVAVIOUR OF THE SYSTEM COMPONENTS

The simulation of a traffic situation can contain the components that can either be deterministic or probabilistic or stochastic. The deterministic components represent those that are subject to only a small degree of uncertainty. Hence the values of deterministic components can be determined by studying the precise history of the system. Stochastic components are subject to significant uncertainty due to its randomness or because it is not possible to gain complete knowledge of its character. Stochastic variables are usually described by statistical distributions.

5.3.1 Statistical Distribution

The initial problem in the simulation phase is, therefore, to device a procedure for selecting a distribution so that the results of the repetition of the process will give a frequency distribution of sampled values that matches the frequency distribution describing the components.

Chapter III and IV of this dissertation describe the selection of a distribution models that are best matched to the components of the simulation models SIMMTRA-345, which has been developed under the present research work. The generation process is proposed to be presented by following distributions :

Arrival headways : Poisson and shifted exponential distribution depending on the approach traffic volume.

Composition and directional distribution of traffic : Discrete distribution

Speed : Normal distribution

5.3.2 Random Number and Variate Generators

5.3.2.1 Random number generators

Statisticians were amongst the first to recognise the need for random numbers (162). By making use of Pseudo random number generators, a large sets of random numbers can be generated and stored (163). There are several methods to generate Pseudo random numbers., some of them are : mid square techniques (164); mid product technique (165); multiplicative congruential or power residual technique (166) and mixed congruential technique (167). Of all the above techniques, the mixed congruential technique was found more suitable to the present simulation study, as it can generate a full cycle of random numbers and there is no need to put any restrictions on the seed numbers. The mixed congruential technique can be represented by equation -

$$R_i = (K \times R_{i-1} + C) \ (\text{Mod } w^m) \qquad (5.31)$$

where

R_i = i^{th} pseudo random number

m = the number of digits in a normal word in the computer

w = the base of the computer

K = the multiplication factor

Mod w^m = the remainder after dividing by w^m

R_o = the 'seed' number required to start the procedure

C = additive constant

It is necessary to specify additive constant 'C', the multiplier K and seed R_o, all positive integers less the modulus m which is chosen as 2^b for binary computers, where b is the number of bits per word. 10^d for a decimal computer (168), where d is the number of digits per word. The flow chart of mixed congruential method of generating random number is presented in Fig. 5.1.

5.3.2.2 Random variates

The following random variates have been included in the simulation model SIMMTRA-345 and its subroutines.

- Generation of arrival times
- Generation of type of vehicle
- Generation of turning manoeuvre for vehicles

All the variates are associated with non-uniform discrete distributions. These discrete distributions can be generated based on the uniformly distributed Pseudo-random numbers generated sequentially.

5.4 SIMULATION UPDATE PROCEDURE OR SCANNING TECHNIQUES

Another step in the modelling of the interactions between components is the determination of the procedure used to update the simulation programme. The simulation model must be updated in a systematic manner. There are following three methods of updating.

5.4.1 Time Update Method

The time update method updates the simulation time at discrete

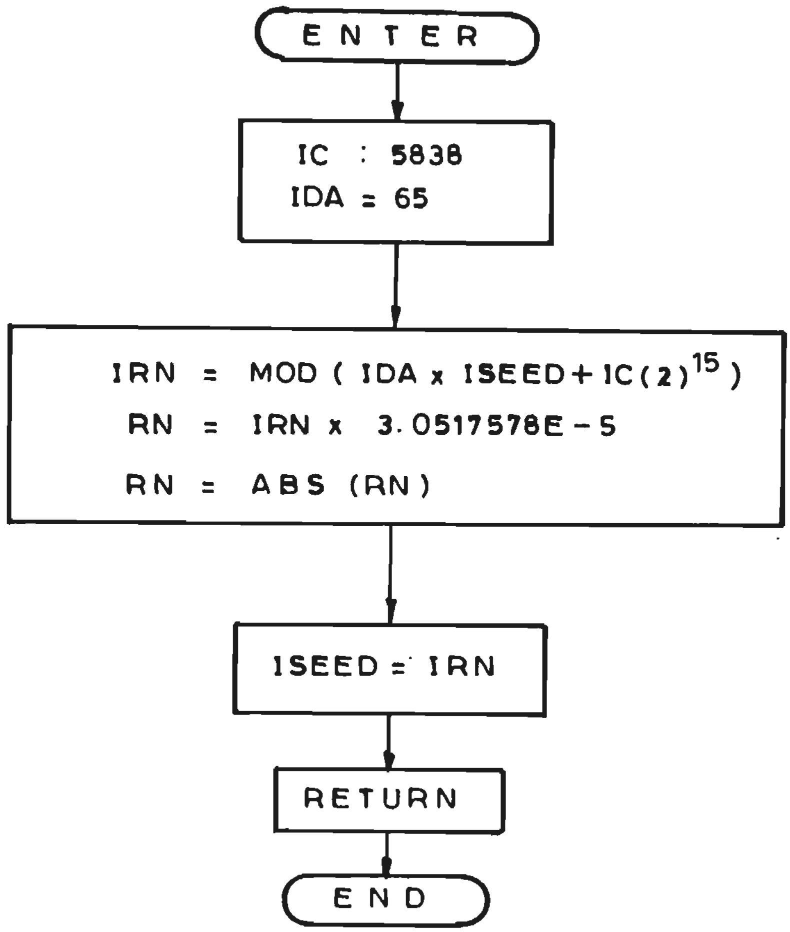


Fig. 5.1 Flow chart of mixed congruential method of generating random numbers

points in time. Suppose simulation starts at time T. After the time advances one increment (Δ t) to T + Δt, the state of traffic at time T + Δ t is determined. The process continues till the simulation is completed. Figure 5.2 shows the flow chart of time update procedure.

5.4.2 Vehicle Update Method

The vehicle update method takes each vehicle as an independent entity and traces its movement through the system. Thus it considers the vehicles one by one and simulates their movements.

5.4.3 Event Update Method

The event update procedure updates the simulation time when the next event occurs. The initial state of the traffic system at time T_k is determined. As soon as the first event occurs the time is updated to T_{K+1}. Similarly simulation model updates the simulation time with every occurrence of event say T_{K+2}, T_{K+3}, ... until the simulation is completed. Figure 5.3 presents the flow chart of the event update procedure that considers the operation of the T-intersection.

In the present simulation study the event update procedure has been made use of for the simple reason that it best suits to the traffic situation at intersection.

5.5 DEVELOPMENT OF SIMULATION MODEL

5.5.1 Introduction

The first step in a simulation study is to develop a model representing the system to be investigated. It is apparent that this requires

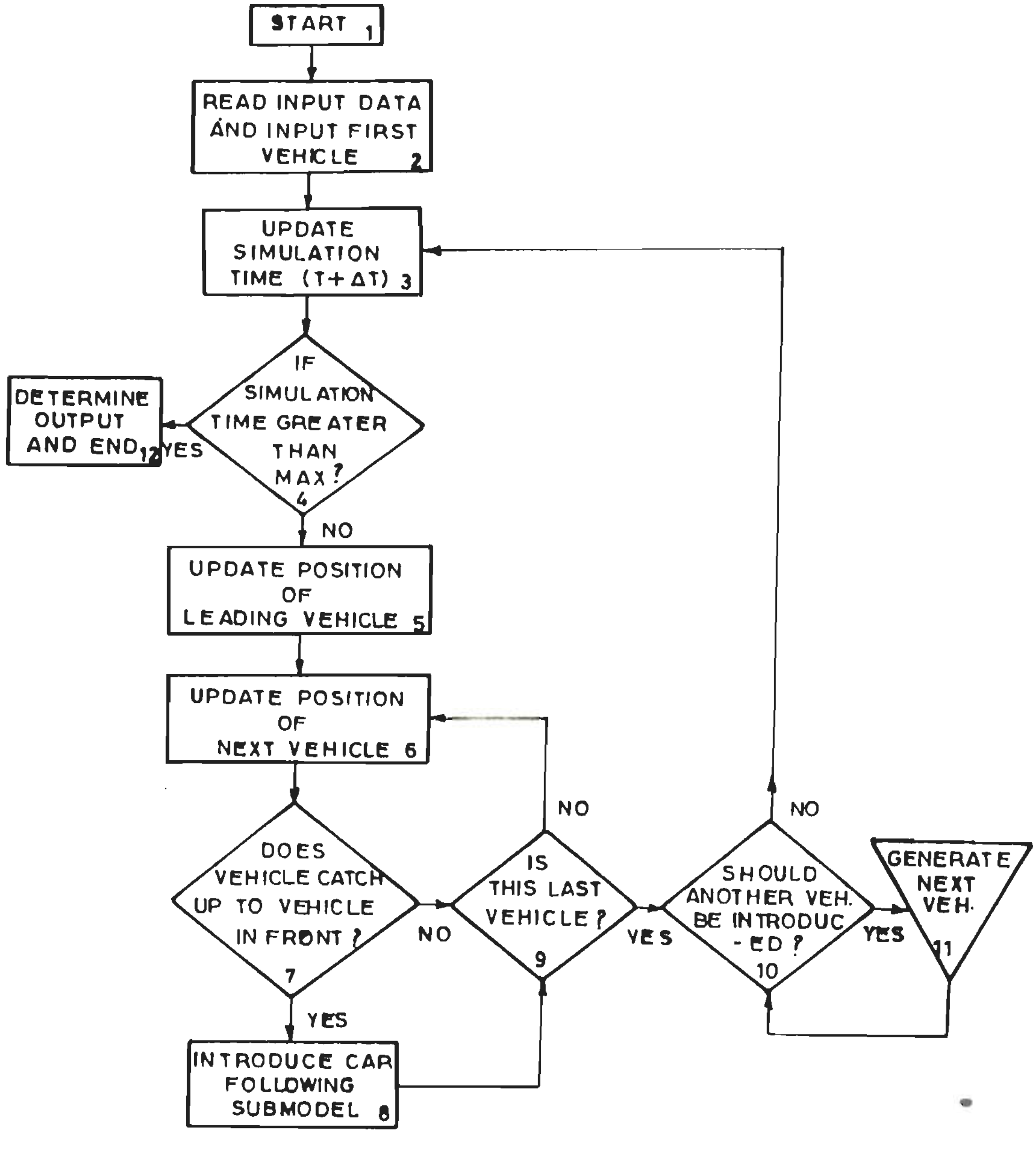


Fig. 5.2 Flow chart of time update procedure

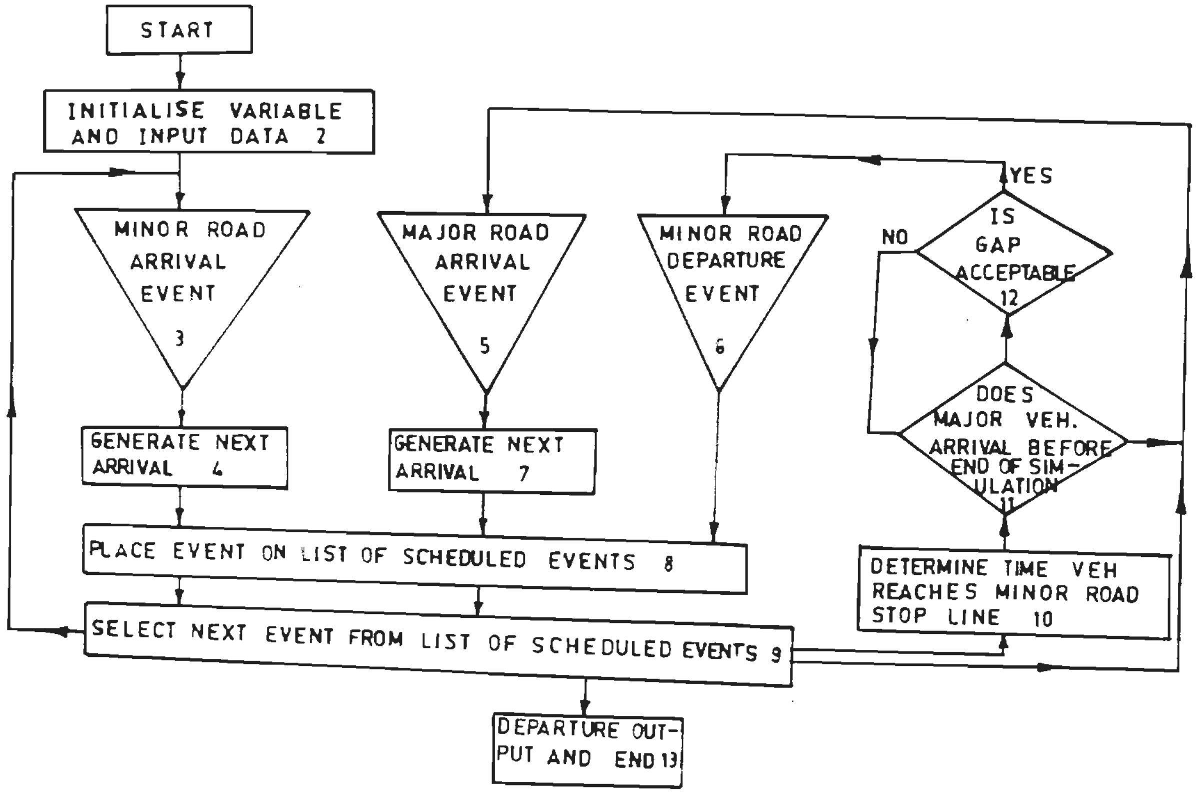


Fig. 5. 3 Flow chart showing the operation of T- intersection through event update procedure

the analyst to become thoroughly familiar with the operating realities of the system. In the light of the previous discussions, it should be emphasised that the development of a simulation model should never start without a clear definition of the objectives to be achieved.

This article describes the general simulation process. A version of this process is presented in Fig. 5.4 The following steps are involved in general simulation process.

(1) Objectives and problem definition : The objectives of simulation process should be clearly defined in advance of the model development. The nature and scope of the problem to be analysed through simulation has to be established.

(2) Data collection and analysis : The experimental data concerning to the problem and other factors are collected and analysed.

(3) System analysis : This stage of the model development refers to the study of system; its components, interactions and interrelationships.

(4) System synthesis : This step consists of organising the results of the system analysis into a unified logical structure. Flow charts, data arrays, computer programme and programming language constitute the essence of this stage.

(5) Model calibration : It is essentially the adaptation of the magnitudes represented by certain elements of the model to the real-life-conditions of the system simulated. The step includes assignment of values of empirical constants.

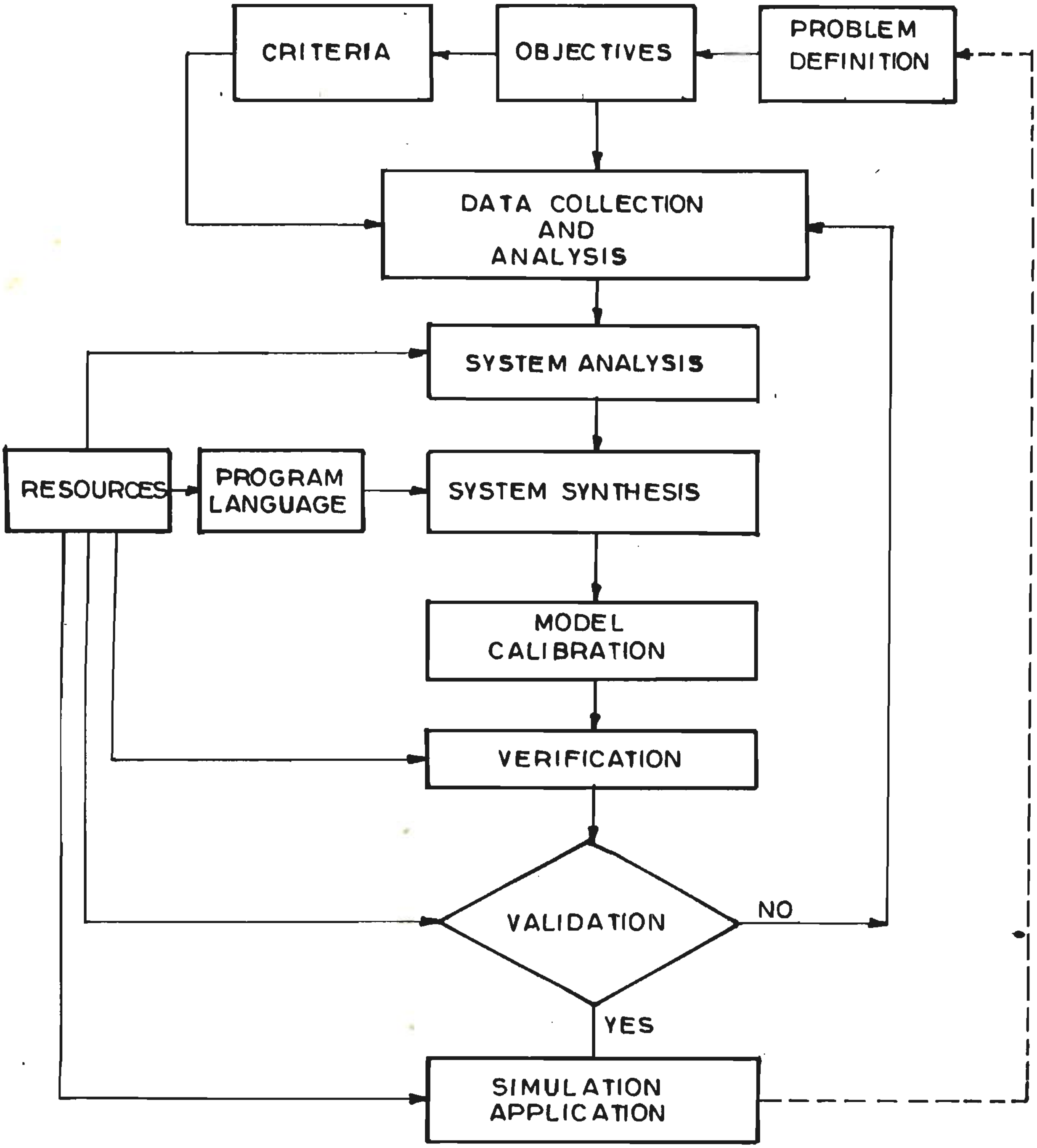


Fig. 5.4 General flow chart : stages of simulation model development

(6) Verification : It is concerned with determining if the model performs as it was designed to. It may include a sensitivity analysis to determine the degree in which the output of the model responds to the variations in its output. Results of this step may suggest change in logical structure of the model.

(7) Validation : This step consists of testing the agreement between the behaviour of the model and the observed behaviour of the real-life simulated. This is done by comparing sets of outputs of the model with equivalent field data. Statistical analyses are usually employed to assess the significance between the two sets of values compared.

(8) Application : This is most exciting and challenging step. Its main purpose is the investigation of system performance and the effect of system changes. However each successful application of the model will enable the user to gain confidence in the model each successful application of the model will encourage new developments or refinements. The model application stage therefore emphasises the cyclic nature of the model development process.

(9) Analysis of simulated data : The results from the simulation experiments are analysed to determine the characteristics of various components of the process, their significance and inter-dependence.

5.6 MODEL FORMULATION

5.6.1 Purpose of the Model

The main purpose of the model is to simulate the mixed traffic conditions at priority type semi-urban and semi-rural intersections to evaluate the performance of an intersection in terms of total delay, average delay and queue length under the prevailing roadway and traffic conditions. The model should be capable of predicting the effect that any change in the system will create in the performance of an intersection. The model has been used to simulate the traffic at 3-leg and 4-leg intersections, but it can be successfully used for 3,4, and 5 leg intersections. The various model features to simulate traffic at intersection are presented in Fig. 5.5.

5.6.2 System Description

The details of the system involving various components, variables, relationships and assumptions are discussed briefly.

Three legged and four legged priority type semi-urban intersections as shown in Fig. 5.6, have been considered for the development of SIMMTRA-345 simulation model. Infact the model is also capable of simulating the mixed traffic on five legged intersections. Physical description of an intersection, traffic system under consideration, various assumptions and constrains have been highlighted in the following articles.

5.6.3 Characteristics of Priority Type Semi-Urban Intersections

Priority type semi-urban intersection is formed by an arterial and a minor road. On most of the intersections, all the approaches are undivided and provided with divisional islands to segregate the up and down traffic. Approach (es) carrying low traffic volume have been considered to form minor road and that carrying higher traffic volume as major road.

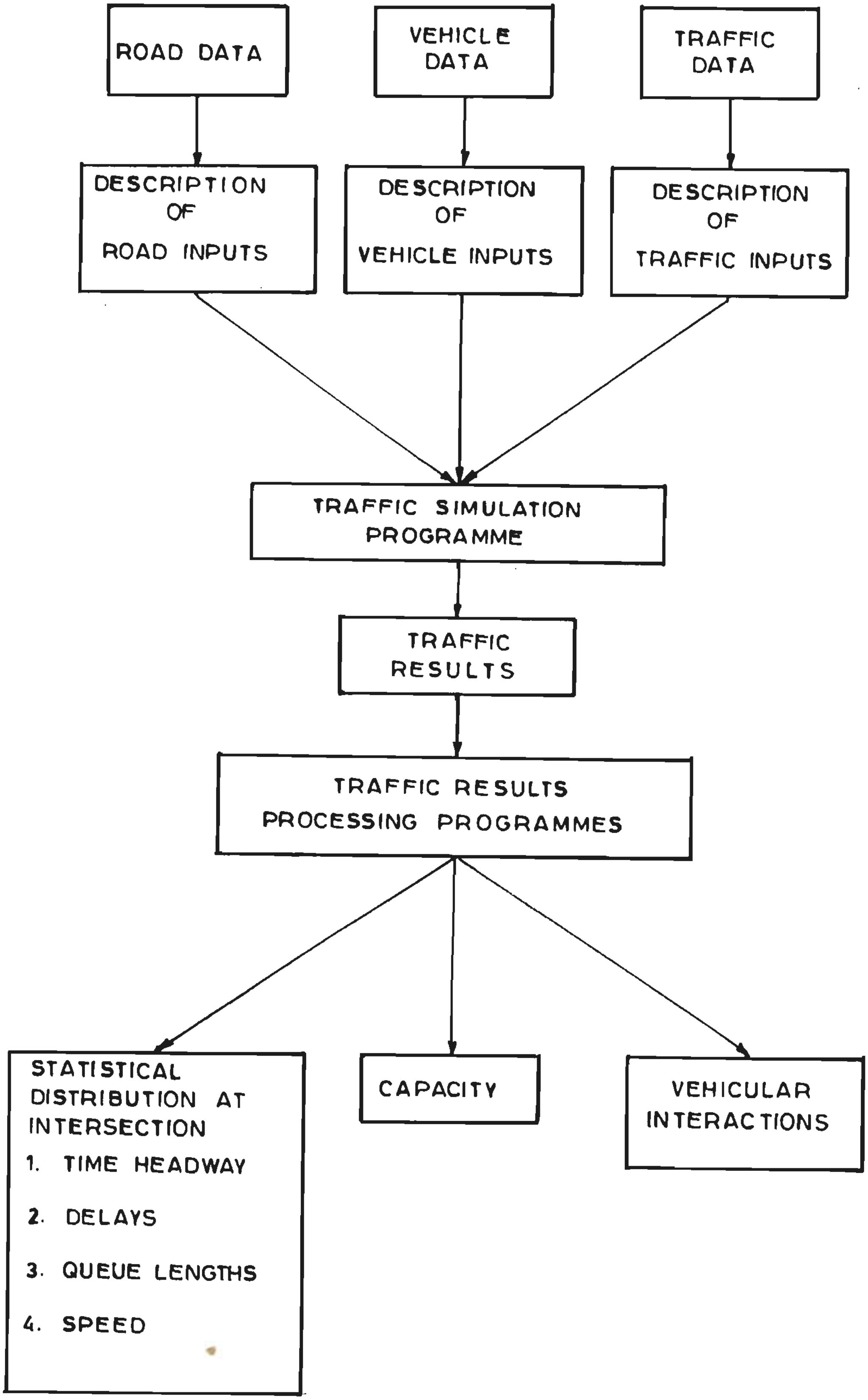
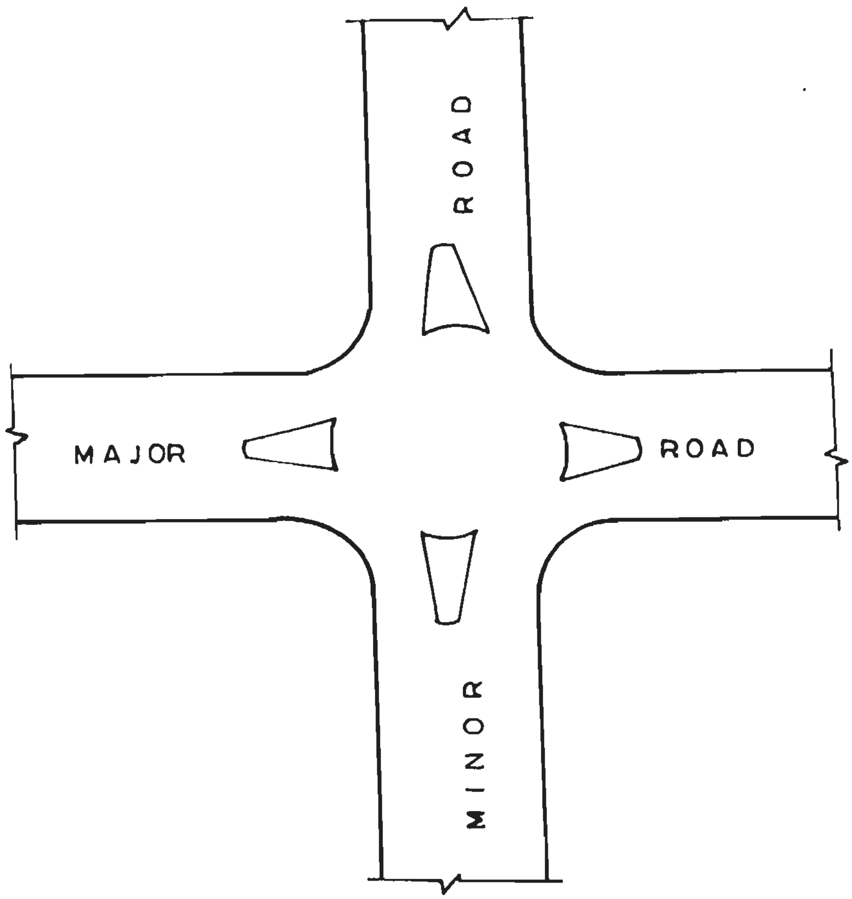
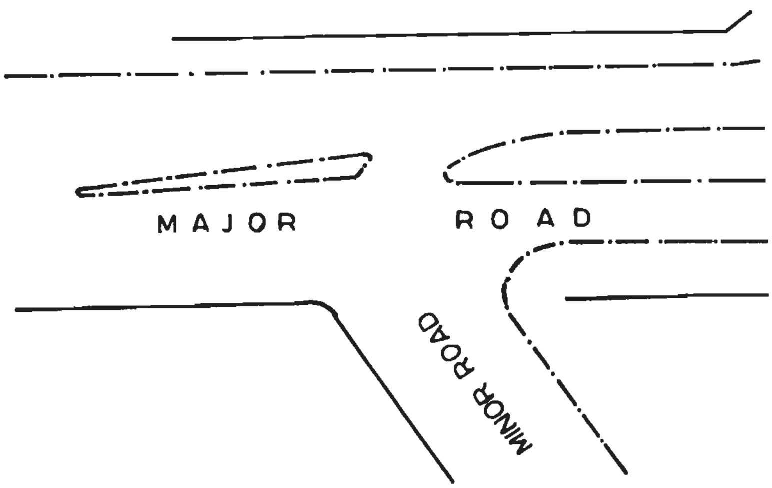


Fig. 5·5 Model features: programme system for traffic simulation of intersection



4 - LEG INTERSECTION



3-LEG INTERSECTION

Fig. 5.6 Schematic diagram of the intersection for simulation study

5.6.3.1 Number of approaches

Coding of approaches has been done in an anticlockwise direction starting from south bound approach. Therefore, incase of 4-leg intersection, sometimes approaches 1 and 3 form minor road and some times 2 and 4 form minor road. Similarly for 3-leg intersections approach 1 or 2 or 3 may be minor road as indicated in Fig. 5.7.

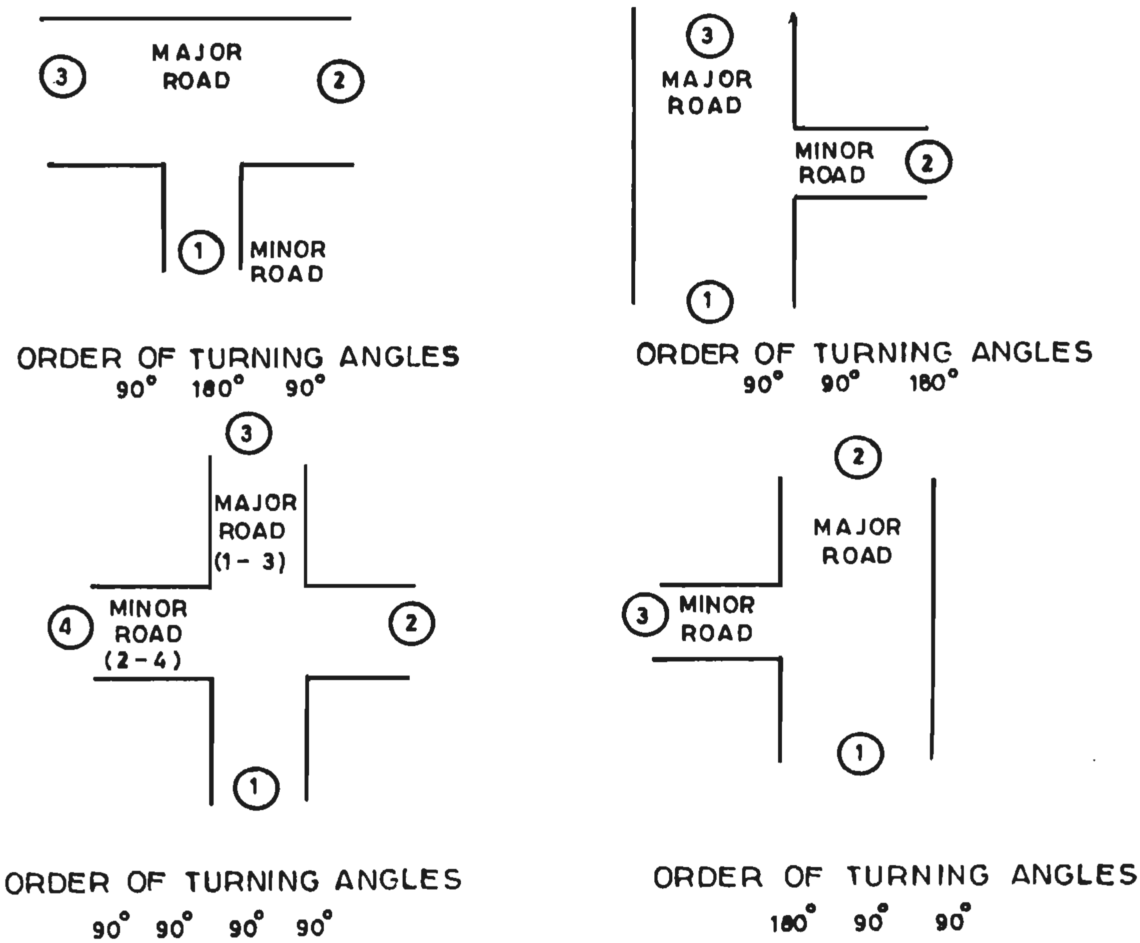
5.6.3.2 Approach widths

Approach widths have been grouped in to three categories as shown in Table 5.1.

TABLE 5.1 - APPROACH WIDTH CONSIDERATION IN SIMULATION MODEL SIMMTRA-345

Sl. No.	Approach Width (m)	Category	Code
1.	3.5	Minor road	1
2.	7.0	Minor road	2
3.	7.0	Major road	3

5.6.3.3 Angle of turn on turning angle - Angle of turn for all the approaches is to be given as an input in tthe model SIMMTA-345. The angles are measured in an anticlockwise direction starting from south bound approach. The order in which the turning angles have been considered is presented in Fig. 5.7. Straight and fairly levelled approaches are assumed for about 300 m length from intersection. Fair visibility is assumed in the model.



(Not to scale)

Fig. 5.7 Numbering (Coding) of approaches and order of turning angles

5.6.4 Traffic System

Traffic considered in the simulation model SIMMTRA-345 is of mixed nature, that is, it consists both motorised (fast moving vehicles, FMV) and non-motorised vehicles (slow moving vehicles, SMV). All the motorised vehicles have been categorised into four groups and non-motorised vehicles into three groups. Thus a total a seven type (groups) of vehicles, viz., car, bus, truck, scooter or motor cycle, bicycle, pedal rickshaw and others (animal and hand drawn carts), representing the mixed traffic system, have been incorporated in the simulation model. However, with some modifications in the model, it is possible to incorporate few additional vehicle modes, if needed.

On most of the intersections the demand volume is not evenly split between the crossing facilities. On an average, a variation of 15 to 20 percentage was observed in the demand volume of crossing approaches.

The flow of motorised and non-motorised modes on an approach is considered as non-segregated unlike the study of Ferrara (61) where the bicycle stream was almost segregated. Also the same approach width is shared by mixed vehicles willing to go right, left or straight. There are no lane marking for either turning or crossing movements. It was found that the tendency of the drivers of scooters, bicycles and pedal rickshaws was to be on the right side of the traffic stream in order to make their right turning or crossing more easy and quick. As same right-of-way is assigned to all vehicle modes willing to clear the intersection and due to this peculiar tendency of some of the vehicles, the interactions amongst the various types of vehicles increase to a great extent. This directly affects the intersection clearing times. It was not practically possible to frame some logic to incorporate these irregular interactions at intersections. The only possible way to account for these interactions was through determining the actual turning and crossing times for all types of vehicles at all approaches. Although from actual average crossing times the actual average crossing speeds were computed for all the seven types of vehicles, but only two speeds, one for motorised (FMV) and another for non-motorised (SMV) vehicles, have been computed and incorporated in to the simulation model SIMMTRA-345. That is, it has been assumed that all the FMV clear the intersection with same average speed and all the SMV clear with the same average speed or the speed differential amongst the same category of the vehicles has been ignored.

It was also observed that these crossing speeds are influenced by approach width and type of approach. The final average crossing speeds for different roadway conditions as have been considered in the present simulation model SIMMTRA-345 are given in Table 5.2.

TABLE 5.2 - OBSERVED AVERAGE CROSSING SPEEDS FOR DIFFERENT ROADWAY CONDITIONS

Sl.No.	Approach Width (m)	Approach Type	Crossing speed (m/sec)	
			Motorised Vehicles	Non-Motorised Vehicles
1.	3.5	Minor	4.167	2.22
2.	7.0	Minor	5.55	2.22
3.	7.0	Major	8.33	2.22

In the simulation model SIMMTRA-345, the logical preference is given to major road traffic over minor road traffic. The left turn from all the approaches is always permitted, that is the left turning vehicles are not subjected to any delay.

5.6.5 Queue discipline

It has been discussed in article 5.6.4 that on most of the priority intersections, the minor approach width is shared by all turning and crossing traffic. Normally no separate lanes have been provided for turning manoeuvers. So if right or straight going vehicles have to wait for appropriate gap in main traffic stream to merge or to cross, the queue is formed on minor road. While forming queue, the drivers of the vehicles always try to position their vehicles closer to divisional island for the two reasons,

1. To leave some pavement width free on the extreme left to enable the left movers to clear the intersection without delay.

2. To facilitate themselves to clear the intersection quickly as soon as the appropriate gap is available in the cross-traffic.

5.6.6 System elements

A brief description of the various elements of a system, in general, is given below so that the traffic system to be simulated can have proper framework and better understanding for its various elements.

Various components, variables, parameters, relationships and constraints form the elements of a system. Components are the object;

constituting the system of interest. These are the entities of the system, whose collective performance determines the output of the system. A vehicle driver unit can be quoted as a component in this traffic system. Variables are those attributes of the system that take on different values under different conditions or different system states. These are further grouped as exogeneous and endogeneous variables. Exogeneous variables are input variables having the origin outside the system. According to Mize and Cox (169), exogeneous variables affect the system but they are unaffected by the system. On the other hand endogeneous variables are produced within the system or resulting from internal causes. These can be further labelled as status variables or output variables depending upon, where they are being tapped.

Parameters are those attributes of the system that do not change during the simulation. Where as relationships in a system are the connections between components, variables and parameters based on physical laws or behavioural logics. Lastly about the constraints, it can be said that they are the limitations imposed on the values of the variables. These are self imposed by the designer or imposed by the nature of the system. Few system elements applicable to the proposed simulation model SIMMTRA-345 in the light of the above discussion are mentioned in the Table 5.3 for illustration purposes.

TABLE 5.3 - SYSTEM ELEMENTS OF THE SIMMTRA-345 SIMULATION MODEL

Sl.No.	System Element	Illustration
1.	Components	Vehicle, driver
2.	Exogeneous variables	Peak hour traffic volume. Traffic composition, conflicting traffic, Approach widths.
3.	Endogeneous variables	Intersection crossing time of vehicle under different traffic conditions, vehicular delay, etc.
4.	Parameters	Mean of the desired crossing speeds for various vehicle modes , Maximum acceleration and deceleration rates.
5.	Relationships	ACCEL = DS**2/RADIS where ACCEL = Acceleration (m/sec/sec) DS = Desired crossing speed (m/sec) RADIS = Radius(m)
6.	Constraints	Maximum queue length

5.6.7 Mathematical Processing of a Component Model

It has been asserted that traffic system can be described in terms of components, variables, parameters and relationships. These elements must be now expressed such that a component model can be constructed that realistically imitates the system being studied. Components are usually expressed quantitatively in terms of their significant attributes. Variables are expressed within functional relationship.

Parameters are expressed as constraints that can be changed only at the command of an analyst. Relationships are expressed as mathematical and logical statements. Collectively these expressions comprise a mathematical model of the system or component model being investigated.

Now, the development of the component model involves the abstraction process of the physical system i.e. intersection or approach traffic system. The desirable degree of abstraction is determined by the purpose of the study. According to Shannon (170), a mathematical model should be simple enough for operation and understanding for the model user, representative enough in the total range of the implications, complex enough to accurately represent the system under study. The performance of mathematical expressions for the component model SIMMTRA-345 can not be predicted with certainty and the outputs are likely to vary with time and thus it leads to a stochastic model.

5.7 COMPUTER APPLICATIONS

5.7.1 Programming Languages

When a simulation programme is to be developed it is important to decide the programming language to be used. The programming languages can be divided in to computer and simulation languages. The choice between languages will be influenced by the aim of the model, the availability of the language, the time needed to programme the model and the type of computer facilities used to run the programme.

5.7.1.1 Computer languages

Computer languages are those procedures commonly used to develop all types of computer programmes. Some of the common languages are BASIC, FORTRAN, ALGOL, PASCAL and PL/1. These languages represent different stages in the development and therefore represent different degree of sophistication.

5.7.1.2 Simulation languages

Simulation languages are those procedures used solely for developing simulation programmes. The basic idea behind simulation language is that the system is described by a discrete population of ENTITIES, possessing identifying properties called ATTRIBUTES, that are capable of manipulation in groups called SETS that evolve as time goes on. The three simulation languages most often used for simulation studies are as under :

1. DESPL (Discrete Event Simulation Programming Language) (171).

DESPL is a discrete simulation language capable to model transportation and traffic systems. It incorporates many of the features of SIMSCRIPT in the medium of the PL/1 language. This enables the language to have access to the advantages of PL/1 while enabling the traffic system designer to translate his ideas into a model with less effort.

2. SIMSCRIPT

It is a widely used simulation programming language designed for simulating discrete systems (172). SIMSCRIPT distinguishes between temporary ENTITIES (like vehicles, drivers) and permanent ENTITIES (like intersection approaches) and temporary ATTRIBUTES (like origin and destination of vehicle) and permanent ATTRIBUTES. There has been a steady evolution and many different versions of SIMSCRIPT have been developed (173, 174).

3. GPSS (General Purpose Simulation System)

The system to be simulated in GPSS is described as a block diagram in which the blocks represent the ACTIVITIES and the lines joining them represent the order in which the ACTIVITIES are to be executed. When there is a choice more than one, line leaves the block and the conditions for the choice are stated in the block.

The use of block diagram to describe systems is common. However, if GPSS is to be used as a basis for a simulation language each block must be precisely defined. The approach used in GPSS is to define a set of BLOCK TYPES, each represents a characteristics action of the system. Figure 5.8 presents some of the BLOCK TYPES.

In addition to above three simulation languages, a few more can be listed as CSMP, GASP, GSL, SIMULA, SIMPL etc.

For developing the present simulation model SIMMTRA-345 a computer language FORTRAN-77 has been made use of, because it is a very common scientific language and available on many computer systems.

5.7.2 Internal Book Keeping

The internal book keeping procedures are vitally important for the efficient operation of the programme. It is possible to minimise the core storage for fast sequential processing in the programme by proper implementation of internal book keeping system. Internal book keeping does not only represent the traffic flow within the computer

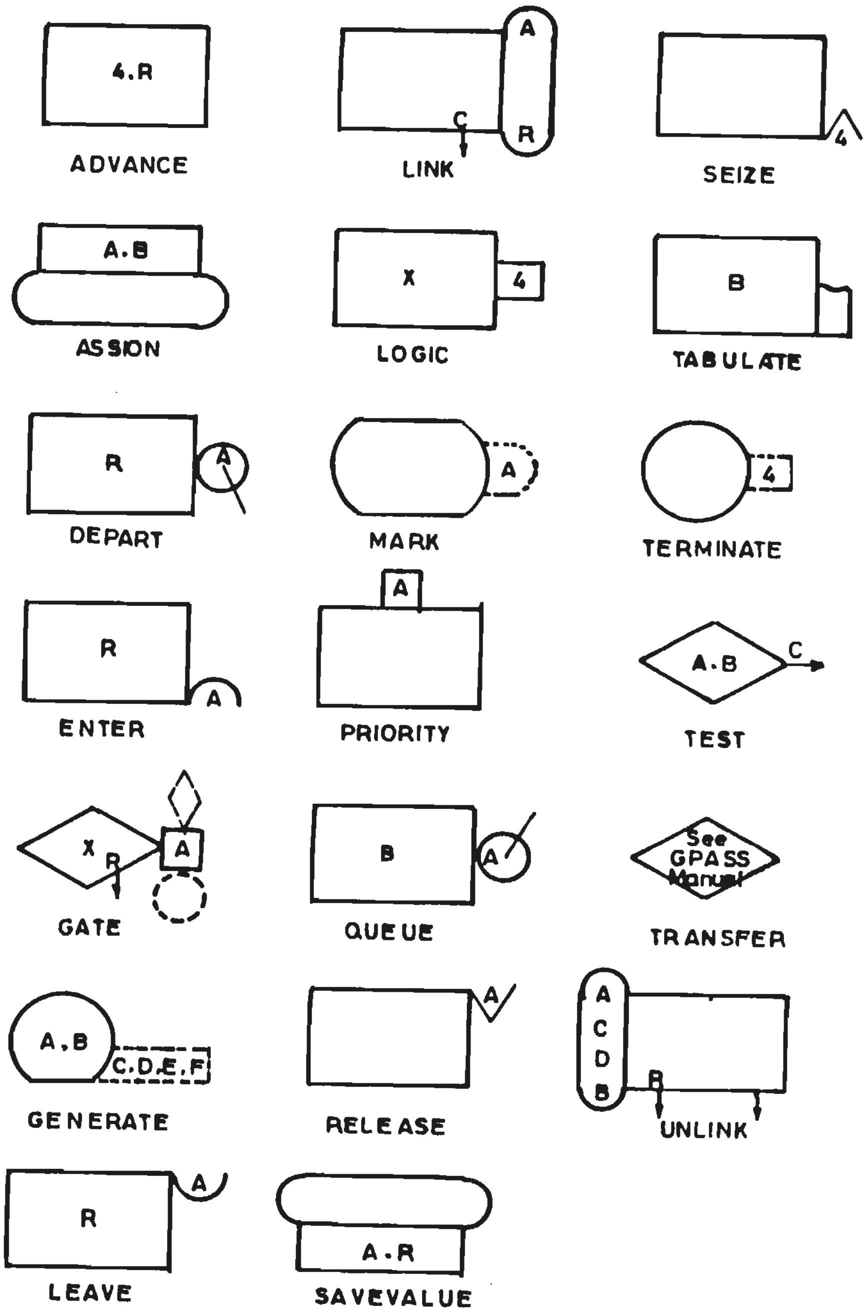


Fig. 5.8 GPSS BLOCK DIAGRAM SYMBOLS

through different methods but also keeps the track of the various modes in the system. In the present simulation programme the representation of vehicular traffic flow within the computer has been adopted through two methods :

1. Memorandom notation (175) and
2. Mathematical array system (176).

The internal book keeping is represented through two or three dimensioned arrays, DCS (I, J) is one of such dimensioned arrays to represent the desired crossing speed of a particular type of vehicles on a particular approach.

5.8 DESCRIPTION OF MAIN PROGRAMME AND SUBROUTINES OF SIMULATION MODEL

Since simulation models are difficult to programme, it is important that the simulation programme should be easy to modify to facilitate easy debugging (177). Programming in a high level language (FORTRAN) is easier and quicker than in symbolic code or machine level language (178). Moreover in most of the Indian Universities the FORTRAN language is taught, hence the majority of the Indian students are conversent only with this language. But simulation programme written in high level language may require large amount of core storage for efficient operation. Since DEC-2050 and HP-9600 computer facilities were available at the University of Roorkee and Civil Engineering Deptt. respectively, the simulation programme has been written in FORTRAN-77 language and run successfully.

5.8.1 Digital Simulation Model SIMMTRA-345 Structure

The digital simulation model SIMMTRA-345 simulates the mixed vehicular traffic at priority type semi-urban, 3-leg and 4-leg intersections. It consists of main programme chain and five subroutines, TIMGEN, VEHGEN, VEHMT, PITTOVT and VDELAY as shown in Fig. 5.9. These subroutines are described routine wise in detail in the following articles.

5.8.1.1 Subroutine TIMGEN

Purpose : It generates the arrival times of the mixed traffic vehicles randomly by making use of subroutine RANDU which computes uniformly distributed random real numbers. The subroutine generates the arrival times of vehicles on all the approaches simultaneously.

Inputs : The input required are, total traffic volume in vehicles per hour on each approach, seed number to start the process of random generation and the maximum time for which the traffic is to be simulated.

The flow chart of subroutine TIMGEN is shown in Fig. 5.10. The details of subroutine RANDU are given in Appendix B.

5.8.1.2 Subroutine VEHGEN

Purpose : Generates mixed traffic vehicles randomly on all the approaches. It generates all type of vehicles available in a traffic stream on an approach randomly. The total number of particular type of vehicle generated depends on the proportion of that vehicle in a traffic stream on a particular approach. The subroutine also generates the

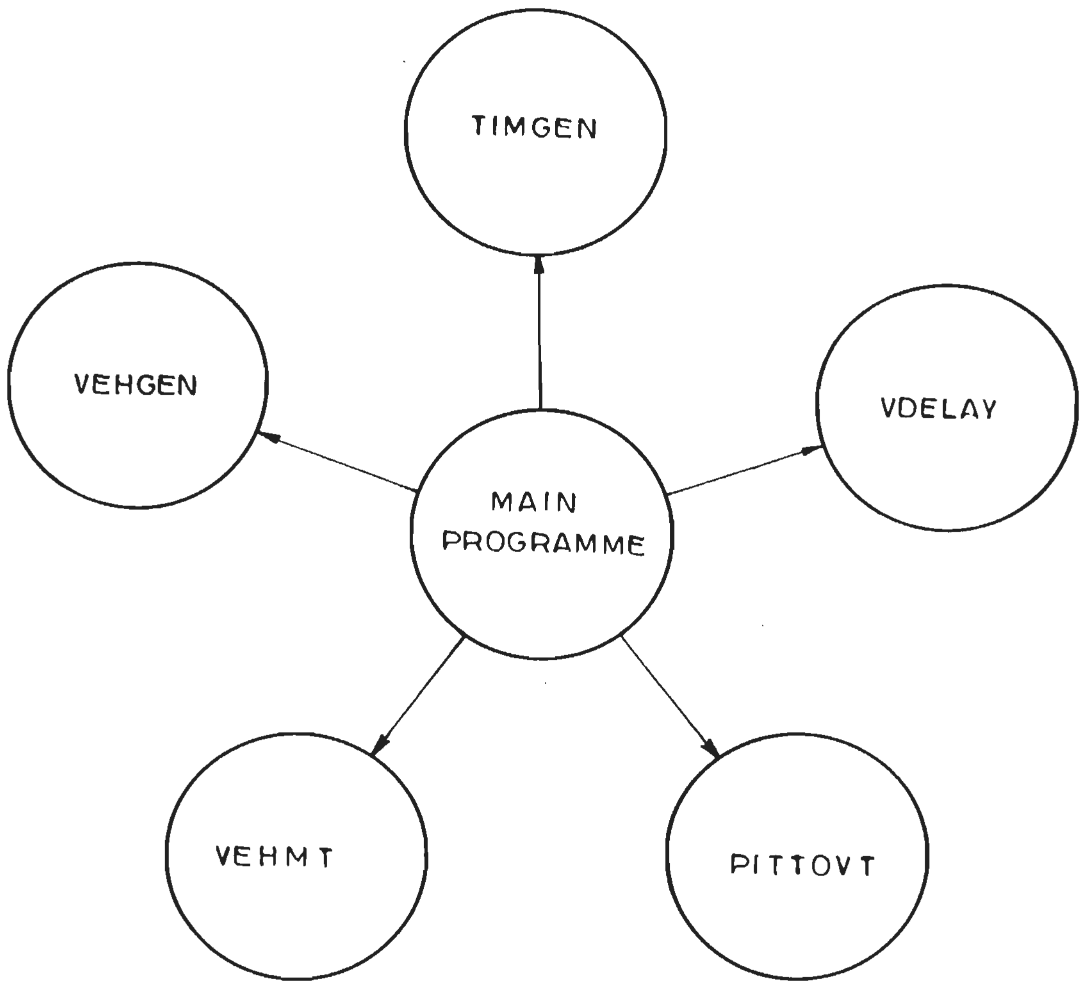


Fig. 5.9 SIMMTRA-345 structure with subroutines

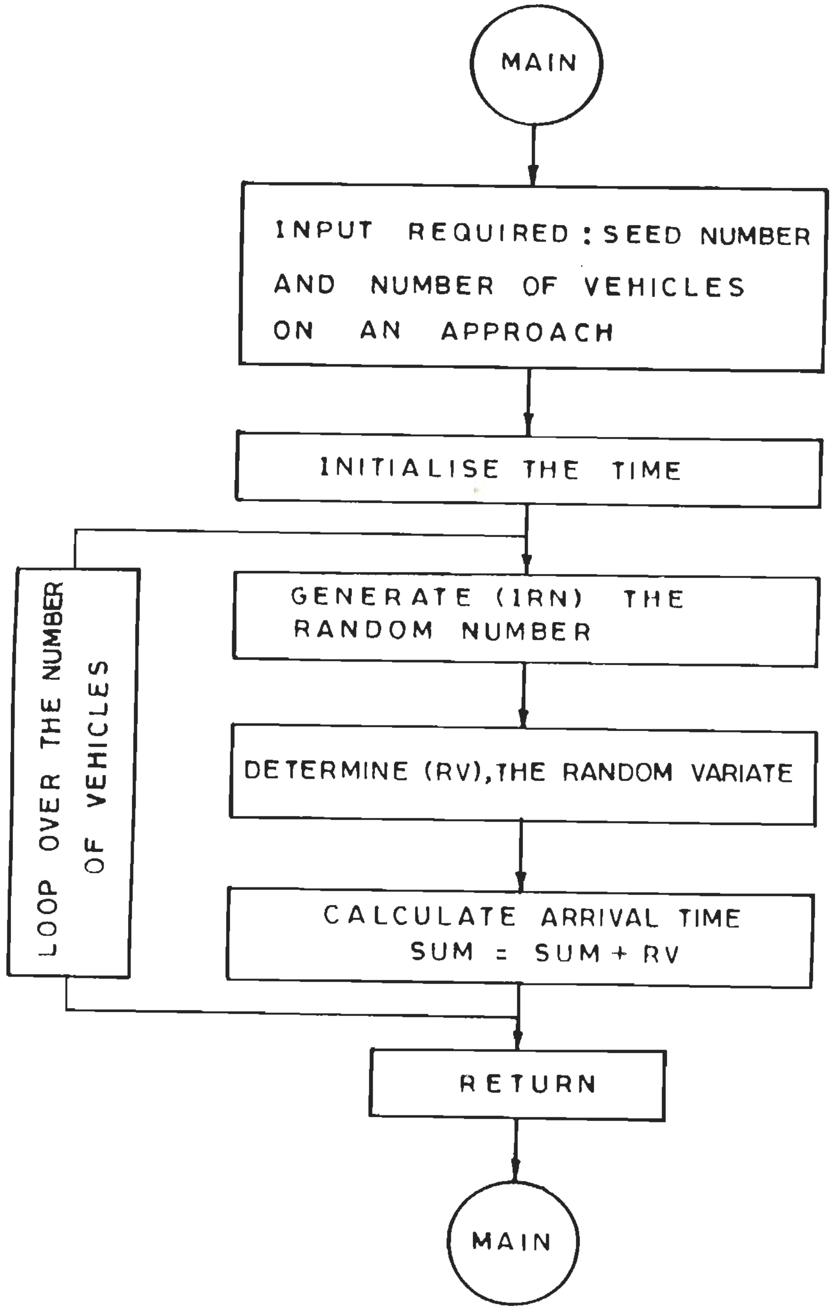


FIG. 5.10 — FLOW CHART OF SUBROUTINE TIMGEN

number of vehicles going to different directions from an approach under consideration depending upon the given percentage of turning and crossing traffic.

Inputs : The inputs for this subroutine are, total traffic volume in vph on each approach, type of vehicles available in traffic stream (maximum 7), proportion, in percentage, of each vehicle type in the traffic stream on each approach and percentage of traffic going to rest approaches.

The flow chart of subroutine VEHGEN is shown in Fig. 5.11.

5.8.1.3 Subroutine VEHMT

Purpose : The main purpose of this subroutine is to assign the crossing and turning manoeuvre to the mixed traffic vehicles randomly depending on the proportion of turning and crossing traffic from an approach to the remaining approaches.

Inputs :

- Total number of approaches (NLANE)
- Proportion of traffic moving in different directions from the approach (PERTR)
- Type of vehicles available in the traffic stream (NTYPEA).

Figure 5.12 shows the flow chart of subroutine VEHMT.

5.8.1.4 Subroutine PITTOVT

Purpose : This subroutine generates the proportion of classified vehicles in the turning and crossing traffic. The generation is done accor-

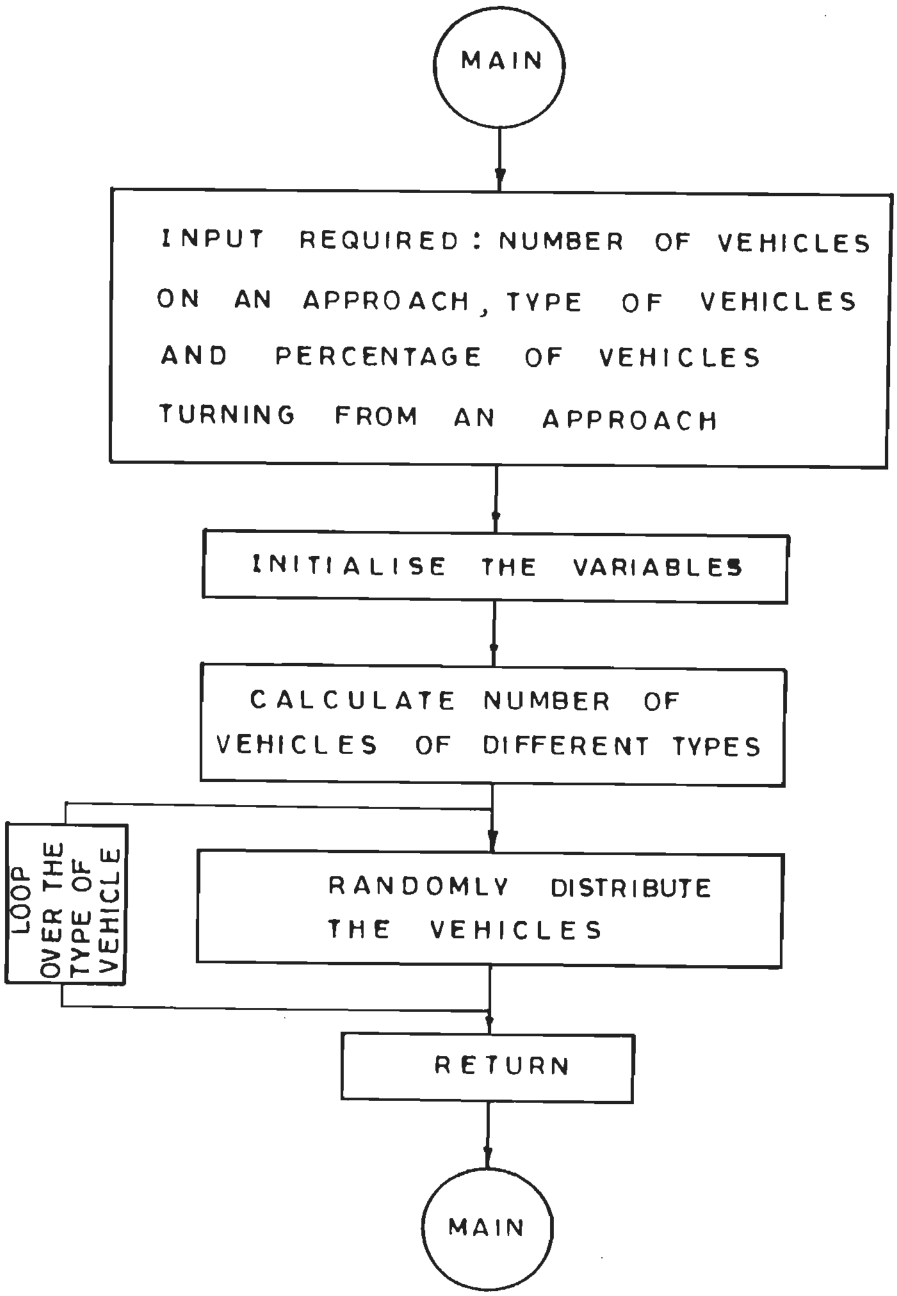


FIG.5.11 — FLOW CHART OF SUBROUTINE "VEHGEN"

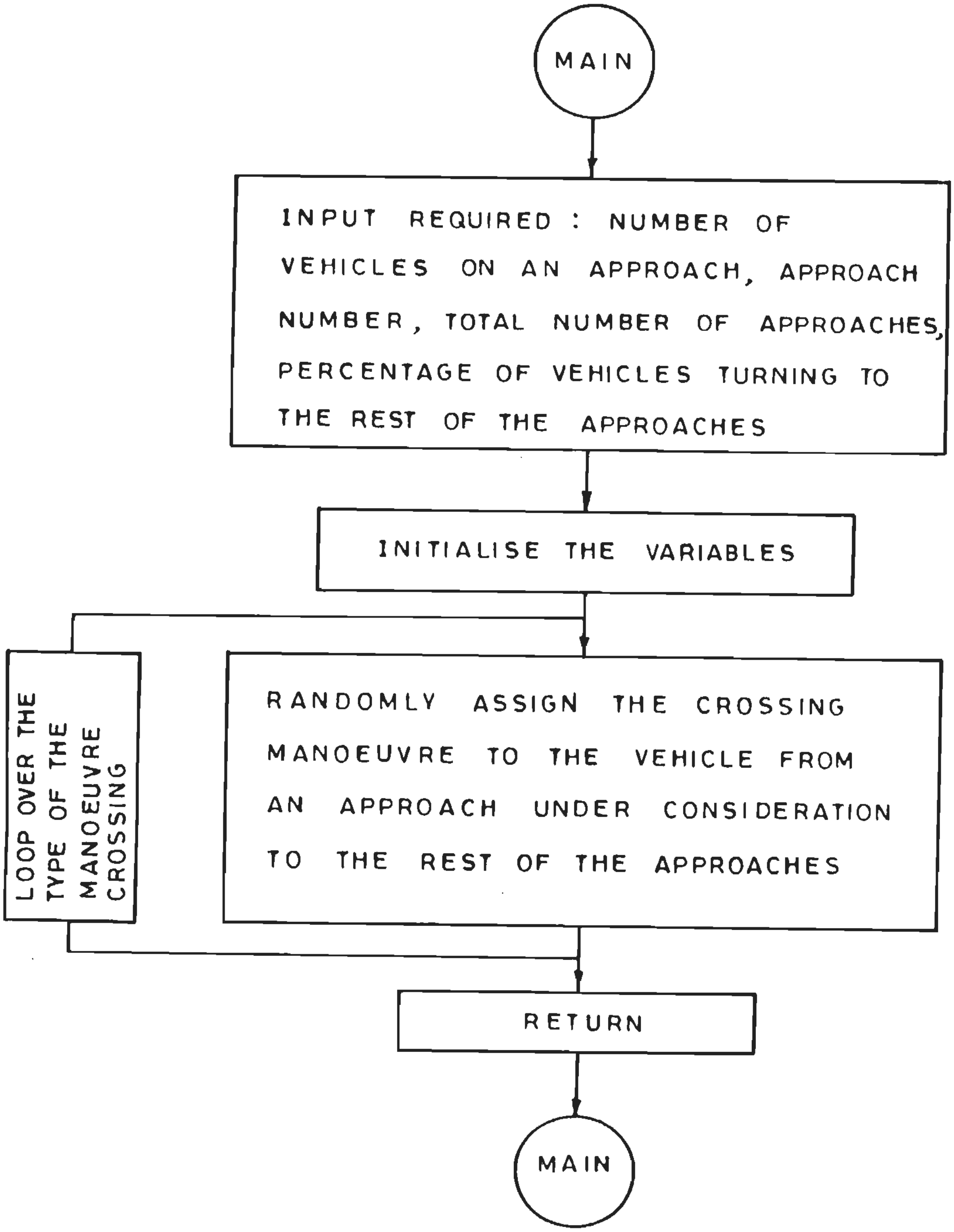


FIG. 5.12 — FLOW CHART OF SUBROUTINE "VEHMT"

ding to the proportion of vehicle type available in the each turning traffic stream from an approach. The generated proportion of vehicle type in turning traffic stream is distributed randomly.

Inputs : - Total mixed traffic volume (NVEH) on an approach (vph)

- Total vehicle types considered in the model (NTYPV).
- Number of approaches meeting at intersection (NLANE).
- Proportion of traffic moving to various approaches from an approach (PERTR).

Figure 5.13 presents the flow chart of subroutine PITTOVT.

5.8.1.5 Subroutine VDELAY

Purpose : It determines whether a vehicle is subjected to delay. It computes the total delay in vehicle-seconds experienced by different vehicles willing either to merge in the major traffic stream or to cross the major traffic stream. It also calculates the average delay caused to each vehicle on an approach and maximum length of queue formed on an approach at any instance of time. The subroutine gives time headway between successive vehicles, average time headway, time headway between same type of vehicles, average time headway between same type of vehicles, available time gap in major traffic stream and time required by different type of minor road vehicles either to merge in main stream or to cross the main traffic stream.

Inputs : - Total traffic volume on each approach (NVEH)

- Number of approaches (NLANE)

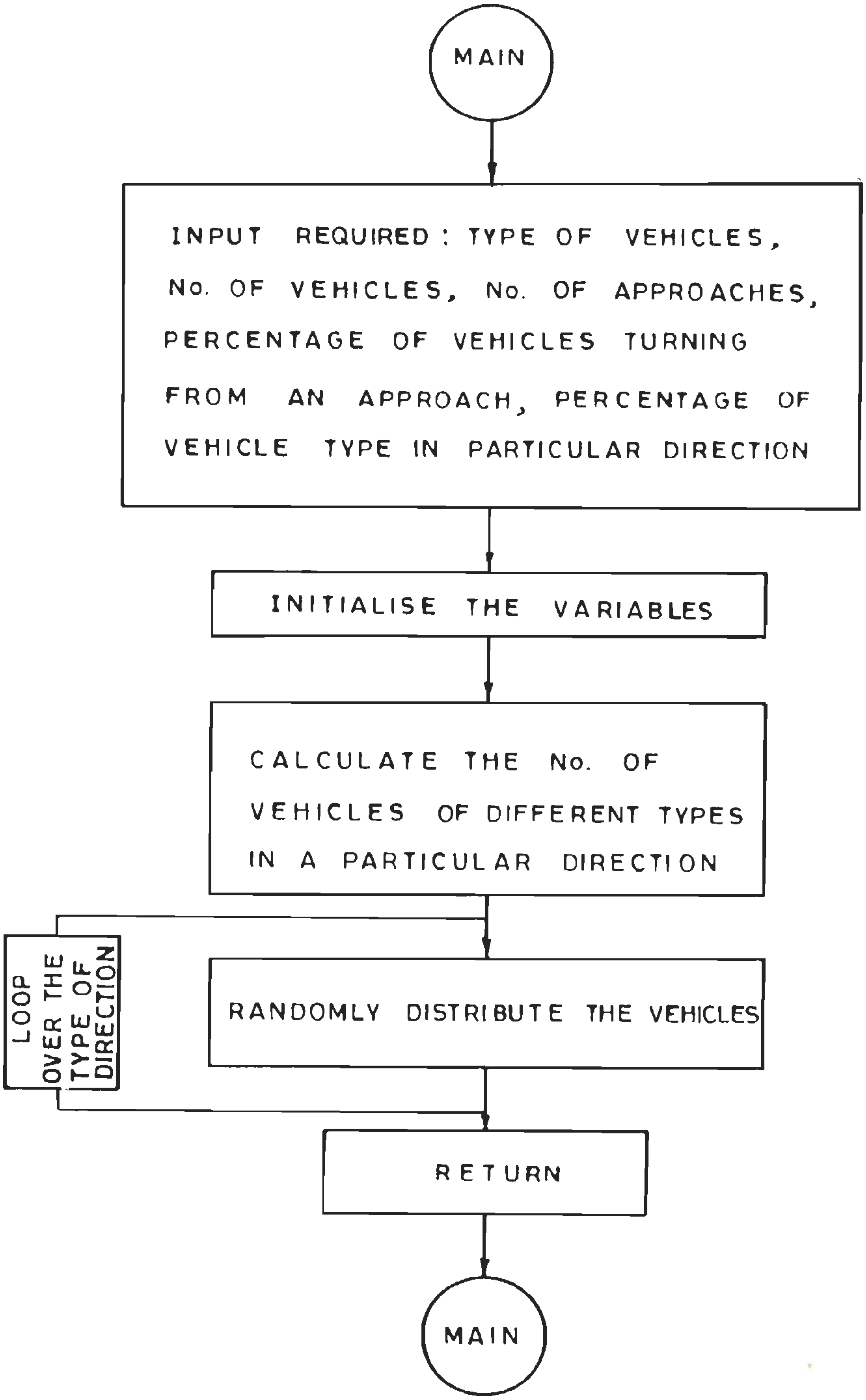


FIG. 5.13 — FLOW CHART OF SUBROUTINE PITTOVT

- Type of movement (MT)
- Angle of turn (ANGTR)
- Arrival time (TIME)

Figure 5.14 contains the flow chart of subroutine VDELAY.

5.8.2 Main Simulation Programme

5.8.2.1 Working of simulation model SIMMTRA-345

As discussed earlier, the model SIMMTRA-345 developed to simulate the traffic at priority type semi-urban 3-leg and 4-leg intersections. The main components of an intersection are intersection approaches, intersection area and exitways (stop lines). The impact of intersection traffic activities is more felt by side road vehicles. The sequential driver decisions and interactions due to the movements of vehicles from exit follow wave propagation in backward direction. This is obvious as driver decisions of the following vehicles are subjected to the decision of leading vehicles.

The various stages of the simulation process are depicted in the flow chart as shown in Fig. 5.15.

Briefly, the simulation is accomplished as follows : Each time a minor road vehicle enters the intersection, the model is analysed. If the minor road vehicle is not delayed, the major road traffic is brought to this time and the minor road vehicles is released. If the minor stream vehicle is delayed due to the non-availability of an appropriate gap in major traffic stream, the system is checked to see

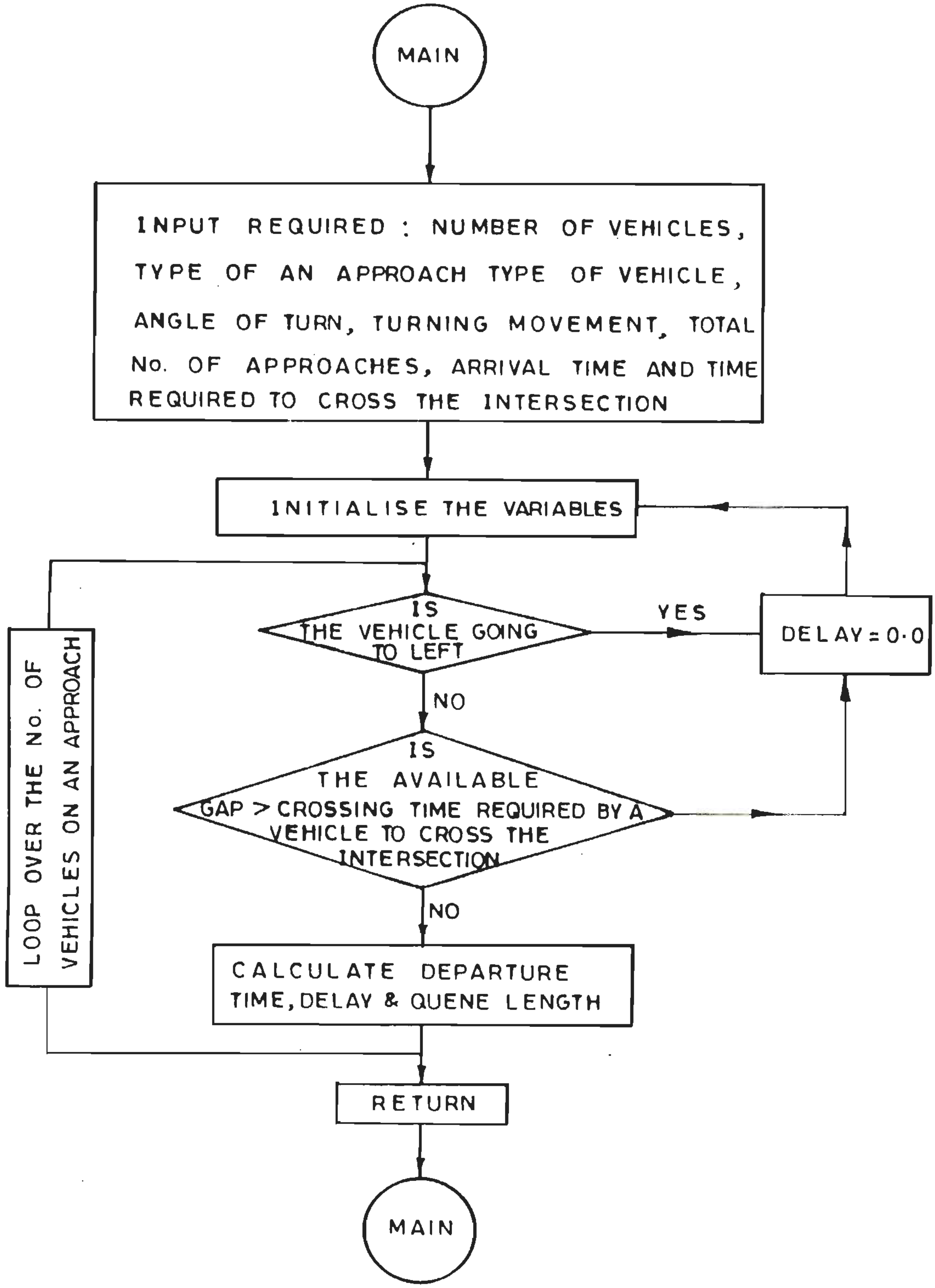
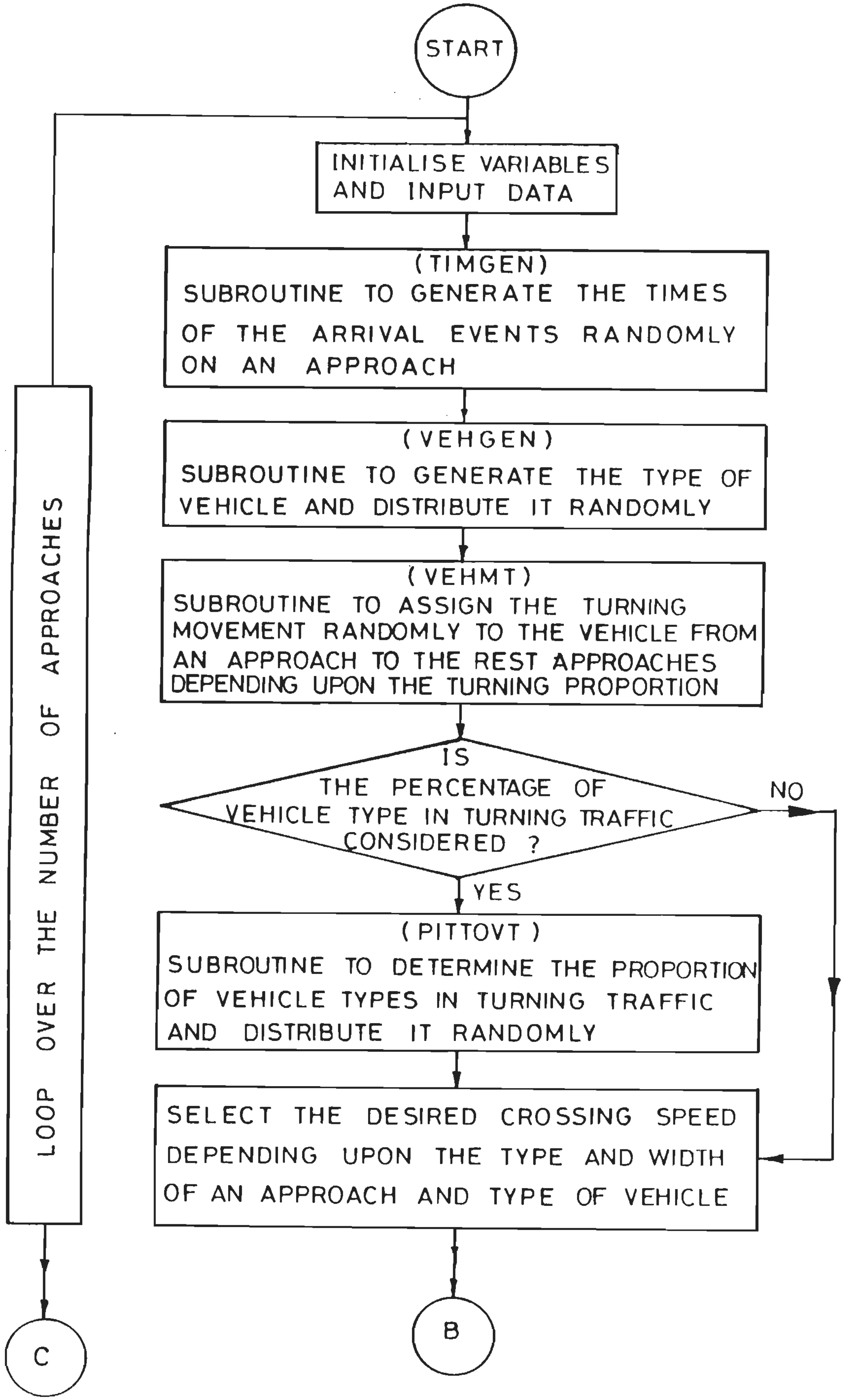


FIG. 5.14 — FLOW CHART OF SUBROUTINE "VDELAY"


START
INITIALISE VARIABLES AND INPUT DATA
(TIMGEN)
SUBROUTINE TO GENERATE THE TIMES OF THE ARRIVAL EVENTS RANDOMLY ON AN APPROACH
(VEHGEN)
SUBROUTINE TO GENERATE THE TYPE OF VEHICLE AND DISTRIBUTE IT RANDOMLY
(VEHMT)
SUBROUTINE TO ASSIGN THE TURNING MOVEMENT RANDOMLY TO THE VEHICLE FROM AN APPROACH TO THE REST APPROACHES DEPENDING UPON THE TURNING PROPORTION
IS THE PERCENTAGE OF VEHICLE TYPE IN TURNING TRAFFIC CONSIDERED ?
NO
YES
(PITTOVT)
SUBROUTINE TO DETERMINE THE PROPORTION OF VEHICLE TYPES IN TURNING TRAFFIC AND DISTRIBUTE IT RANDOMLY
SELECT THE DESIRED CROSSING SPEED DEPENDING UPON THE TYPE AND WIDTH OF AN APPROACH AND TYPE OF VEHICLE
LOOP OVER THE NUMBER OF APPROACHES
C
B

[CONTD.]

[CONTD.]

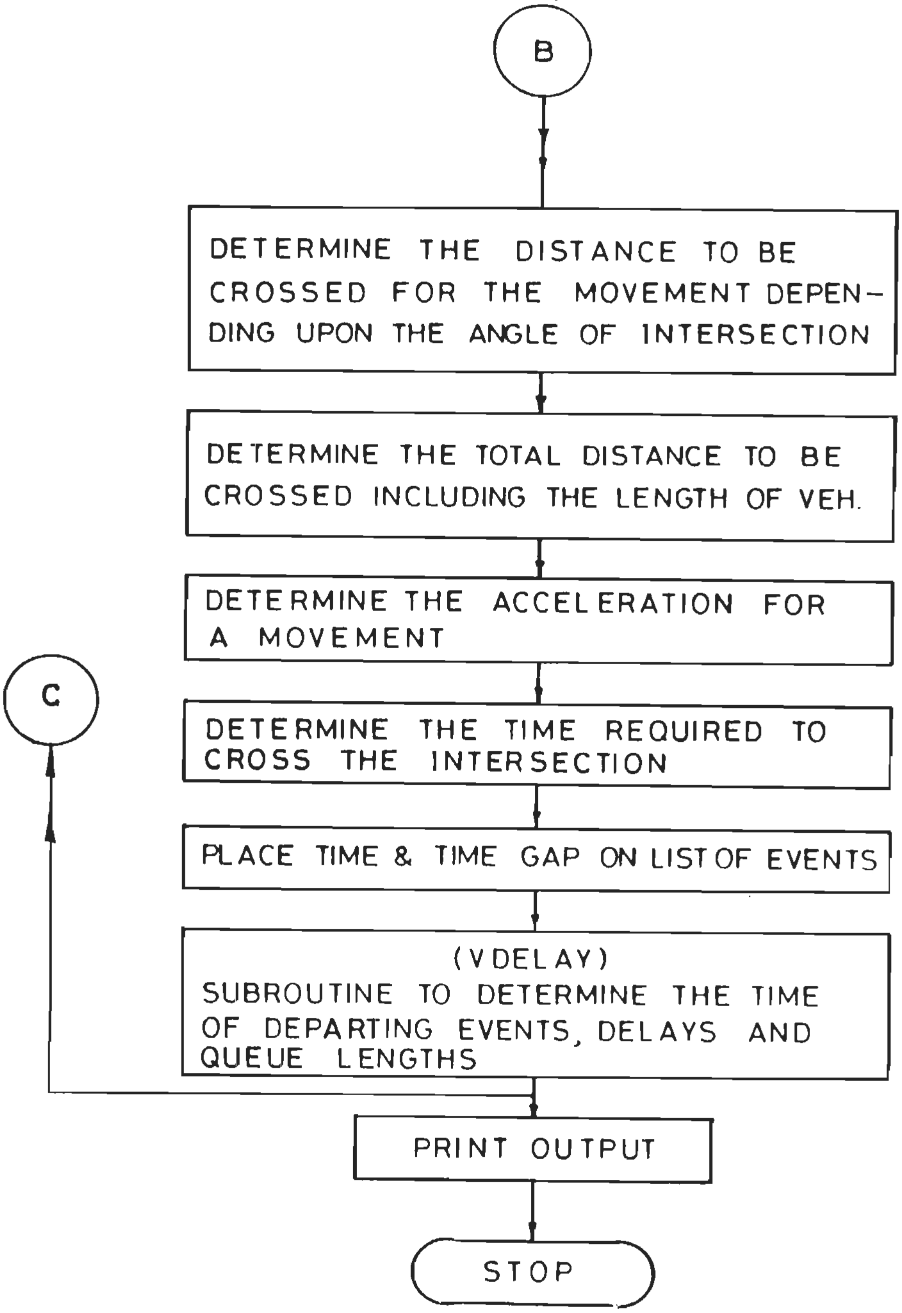


FIG. 5.15 — MASTER FLOW CHART OF SIMULATION MODEL SIMMTRA-345

when minor street vehicle might be released. The process is repetitive generating new traffic as necessary and recording the amount of delay to the detained vehicles and formation of queue lengths on minor and major roads.

Vehicular flows are based on reasonable logic decisions by drivers as warranted by the traffic situations and on some important assumptions. The various logics and the assumptions associated with them, involved in the decision making phenomenon are described in the following articles.

5.8.2.2 SIMMTRA-345 Logic and rules of operation

Vehicle flow mechanism and waiting at an approach for the clearance is based on the certain rules of operation as discussed below.

1. The preference is given to all major stream vehicle movements over minor stream vehicle movements.

2. The major stream vehicle movements do not get affected (in terms of delays) by the increase of decrease in minor stream traffic volumes.

3. The major stream vehicular delays get affected when conflicting traffic in major stream varies.

4. The minor stream vehicular delays are highly impelled by major stream vehicular movements.

Minor road vehicle accepts the available gap in the major traffic stream if it is greater than the crossing time necessary for that particular type of vehicle to complete the turning manoeuvre safely. On the other hand if available gap is less than the required crossing time, vehicle will wait till the safe crossing gap in available. This waiting time is recorded as a delay to that vehicle.

The left turns are permitted on all the approaches. In fact this permitted left turn traffic rule exists in India almost for all the situations under semi-rural and semi-urban situations without traffic signals. This is how it has been incorporated in the model. This means no left turning vehicle would be subjected to any delay and it can clear the intersection without waiting as this movement does not come in to conflict with any other movement.

The following logics which have bearing on interactions are incorporated in the simulation process.

1. Vehicle registration logic
2. Gap acceptance logic
3. Queue building logic
4. Queue discharge logic

1. Vehicle registration logic : A vehicle is said to be eligible for registration only when its arrival time tallies with simulation clock time. Until that period it is in backlog area. Once a vehicle gets registered, the backlog cell gets vacant and calls for generation of next vehicle for the approach. The vacant cell gets restored and is ready for regiatration. Figure 5.16 shows the vehicle registration

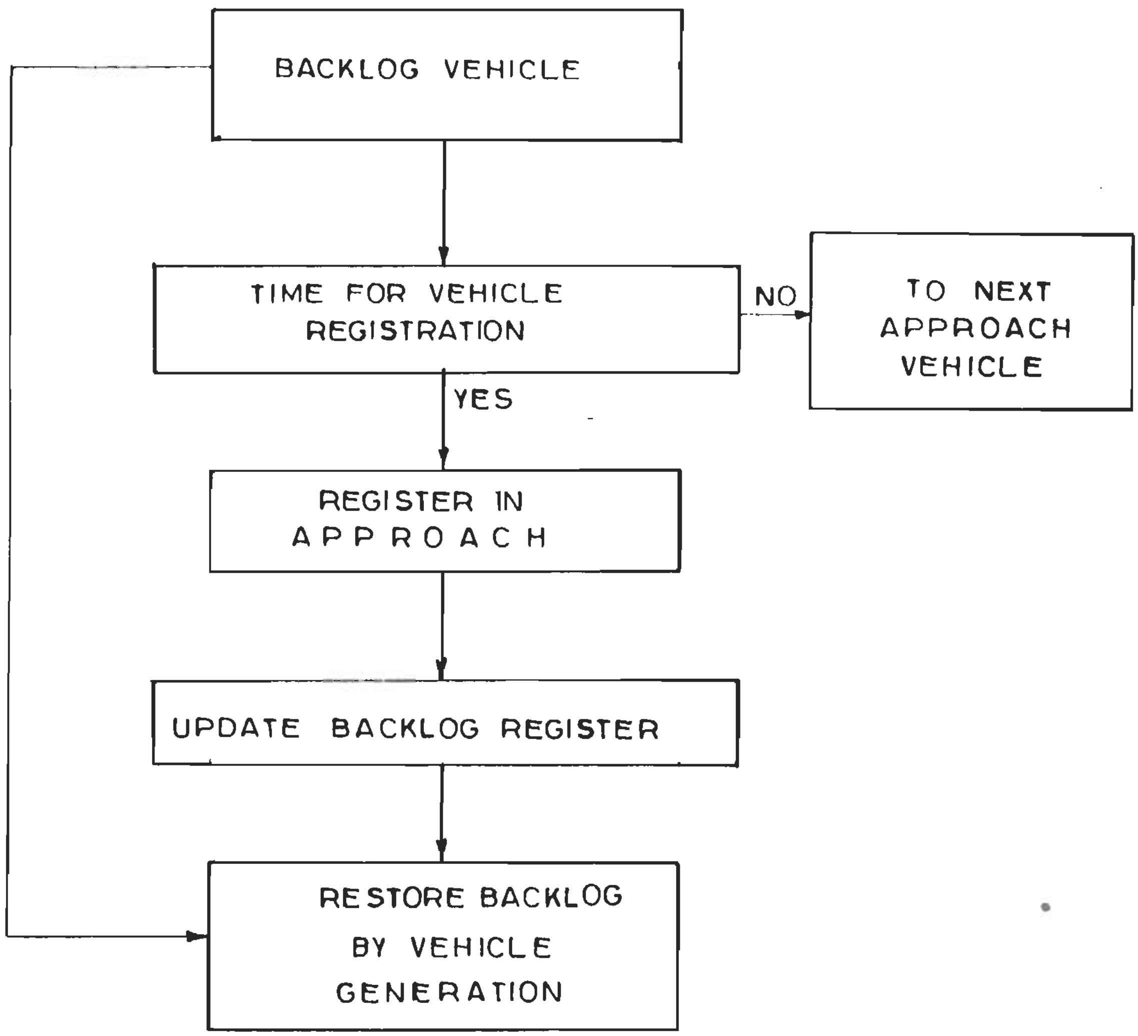


Fig. 5.16 Vehicle registration logic

logic.

Once vehicle has registered (arrived), there are three possible decisions to take

i. Entering in to intersection area

ii. In case suitable gap is not available to stop at a stop line as the leader of queue, and

iii. Joining the queue if it already exists.

Out of these three decisions, the first two are based on gap acceptance logic by the gap seekers. Third decision is inevitable if queue is already formed at an approach.

2. Gap acceptance logic : Acceptable gaps are subjective and stochastic in nature. The decision is variable even for the same driver under different traffic situations. In the present simulation programme SIMMTRA-345, intersection clearing time is determined depending on the vehicle type that has arrived at the approach, its desired clearing speed and the type of manoeuvre. This clearing time is determined for each arrived vehicle on all the approaches. For a gap seeking vehicle, if the available gap is greater than safe clearing time of the vehicle, the vehicle will complete the manoeuvre. But in case the available gap is shorter than computed safe clearing time of the vehicle, the vehicle will wait till it gets the required gap. The gap acceptance logic for SIMMTRA-345 is shown in Fig. 5.17.

Based on the type of approach and vehicle turning manoeuvre, there are various gap seeking cases for 3-leg and 4-leg intersections

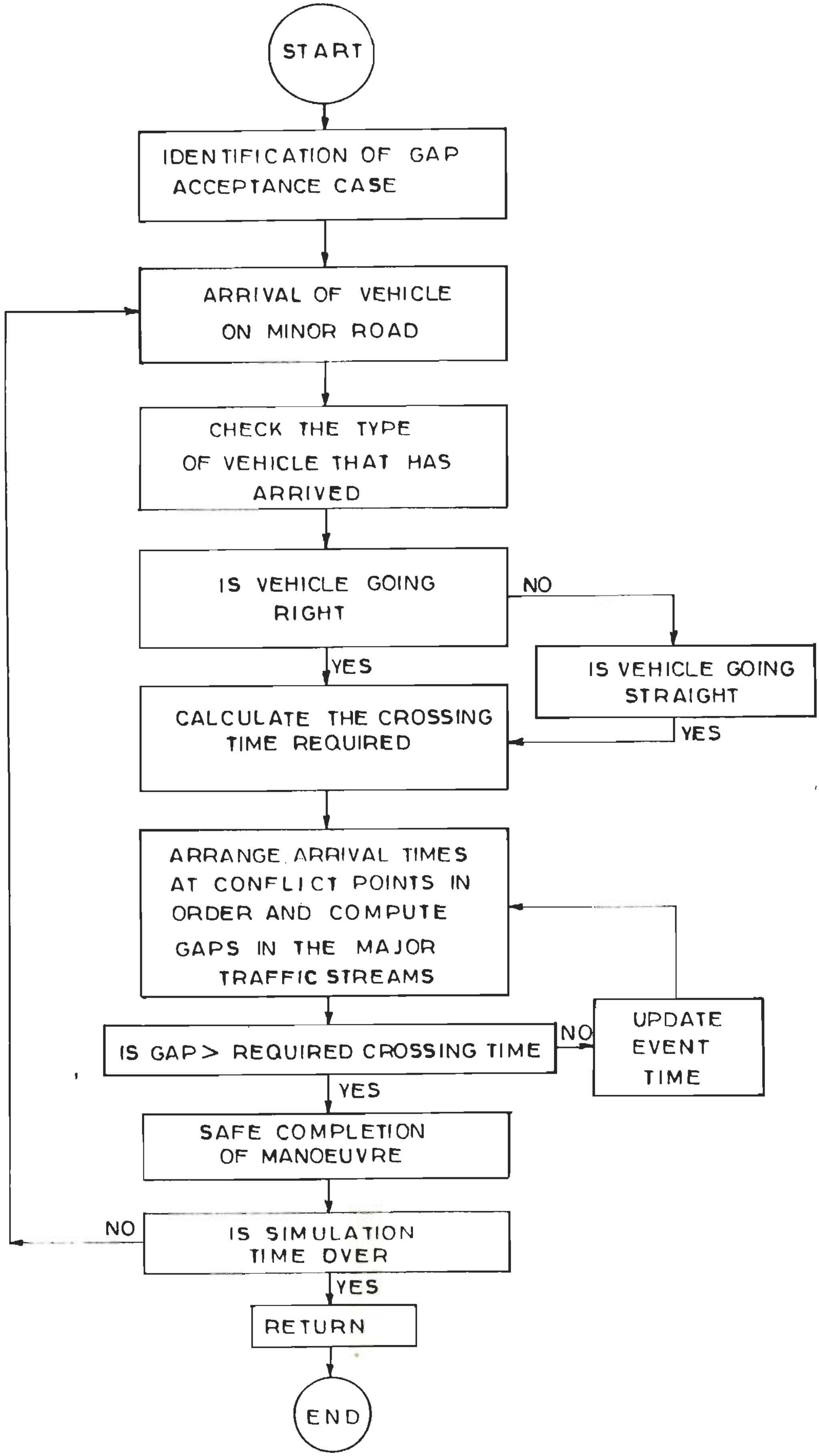


Fig. 5.17 Gap acceptance logic for simulation model Simmtra - 345

as shown in Table 5.4 and Fig. 5.18.

TABLE 5.4 – GAP SEEKING CASES FOR PRIORITY INTERSECTION APPROACHES (4-leg Intersection)

Approach No.	Approach Type	Manoeuvre	Conflicting Streams	Case
1 & 3	Major	Straight	One	I
1 & 3	Major	Right turn	One	II
2 & 4	Minor	Straight	Four	III
2 & 4	Minor	Right turn	Four	IV
Three Legged Intersection				
1	Minor	Right turn	Two	I
2 & 3	Major	Right turn	One	II

3. Queue formation logic : Queue building process normally takes place on the minor road approaches and some times on the major road approaches under the different traffic situations prevailing independently or combined at the same time. When there are high traffic volumes on major approaches, the time headway between vehicles reduces, and as a result the size of the time gap in major traffic stream also reduces. This traffic situation provides less number of acceptable gaps to gap seekers on minor road, as a result the queue is formed on minor road.

In another traffic situation, when there is moderate traffic on the major road approaches but slightly heavy traffic on minor road approaches which increases the number of gap seekers. This may lead to queue formation on minor road.

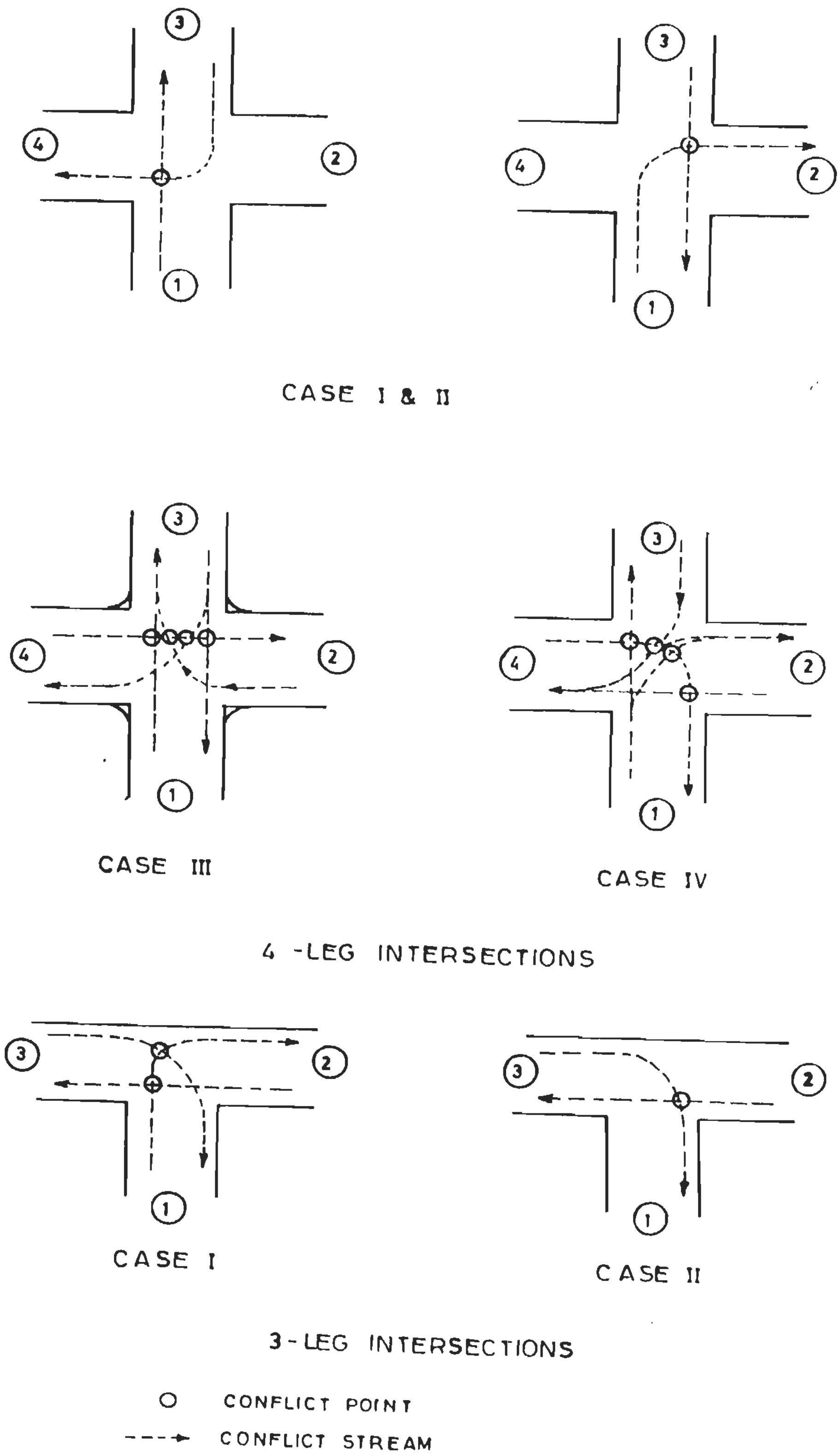


Fig. 5.18 Gap seeking cases for priority intersections

In case of major road queue formation, when the proportion of the right turning traffic in the major traffic stream in high, the queue may be formed.

As has already been discussed in article 5.6.5, the queue formation on minor road does not follow any particular discipline in case of priority type intersections under mixed traffic conditions. As no separate arrays are formed for different turning movements and whole approach width is shared by all types of vehicles and for all turning manoeuvres, no systematic queue array arrangement has been incorporated in the model.

4. Queue discharge logic : Whenever the required gap is available in major traffic stream, the first vehicles in the queue that was waiting for the gap would accelerate and clear the junction. Once the first vehicle is released from the queue, updating of approach vehicle and queued vehicles (if there are more than one vehicle in the queue) is done.

5.9 SIMMTRA-345 MODEL INPUTS

5.9.1 Introduction

The first step in any modelling exercise is to obtain a precise statement of the objectives of the exercise. Without this it is unlikely that the model may serve the purpose for which it has been developed. These objectives should enable the modeller to determine the level of details required in the input of a simulation model.

Further, the character of the model should enable the model builder to determine the range of inputs to be considered in the model. For instance, as discussed in article 4.4.3 (Table 4.12), if Poisson distribution was used to generate traffic, then the range of traffic volume to be simulated should range from 0 to 200 vehicles/hour.

An important point to remember while preparing input procedures is that these procedures will be used by others. The language used must therefore be consistent with that used by other users.

5.9.2 Factors Affecting the Choice of Input Procedures

The choice of input procedure for simulation model are constrained by a number of considerations. Some of them are discussed below.

1. **Computer facilities** : The input procedures are limited to the facilities of software that are available at the computer installation.

2. **Transfer of programme to other facilities** : Even if the computer facility where the model is developed has a great variety of input periferals and other facilities, where the model is to be used may not be so well blessed. Therefore the input procedures should take in to account the facilities available at other sites.

The cost of developing the input procedures must be weight against the benefits to be gained from developing them.

5.9.3 Input Information

The various computer input variables considered in the simulation model SIMMTRA-345 are briefed in Table 5.5. Typical computer inputs to the model SIMMTRA-345 are presented in Table 5.6.

TABLE 5.5 - COMPUTER INPUT VARIABLES CONSIDERED FOR SIMMTRA-345

Variable	Description
SMAX	Maximum simulation time in seconds
ALVEH	Length of the vehicle in meters
DCS	Desired crossing speed
NTYPV	Total vehicle types considered
NLANE	Number of approaches meeting at junction
ANGLE	Number of angles of turn (=NLANE)
ILANE	Approach number (I=1, NLANE)
ISEED	Initial seed number
ITYPL	Total type of vehicles on the approach
WD	Width of an approach (meters)
PERTR	Proportion of turning traffic from an approach (percentage)
PERVT	Proportion of vehicle type on an approach (percentage)
HDWAY	Time headway between successive vehicles (seconds)
HDWYT	Time headway between same type of vehicles (seocnds)
RN	Random number
RV	Random variate
TIME	Arrival time of vehicle (seconds)
TGAP	Time gap (seconds)
CSRF	Crossing speed reduction factor

MVT	Total turning movements
LANNO	Approach category
NV	Traffic volume on an approach (vph)
IVEHT	Vehicle type
PVTL	Proportion of vehicles turning to the approach (percentage)
FACT	Equivalent passenger car values for different vehicles
ANGTR	Angle of turn (radians)
CRDIS	Crossing distance (meters)
RADIS	Radius of turning path (meters)
ACCEL	Acceleration (m/sec^2)
DS	Desired crossing speed of particular vehicle on a type of an approach (m/sec.)
DIST	Total distance to be crossed by vehicle including its own length (meters)
TMGAP	Time required to clear the intersection (sec.)
LQUE	Length of queue at a particular time (no. of vehicles)
TDELY	Total delay for an approach (veh.sec.)
AVDLY	Average delay per vehicle for an approach (sec.)
MAXO	Maximum length of queue (no. of vehicles)
WTIM	Warm up time (sec.)

5.10 MODEL SIMMTRA-345 OUTPUT

5.10.1 Introduction

This stage in simulation programme is concerned with the extraction and presentation of the data describing the system operations.

TABLE 5.6 : TYPICAL COMPUTER INPUTS TO SIMULATION MODEL SIMMTRA-345 (4-Leg Intersection, Km. 201.000)

3600.0	(Simulation time (seconds))
7 4	(Total vehicle type and total approaches)
90 90 90 90	(Angles of all approaches (degrees))
1 3	Approach No. 1 is of type 3
2 2	Approach No. 2 is of type 2
3 3	Approach No. 3 is of type 3
4 2	Approach No. 4 is of type 2
969 566 683 693	(Traffic volumes on 4 approahes)
8 98 44.89 46.13	(Turning traffic in percentage right, straight and left respectively from approach no. 1)
11.87 4.23 8.46 32.40 36.95 4.44 1.65	Percentage of vehicle type on approach no. 1, Car, Bus, Truck, Scooter, Bicycle, Pedal rickshaw & Others respectively)
1	
14.94 0.0 2.30 39.08 39.08 4.60 0.0	(Percentage of veh. type going to right from approach no. 1)
15.63 3.91 10.80 34.02 29.89 4.83 0.92	(Percentage of veh. type going to straight from approach no. 1)
7.61 5.37 7.38 29.53 43.40 4.03 2.68	(Percentage of veh. type going to left from approach no. 1)
3.0 38.52 58.48	(% of turning traffic from approach no. 2 going to left, straight and right respectively)
3.71 0.0 2.83 23.67 54.60 10.07 5.12	(Percentage of vehicle type on approach no. 2)
1	
0.0 0.0 5.88 35.29 58.83 0.0 0.0	(Percentage of vehicle type going to left from approach no. 2)
5.50 0.0 1.38 32.11 44.49 11.93 4.59	(Percentage of vehicle type going to straight from approach no. 2)
2.72 0.0 3.62 17.52 61.03 9.37 5.74	(Percentage of vehicle type going to right from approach no. 2)
57.98 31.19 10.83	(Percentage of turning traffic from approach no. 3 going to straight, left & right respectively)
12.74 3.22 10.25 29.43 34.11 7.03 3.22	(Percentage of vehicle type on approach no. 3)
1	
17.42 5.56 13.64 30.05 28.28 4.29 0.76	(Percentage of vehicle type going to straight from approach no. 3)
6.10 0.0 1.41 24.41 47.42 13.62 7.04	(Percentage of vehicle type going to left from approach no. 3)
6.76 0.0 17.57 40.54 27.03 2.70 5.40	(Percentage of vehicle type going to right from approach no. 3)
52.09 45.60 2.31	(Percentage of turning traffic from approach no. 4 going to right, straight & left respectively)
6.07 2.45 5.48 25.11 52.67 5.77 2.45	(Percentage of vehicle type on approach no. 4)
1	
9.42 4.71 7.48 27.70 45.71 2.49 2.49	(Percentage of vehicle type going to right from approach no. 4)
2.22 0.0 1.90 21.20 62.34 9.81 2.53	(Percentage of vehicle type going to straight from approach no. 4)
6.25 0.0 31.25 43.75 18.75 0.0 0.0	(Percentage of vehicle type going to left from approach no. 4)

Before outputting data it is necessary to know what data and type of performance measures should be extracted from the system.

5.10.2 Measures of Performance Considered for the Simulation Model SMITTRA-345

An important aspect of the interpretation of the output of a simulation is a clear statement of performance measures of the system. There are always large number of performance measures, but in case of performance of an intersection, the distribution of delays may be the most important of the all.

The performance of priority type semi-urban intersection, in the present study, has been measured in terms of total delay, average delay and queue length.

5.10.3 Output Details of SIMMTRA-345

The simulation model SIMMTRA-345 simulates the traffic for one clock hour of real world system. It takes about one minute computer time for single run. At the termination of each simulation run, the results of each simulated hour are printed and include the following items for an each approach, for minor street and for major street.: serial number, type of vehicle that has arrived, arrival time of the vehicle, its turning movement, time headway between successive vehicles time headway between same type of vehicles, delay to the vehicles and information on queue formation at various stages of time.

The output of simulation model SIMMTRA-345 is in the tabular form. The details of typical output in tabular form for one of the approaches are shown in Appendix C..

The gist of the output for one of the approaches has been presented in Table 5.7.

TABLE 5.7 – GIST OF THE OUTPUT OF SIMULATION MODEL SIMMTRA – 345 (3-leg Intersection, Approach No. 1, Minor road, Km 20.000) (Traffic volume : 183 vph)

Sl.No.	Output Item	Value
1.	Total Delay	47.64 (veh.sec.)
2.	Average Delay	0.26 (sec.)
3.	Average Headway	20.51 (sec.)
4.	Average Headway for Type No. 1 *	44.08 (sec.)
5.	Average Headway for Type No. 2	541.43 (sec.)
6.	Average Headway for Type No. 3	96.46 (sec.)
7.	Average Headway for Type No. 4	56.29 (sec.)
8.	Average Headway for Type No. 5	174.80 (sec.)
9.	Average Headway for Type No. 6	No vehicle
10.	Average Headway for Type No. 7	No vehicle
11.	Total Equivalent Passenger Car Values	234.40 (EPCV)
12.	Maximum Length of Queue	1 (No. of vehicle)

* 1 = Car, 2 = Bus, 3 = Truck, 4 = Scooter/Motor cycle, 5 = Bicycle, 6 = Pedal rickshaw, 7 = Others.

5.11 VALIDATION OF SIMMTRA-345

5.11.1 Introduction

This is probably the most difficult part in the whole process of model development. But the develoment of simulation models can not be considered complete until they are tested for their reliable outcomes which should be very close to that of real systems (178). Then only model builder and user will have confidence in the working of the model. This important task is the validation process which has been discussed in the following articles.

5.11.2 Validation Process

Validation is the process of comparing the simulation system in inference with that of the complex real situation being modelled. It provides the user an acceptable level of confidence about the model performance. In simple words it is testing of the agreement between the behaviour of the model and that of the real system.

Problems in validation can arise from many areas, the most important of which are :

i) Incorrect methodology

ii) Poor experimental design

iii) Model instability

i) Validation against methodological errors : The most common methodological errors in stochastic models arise from poor numerical analysis. An important cause of methodology errors in stochastic models is the use of inappropriate random number generator. This error has been accounted for by selecting appropriate random number generator.

ii) Validation against poor experimental design : Possible sources of an error arising from poor experimental data may include the following-

(a) The type of data available may not be appropriate to the type of information required from the model, this means that a model attempts to extract more from the data than is available.

(b) The quantity of data available may be restricted causing large uncertainties in parameter estimates.

(c) The data which is being used for the validation of simulation model, may contain systematic error that is normally caused due to incorrect equipment calibration.

iii) Validation against model instability : The model itself must satisfy a stability condition. Most often this will take a form of requiring that a small change in the input data will lead to small changes in output.

The simulation model SIMMTRA-345 has been validated for poor experimental design and stability conditions.

5.11.3 Testing of Simulation Model SIMMTRA-345

Field testing plays an important part in testing the overall reliability of a simulation model. The usual procedure is to obtain data describing the system being simulated by collecting data in the field and compare the performance of the model with the results of the field study (179).

5.11.4 Comparison of Observed and Predicted Behaviour

Validation of a simulation model, therefore, requires a comparison of the model behaviour with that of the real world. This can be normally accomplished by first collecting appropriate data in the field. This may involve the collection of input data corresponding to the requirements of the model and the corresponding output information. The simulation model is then run using the appropriate input data and the output is compared with that of the field study.

In the present simulation study the model SIMMTRA-345 has been validated by comparing two outputs as discussed below.

Firstly the simulation model is run by giving the input data file as presented in Table 5.6. In this case all the parameters such as arrival time, type of vehicle, turning manoeuvre, headway, delay queue length and intersection clearing time for each vehicle could be had in an output. The parameters such as arrival time, type of vehicle, turning manorurve are generated randomly by the model with the help of subroutines. The gist of output of this first run is presented in Table 5.7.

While running the simulation model for second time, the observed arrival times for the type of vehicles were introduced into the input data file keeping all the other input data undisturbed. This means that in the second run the simulation model will compute above parameters for the given observed data set of type of vehicles and their arrival times (see Appendix D). The input data file for validation of model SIMMTRA-345 is presented in Table 5.8 and the gist of output for second run is presented in Table 5.9. The detailed tabular output for second run is presented in Appendix E.

TABLE 5.8 – TYPICAL INPUT DATA FILE FOR VALIDATION OF MODEL SIMMTRA-345 (4-leg Intersection, Km. 201.000)

```
3600.0
7 4
90 90 90 90
1 3
2 2
3 3
4 2
969 566 683 693
8.98 44.89 46.13
1
14.94 0.0 2.30 39.08 39.08 4.60 0.0
15.63 3.91 10.80 34.02 29.89 4.83 0.92
7.61 5.37 7.38 29.53 43.40 4.03 2.68
3.0 38.52 58.48
1
0.0 0.0 5.88 35.29 58.83 0.0 0.0
5.50 0.0 1.38 32.11 44.49 11.93 4.59
2.72 0.0 3.62 17.52 61.03 9.37 5.74
57.98 31.19 10.83
1
17.42 5.56 13.64 30.05 28.28 4.29 0.76
6.10 0.0 1.41 24.41 47.42 13.62 7.04
6.76 0.0 17.57 40.54 27.03 2.70 5.40
52.09 45.60 2.31
1
9.42 4.71 7.48 27.70 45.71 2.49 2.49
2.22 0.0 1.90 21.20 62.34 9.81 2.53
6.25 0.0 31.25 43.75 18.75 0.0 0.0
```

The simulation model SIMMTRA-345 has been validated for both 3-leg and 4-leg semi-urban priority type intersections. As explained earlier the simulation model was run twice for each intersection selected

TABLE 5.9 : GIST OF OUTPUT OF SIMULATION MODEL SIMMTRA-345 WITH GIVEN OBSERVED DATA (3-LEG INTERSECTION, APPROACH NO.1, MINOR ROAD, Km. 120.000) (Traffic Volume 183 Vph)

Sl. No.	Output Item		Value	
1.	Total Delay		44.58	(Veh-Sec.)
2.	Average Delay		0.24	(Sec.)
3.	Average Headway		19.39	(Sec.)
4.	Average Headway for Vehicle Type	1	46.47	(Sec.)
5.	-------	2	702.00	(Sec.)
6.	-------	3	112.80	(Sec.)
7.	-------	4	66.52	(Sec.)
8.	-------	5	186.58	(Sec.)
9.	-------	6	0.0	(Sec.)
10.	-------	7	0.0	(Sec.)
11.	Total Equivalent Passenger Car Values		232.08	(EPCV)
12.	Maximum Length of Queue		2	(No.of vehicle)

for validation. During the first run the simulation model generated arrival time, type of vehicle and turning manoeuvre and computed average headway, average delay and maximum queue length for each approach. Whereas during the second run, the simulation model computes average headway, average delay and maximum queue length for the given data set of type of vehicle and their arrival timings. The turning manoeuvre is generated by simulation model subject to the given turning percentages. The gist of the two runs for two intersections (one 3-leg and one 4-leg) has been presented in Table 5.10 and 5.11.

TABLE 5.10 : GIST OF OUTPUTS FOR 3-LEG INTERSECTION (TWO RUNS WITH & WITHOUT OBSERVED DATA) (Km. 20.000) TRAFFIC VOLUMES 183, 316, 443 Vph (Approach No. 1 is minor road)

Output Item		Without Observed Data			With Observed Data		
		Approach 1	2	3	1	2	3
Total Delay		47.64	373.19	292.27	44.58	280.04	303.23
Average Delay		0.26	1.18	0.66	0.24	0.87	0.68
Average Headway		20.51	11.87	8.27	19.39	11.43	8.09
Average Head Veh. Type	1*	40.08	31.28	20.55	46.47	31.37	20.53
-------	2*	541.43	69.45	57.59	702.00	71.58	58.77
-------	3*	96.46	102.56	58.66	112.80	124.29	56.11
-------	4*	56.29	29.59	28.25	66.52	33.23	30.27
-------	5*	174.80	200.01	109.31	186.58	187.28	102.00
-------	6*	-	-	-	-	-	-
-------	7*	-	-	-	-	-	-
Equivalent passenger car values (EPCV)		234.40	441.44	654.03	232.08	430.58	660.27
Maximum length of queue		1	3	1	2	2	2

* 1 = Car; 2 = Bus; 3 = Truck; 4 = Scooter/Motor cycle; 5 = Bicycle; 6 = Pedal Rickshaw; 7 = Others

TABLE 5.11 : GIST OF OUTPUTS FOR 4-LEG INTERSECTION (TWO RUNS : WITH & WITHOUT OBSERVED DATA) (Km. 148.000 VOLUME 108, 133, 141, 82 Vph) (Approach 1 & 3 major road and 2 & 4 minor road)

Output Item		Without Observed Data				With Observed Data			
		Approach 1	2	3	4	1	2	3	4
Total Delay		102.34	369.25	100.03	184.90	62.46	427.55	103.56	128.50
Average Delay		0.95	2.78	0.71	2.25	0.58	3.21	0.73	1.57
Average Headway		34.78	28.19	26.92	43.35	31.32	26.52	25.06	40.66
Average Headway Veh. Type	1*	86.90	92.14	224.05	334.86	86.13	89.53	224.40	277.89
------	2*	434.87	310.60	481.37	539.14	301.40	308.67	377.29	341.60
------	3*	70.11	85.96	189.51	597.65	66.09	99.19	212.53	765.00
------	4*	202.23	94.70	82.47	135.93	168.20	112.55	89.03	170.28
------	5*	473.08	120.58	45.23	77.01	623.00	125.52	56.08	77.52
------	6*	-	-	-	-	-	-	-	-
------	7*	-	-	-	-	-	-	-	-
Equivalent passenger car values (EPCV)		230.50	204.74	130.44	60.85	237.28	196.62	145.81	67.75
Maximum length of queue		2	2	3	2	3	3	3	2

* 1 = Car; 2 = Bus; 3 = Truck; 4 = Scooter/Motor cycle; 5 = Bicycle; 6 = Pedal rickshaw; 7 = Others

5.12 SUMMARY

This chapter presents the stages and logic in developing the simulation model SIMMTRA-345. Sequentially the various traffic stream parameters like approach volumes, traffic composition, conflict traffic and roadway parameters like number of approaches, width of approaches, angle of turn etc. have been incorporated in the simulation model.

The operations of the model, which are analysed using HP-9600 and DEC-2050 computer systems at University of Roorkee, have also been presented herein. Lastly, the steps of model validation are presented.

CHAPTER VI

SIMULATION RESULTS AND APPLICATIONS OF SIMULATION MODEL

6.1 INTRODUCTION

Through the development of a generalised approach of simulation modelling and analysis of processed field data, the simulation results obtained for vehicular interactions and estimation of composition factor and conflict factor for determining the equivalent passenger car values (EPCV) can now be presented. This chapter will discuss some of the procedures available for interpreting the output of a simulation model. An attempt has been made to develop the level-of-service (LOS) criteria for priority type semi-urban intersections under mixed traffic conditions.

These results presented herein and the practical applications of SIMMTRA-345 there of in understanding the heterogeneous mixed traffic flow are presented in more summarised tabular, graphical or in the form of nomograms for quick evaluations and ready availability.

6.2 WARM UP TIME

It concerns with starting of the simulation from an arbitrary point, It can be simulating traffic flow at highway intersection, it is not correct to assume that the system is empty at the start of simulation. Common practice therefore is to run the model till it reaches some equilibrium conditions. The vehicles entering the intersection during this time period are not considered in the calculation of the performance measures. The simulation time taken to reach this equilibrium is termed the "warm up" time. In the present research work the warm up time of 2 seconds is considered.

6.3 VEHICULAR INTERACTIONS AND INTERPRETATIONS

The basic objective of the study of intervehicular interactions, as outlined earlier, is to analyse the phenomenon of vehicular flow of different incompatible types of vehicles, at priority type semi-urban intersections through simulation, so that the mechanism of flow may be better understood and evaluated for its subsequent use in traffic planning and system improvements. The intervehicular interactions in complex heterogeneous traffic streams, are not well understood as yet; the evaluated interactions within the realsm of the objectives and scope have been presented in the current chapter to understand the phenomenon in a better way.

6.4 SIMULATION EXPERIMENTS WITH SIMMTRA-345

SIMMTRA-345 is basically designed to study the traffic quality at priority type semi-urban 3-leg and 4-leg intersections. It will be recalled that an imortant aspect to the interpretation of the output of a simulation is a clear statement of the measures to be used to measure the performance of the system. Vehicular delays are considered to be one of the best performance measures for evaluating traffic quality at priority type intersection. In the present simulation model the following performance measures have been incorporated to determine the vehicular interactions in terms of delays and their effects on over all performance of an intersection.

1. Total delay experienced by all vehicles on an approach (in vehicle seconds).

2. Average delay experienced by each vehicle on an approach (in seconds).

3. Maximum length of queue on an approach (in number of vehicles).

These above performance measures for 3-leg and 4-leg intersections have been determined under the varied traffic and geometric conditions as stated below :

1. Approach traffic volumes
2. Composition of traffic (vehicle type proportion)
3. Conflict traffic (turning proportion)
4. Angle of turn, and
5. Approach width.

In this study the traffic composition, the turning and crossing speed characteristics of different type of vehicles and their manoeuvering behaviour, all together, provide the mixed traffic environment.

6.4.1 Approach Traffic Volumes

The approach traffic volume levels are not likely to exceed 700 vph per minor road approach and 1000 vph per major road approach. However, in the present research work the vehicular interactions are determined for the following minimum and maximum levels of traffic volumes-

1. For majro road

   Minimum 300 vph per approach

   Maximum 1000 vph per approach

2. For minor road

   Minimum 100 vph per approach

   Maximum 1000 vph per approach

6.4.1.1 Simulation procedure

To utilize the simulation model SIMMTRA-345 to provide vehicular delay, a number of simulation runs were performed beginning with minimum traffic volume levels on major and minor approaches and gradually increasing these traffic volume levels with each additional run. While changing the traffic volume levels for same type of intersection, the composition of traffic and turning movements on all the approaches are held constant.

In the first ten runs of this series, the approach traffic volume on major road approaches is held constant (300 vph) while increasing the traffic volume on minor road approaches starting from 100 vph to 1000 vph with stepping up of increment of 100 vph.

Similar sets of ten runs each are performed with volume level on major road approaches are stepped-up with increment of 100 vph.

The simulation model SIMMTRA-345 is run for both 3-leg and 4-leg intersections.

6.4.1.2 Simulated results

An evaluation of the results of this series of runs provide an insight into the relationship between delay and approach volumes. The output results for this series of runs for different traffic volume levels for three legged and four legged intersections have been presented in the form of tables and nomograms. The following inter-relationships have been established between input data and output results.

1. Major road flow versus total delay, mean delay and queue length for 3-leg intersection. Results of this series of simulation runs are presented in table 6.1 and Figs. 6.1 to 6.3.

2. Major road flow versus total delay, mean delay and queue length for 4-leg intersection. The results of this set of computer runs are presented in Table 6.2 and Figs. 6.4 to 6.6.

3. Minor road flow versus total delay, mean delay and queue length for 3-leg intersection. The results of this series of runs are presented through Table 6.3 and Figs. 6.7 to 6.9.

4. Minor road flow versus total delay, mean delay and queue length for 4-leg intersection. The results of this series of simulation runs are presented in Table 6.4 and Figs. 6.10 to 6.12.

5. Major volume versus minor volume for 3-leg intersections (Table 6.5 and Fig. 6.13).

Table 6.1 to 6.4 and Figs. 6.1 to 6.12 show that at low volumes, because only little interaction exists between the vehicles, the minor road vehicles are subjected to little delay. As the volume level on major road increases, the minor road vehicles did yield significant deviation in the delays even at low volumes.

The simulation findings show the trend of delays for three legged and four legged intersections under different traffic volume levels. It can be noted that for higher approach flows the curves become nearly linear indicating the steep rise in delays. For all other characteristics of disturbances the slope keeps increasing with flow as can be seen in

TABLE 6.1 - RELATIONSHIPS BETWEEN MAJOR ROAD FLOW AND TOTAL DELAY, MEAN DELAY AND QUEUE LENGTH ON MINOR ROAD (Simulated Results, 3-Leg Intersections)

Major road flow (vph)	MINOR ROAD FLOW (vph) 100	200	300	400	500	600	700	800	900	1000
	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH. SEC.)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
800	827.70	2252.50	3844.92	5345.40	7804.01	9539.69	12438.69	14453.18	18018.54	18331.50
900	1606.00	3104.95	5158.03	6819.08	8858.27	12370.97	14905.66	14227.34	19267.43	20195.54
1000	1583.93	4049.05	5408.74	8536.99	11149.58	14455.00	17680.85	20623.63	25482.22	29637.50
1100	2438.69	4797.12	8087.32	12046.83	15462.12	20302.11	23455.77	27875.41	31783.52	35057.66
1200	2021.69	4877.20	9189.10	13883.69	20394.02	21759.88	27737.46	32260.84	40858.28	43731.00
1300	3242.12	5746.40	19089.96	21978.00	33067.29	42811.40	51177.41	66246.38	71667.30	87180.20
1400	1747.63	7764.18	15097.17	20216.32	27887.58	38322.54	40932.05	55486.28	53172.61	62961.92
1500	5399.39	10321.67	19821.43	26044.43	33625.55	41340.91	53210.30	60617.95	71825.34	88833.89
1600	7347.00	13694.25	24574.55	31223.40	43888.82	48898.36	71856.59	82163.52	88341.96	106554.38
1700	7056.44	21393.47	30570.66	39208.75	58678.21	72129.19	94932.37	103367.5	124279.5	122052.60
1800	9091.46	20230.66	34390.27	47150.63	55807.21	67074.32	89425.11	93316.99	114151.8	121115.50
1900	18421.35	43928.05	72771.91	91219.16	119737.00	138182.3	168918.0	189226.3	232544.7	244544.90
2000	9291.55	33949.35	56737.41	66448.18	96884.81	96910.26	134886.3	152698.2	179048.9	218636.20
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)									
800	8.28	11.26	12.82	13.36	15.61	15.90	17.77	18.07	20.02	18.33
900	16.06	15.52	17.20	17.05	17.72	20.62	21.29	17.78	21.41	20.20
1000	15.84	20.26	18.03	21.34	22.30	24.09	25.26	25.76	29.42	29.64
1100	24.39	23.99	26.96	30.12	30.92	33.84	33.51	34.84	35.32	35.06
1200	20.22	24.39	30.63	34.71	40.79	36.27	39.62	40.33	43.40	45.70
1300	32.42	28.73	63.63	54.95	66.13	71.35	73.11	82.81	79.63	87.18
1400	17.48	38.82	50.32	50.54	55.78	63.87	58.47	69.36	59.08	62.96
1500	53.99	51.61	66.07	65.11	67.25	68.90	76.00	75.77	79.81	88.93
1600	73.47	68.47	81.92	78.06	87.78	81.50	102.65	102.70	98.16	106.55
1700	70.56	106.96	101.90	98.02	117.36	120.22	135.62	129.21	138.09	122.05
1800	90.91	101.15	114.63	117.88	111.61	111.79	127.75	116.65	126.84	121.12
1900	184.21	219.64	242.57	228.05	239.47	230.30	241.31	236.53	258.38	244.54
2000	92.92	169.75	189.12	166.12	193.77	161.52	192.69	190.87	198.94	218.64
	QUEUE LENGTH FORMED ON MINOR ROAD (NO. OF VEHICLES)									
800	3	6	9	11	12	13	16	23	20	20
900	4	9	11	11	18	17	21	18	38	35
1000	3	7	9	12	15	21	24	25	32	51
1100	7	8	12	17	14	31	22	32	33	27
1200	4	6	11	15	17	21	28	38	46	31
1300	8	9	13	13	17	24	30	32	34	42
1400	5	9	15	23	23	32	33	69	35	52
1500	6	14	17	21	30	40	35	42	60	93
1600	11	17	22	26	35	38	61	55	70	63
1700	10	17	26	29	47	56	65	76	92	99
1800	9	16	25	38	40	52	60	70	68	89
1900	17	40	54	69	51	85	117	146	165	168
2000	10	28	39	55	48	65	86	119	117	114

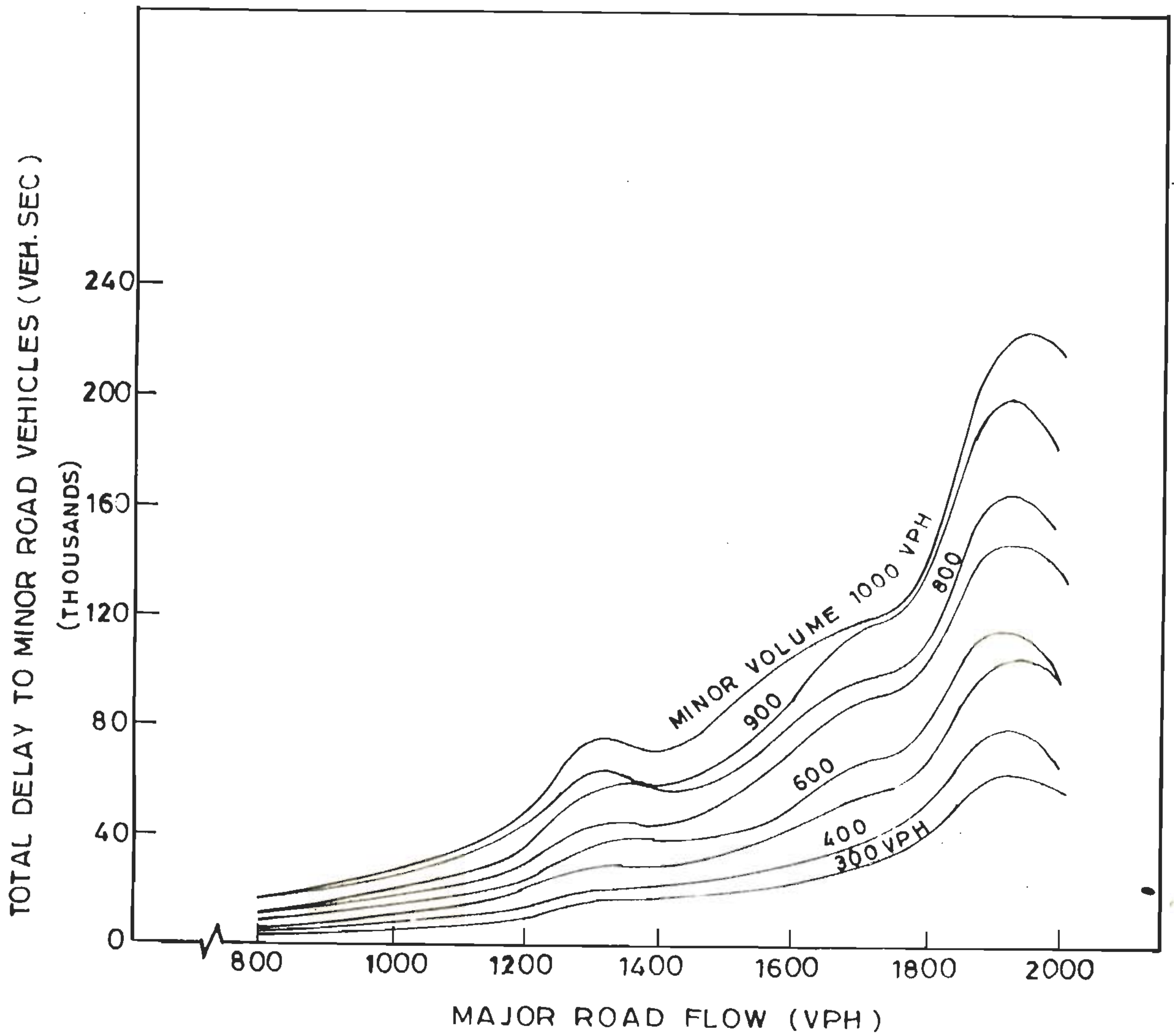


Fig. 6.1 Relationship between major road flow and total delay to minor road vehicles.

(SIMULATED RESULTS, 3-LEG INTERSECTION)

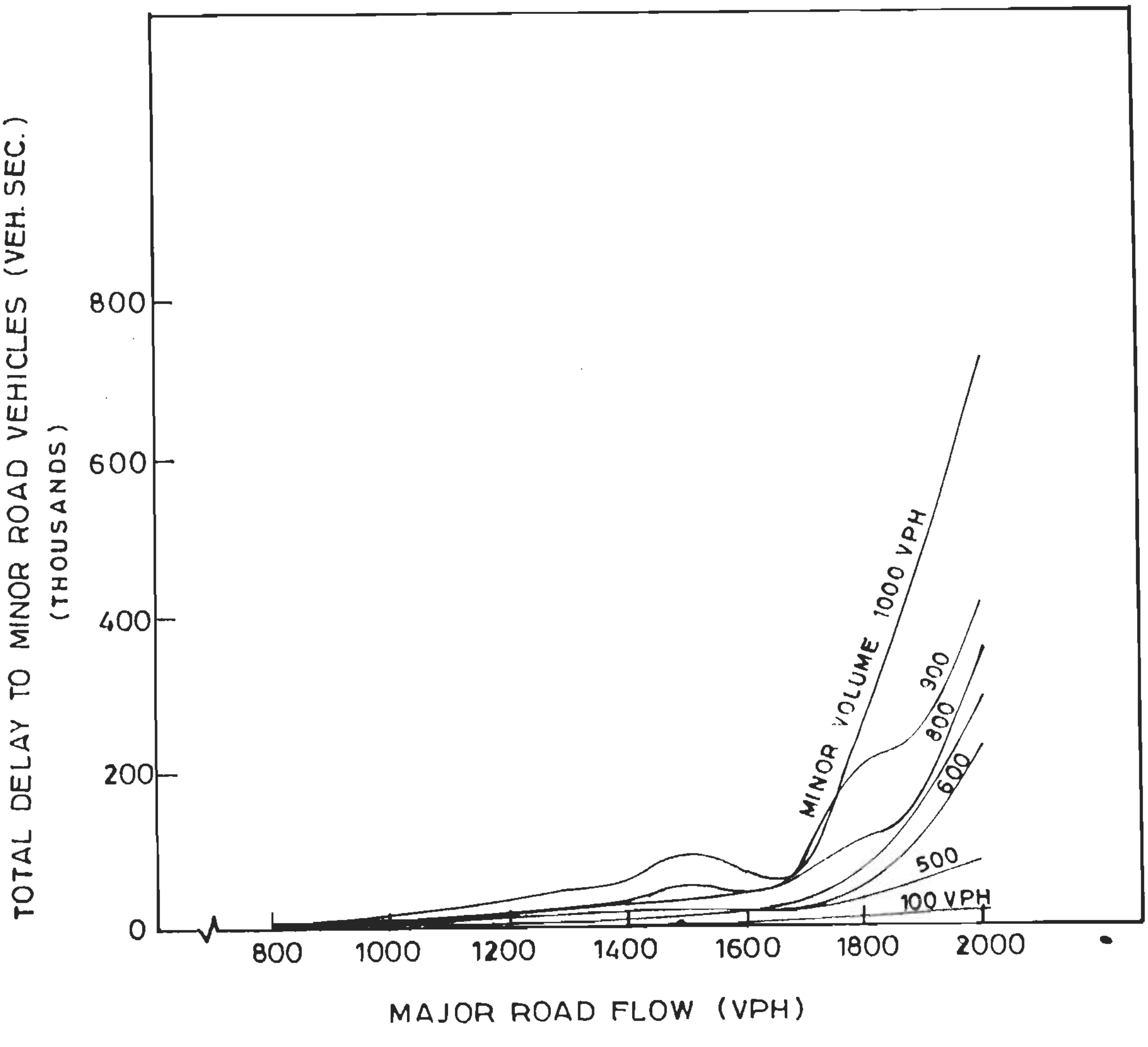


Fig. 6.2 Relationship between major road flow and total delay to minor road vehicles.

(SIMULATED RESULTS, 4-LEG INTERSECTION)

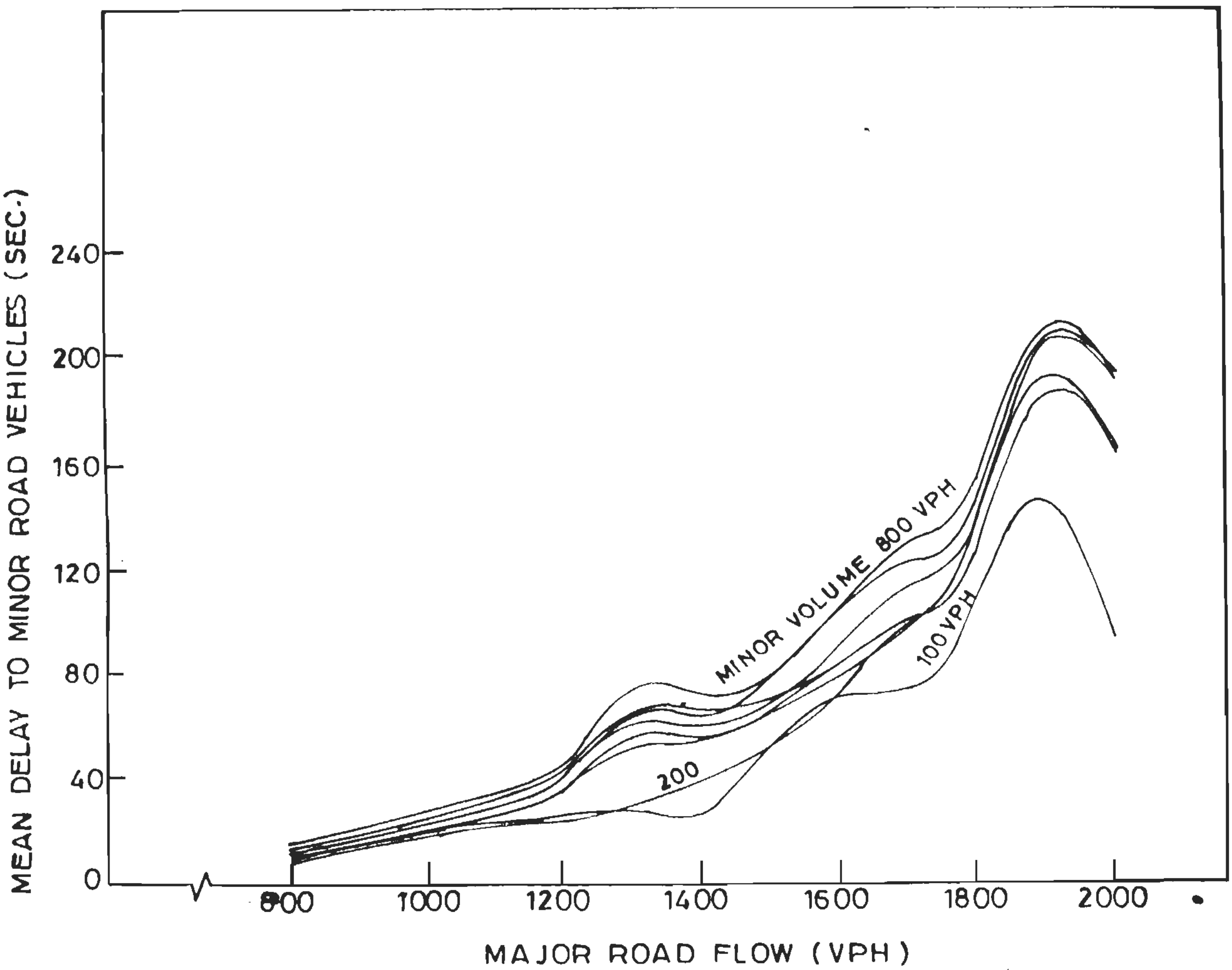


Fig. 6.3 Relationship between **major road flow and mean delay to minor road vehicles**

(SIMULATED RESULTS, 3-LEG INTERSECTION)

TABLE 6.2 - RELATIONSHIP BETWEEN MAJOR ROAD FLOW AND TOTAL DELAY, MEAN DELAY AND QUEUE LENGTH ON MINOR ROAD (Simulated Results, 4-Leg Intersections).

Major Volume (vph)	MINOR VOLUMES (VPH) 100	200	300	400	500	600	700	800	900	1000
	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH-SEC)									
800	577.20	1050.30	1319.40	2131.10	3022.00	4728.30	5676.70	6891.90		
900	441.20	1195.90	1933.40	3752.90	4100.70	5716.90	9874.70	10823.50	12276.60	
1000	689.40	2402.80	2401.40	4367.20	4538.70	7883.10	12376.90	14051.30	17244.60	19520.80
1100	705.80	2273.90	2286.20	4051.90	7437.50	8371.30	10819.40	14667.90	17509.60	26664.50
1200	677.10	1904.30	3377.10	4233.60	8399.70	9649.80	16001.10	21015.00	21301.10	32945.20
1300	705.50	2224.50	3719.70	5734.40	9357.80	16579.10	19664.30	29049.20	29693.60	54191.30
1400	804.50	3410.90	4106.10	8404.00	11066.30	20892.70	23982.70	29166.20	30313.70	49923.80
1500	1231.20	3869.80	5581.60	8655.70	14985.10	25512.10	28093.60	40065.50	59735.80	107198.40
1600	1188.50	4104.80	6384.70	13089.40	22996.90	22911.10	27253.00	46549.20	44572.80	70126.00
1700	1501.60	4174.70	6447.90	11148.10	20598.00	24568.60	30484.70	55480.20	59603.30	17271.80
1800	1447.70	3933.90	11232.20	21936.40	35310.80	53565.70	75573.90	127592.00	255769.40	308324.60
1900	1467.20	4643.60	16815.90	26407.10	65354.60	107304.10	141619.80	125595.70	201907.30	454154.00
2000	1668.90	13854.50	23139.70	55193.40	81517.60	226498.00	293812.30	354706.60	412195.70	718755.40
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)									
800	8.60	10.30	8.90	10.70	12.10	15.70	16.20	17.10		
900	9.50	12.10	12.90	19.00	16.40	19.10	28.20	27.10	27.10	
1000	13.00	23.40	16.00	21.50	18.20	26.30	35.20	34.90	38.10	38.90
1100	13.60	22.10	15.20	20.10	29.40	27.90	30.80	36.60	38.80	53.20
1200	13.20	18.90	22.30	21.40	33.40	32.30	45.80	52.40	47.20	65.50
1300	13.90	22.00	24.90	23.80	37.20	54.90	55.90	72.60	66.30	108.40
1400	15.60	33.40	27.10	41.90	44.40	69.40	68.40	73.00	67.50	100.40
1500	25.40	37.40	36.30	43.00	59.30	85.10	80.70	100.20	132.70	212.70
1600	24.00	40.40	42.20	65.00	90.40	76.00	77.60	117.10	98.90	158.10
1700	32.60	42.70	43.10	55.70	82.80	82.00	87.40	138.60	132.70	344.40
1800	28.90	38.50	75.30	111.80	141.70	157.00	215.60	320.50	564.50	612.60
1900	28.30	45.60	114.50	134.00	262.40	357.40	403.40	314.90	446.80	901.00
2000	31.60	131.50	156.60	277.30	325.60	748.60	832.30	879.30	908.40	782.10
	LENGTH TO QUEUE ON MINOR ROAD (NO. OF VEHICLES)									
800	2	3	2	5	8	8	8	7		
900	2	2	4	7	8	8	17	18	10	
1000	2	4	4	5	6	12	9	9	16	17
1100	2	4	4	4	8	13	12	16	19	28
1200	2	4	5	6	8	18	20	30	22	23
1300	3	3	4	8	9	20	26	37	36	47
1400	2	4	7	8	13	23	28	35	33	44
1500	3	4	6	10	14	31	27	34	48	50
1600	2	5	8	17	14	22	17	39	41	55
1700	3	5	8	10	15	19	19	38	41	86
1800	3	4	14	23	46	46	69	72	82	
1900	3	14	17	22	35	55	59	69	78	101
2000	3	6	19	28	36	57	72	82	97	103

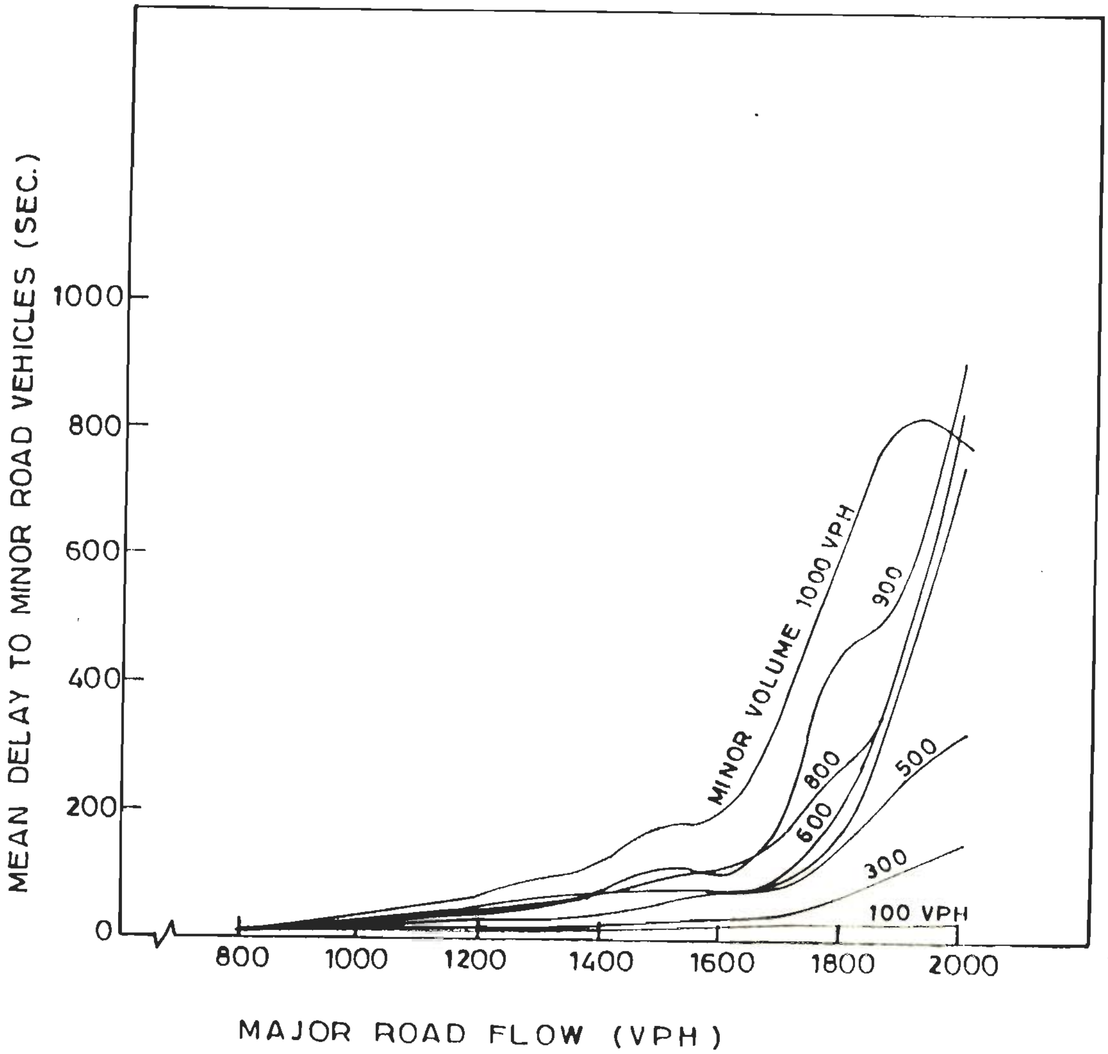


Fig. 6.4 Relationship between major road flow and mean delay to minor road vehicles

(SIMULATED RESULTS, 4-LEG INTERSECTION)

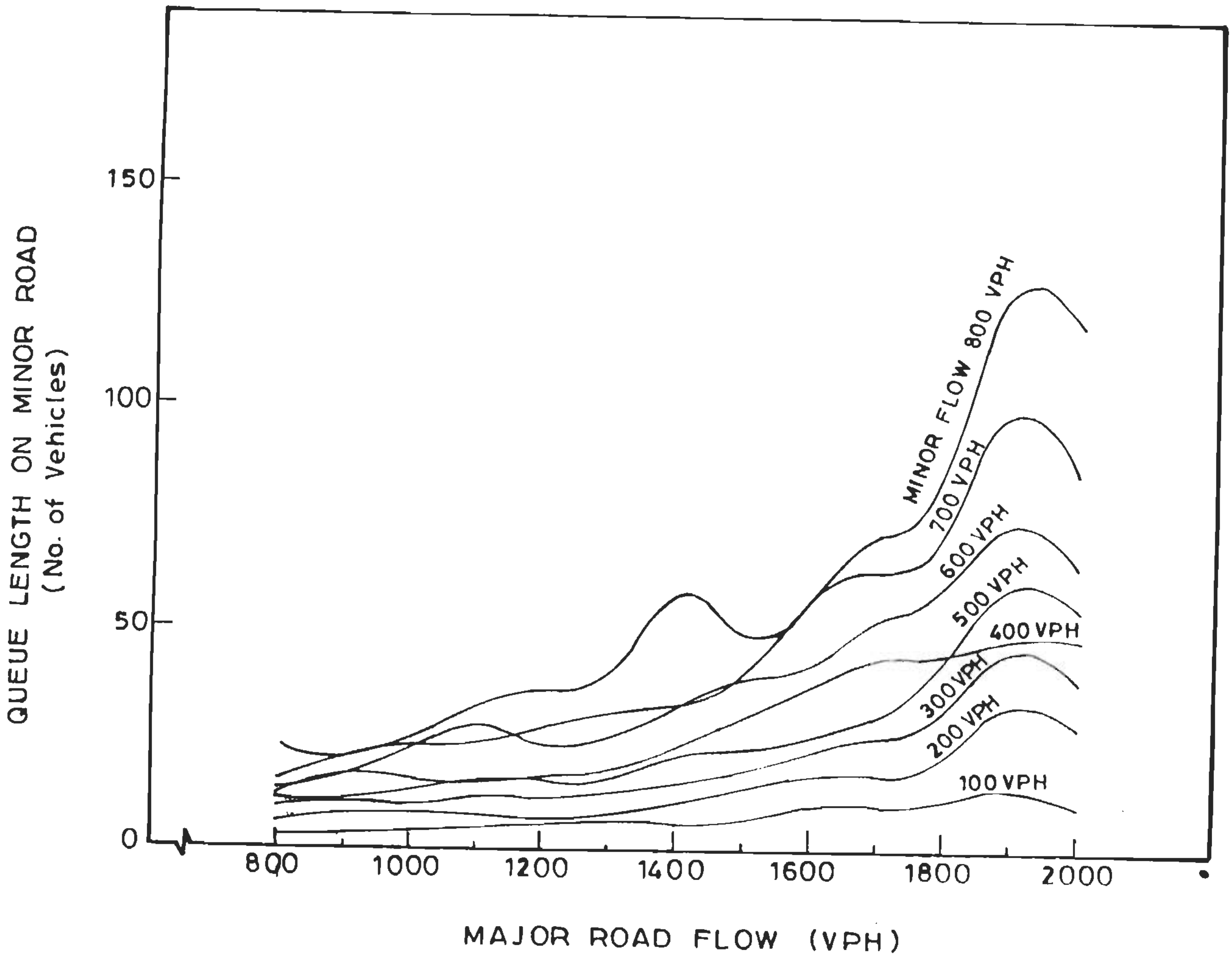


Fig. 6.5 Relationship between major road flow and queue length on minor road.
(SIMULATED RESULTS, 3-LEG INTERSECTION)

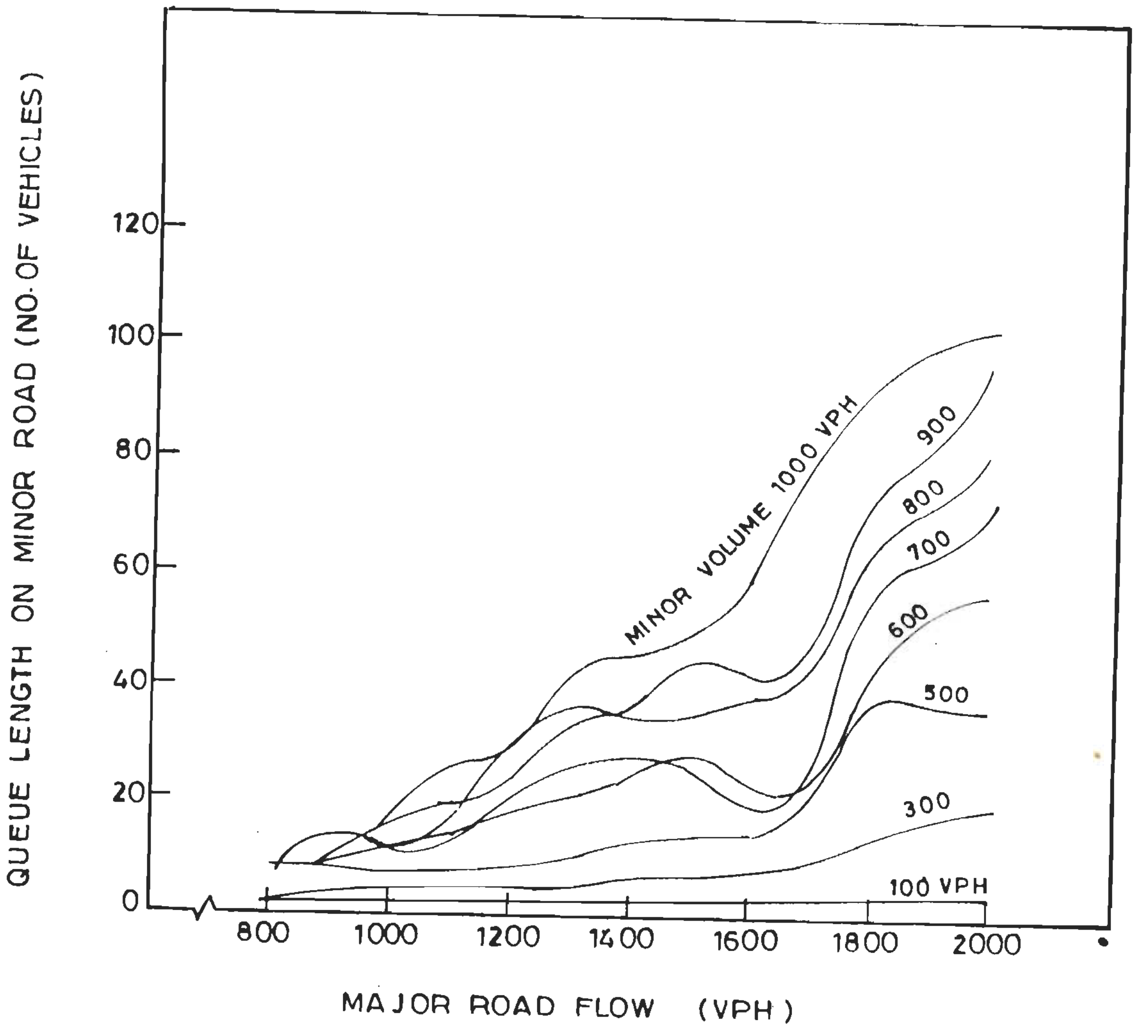


Fig. 6. 6 Relationship between major road flow and queue length on minor road

(SIMULATED RESULTS , 4-LEG INTERSECTION)

TABLE 6.3 – **RELATIONSHIP BETWEEN MINOR ROAD FLOW AND TOTAL DELAY, MEAN DELAY AND QUEUE LENGTH ON MINOR ROAD (Simulated Results, 3-Leg Intersections)**

Minor Volumes (vph)	MAJOR ROAD FLOW (VPH) 800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH-SEC.)												
100	827.70	1606.00	1583.93	2438.69	2021.69	3242.12	1747.63	5399.39	7347.00	7056.44	9091.46	18421.35	9291.55
200	2252.50	3104.95	4049.05	4797.12	4877.20	5746.40	7764.18	10321.67	13694.25	21392.47	20230.66	43928.05	33949.35
300	3844.92	5159.03	5408.74	8087.32	9189.10	19089.96	15097.17	19821.43	24574.55	30570.66	34390.27	72771.91	56737.41
400	5345.40	6819.08	8536.99	12046.83	13883.69	21978.00	20216.32	26044.43	31223.40	39208.75	47150.63	91219.16	66448.18
500	7804.01	8858.27	11149.58	15462.12	20394.02	33067.29	27887.58	33625.55	43888.82	58678.21	55307.21	119737.0	96894.81
600	9539.69	12370.97	14455.00	20302.11	21759.88	42811.40	38322.54	41340.91	48898.36	72129.19	67074.32	138182.3	96910.26
700	12438.69	14905.66	17680.85	23455.77	27737.46	51177.41	40932.05	53210.30	71856.59	94932.37	89425.11	168918.0	134886.3
800	14453.18	14227.34	20623.63	27875.41	32260.84	66246.38	55486.28	60617.95	82163.52	103369.5	93316.99	189226.3	152698.2
900	18018.54	19267.43	26482.22	31783.52	40858.28	71667.30	53172.61	71825.34	88341.96	124279.5	114151.8	232544.7	179043.8
1000	18331.50	20195.54	29637.50	35057.66	43731.00	87180.20	62961.92	88833.89	106554.38	122052.6	121115.5	244544.9	218636.2
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)												
100	8.28	16.06	15.84	24.39	20.22	32.42	17.48	53.99	73.47	70.56	90.91	184.21	92.92
200	11.26	15.52	20.25	23.99	24.39	28.73	38.82	51.61	68.47	106.96	101.15	219.64	169.75
300	12.82	17.20	18.03	26.96	30.63	63.63	50.32	66.07	81.92	101.90	114.63	242.57	189.12
400	13.36	17.05	21.34	30.12	34.71	54.95	50.54	65.11	78.06	98.02	117.88	228.05	166.12
500	15.61	17.72	22.30	30.92	40.79	66.13	55.78	67.25	87.78	117.36	111.61	239.47	193.77
600	15.90	20.62	24.09	33.34	36.27	71.35	63.87	68.90	81.50	120.22	111.79	230.30	161.52
700	17.77	21.29	25.26	33.51	39.62	73.11	58.47	76.01	102.65	135.62	127.75	241.31	192.69
800	18.07	17.78	25.76	34.84	40.33	82.81	69.36	75.77	102.70	129.21	116.65	236.53	190.87
900	20.02	21.41	29.42	35.32	43.40	79.63	59.08	79.81	98.16	138.09	125.84	258.38	198.94
1000	18.33	20.20	29.64	35.06	45.73	87.18	62.96	88.83	106.55	122.05	121.12	244.54	218.64
	LENGTH OF QUEUE ON MINOR ROAD (NO. OF VEHICLES)												
100	3	4	3	7	4	8	5	9	11	10	[illegible]	17	10
200	6	9	7	8	6	9	6	14	17	17	[illegible]	40	28
300	9	11	9	12	11	13	15	17	22	26	23	54	39
400	11	11	12	17	15	13	23	21	26	29	33	59	55
500	12	18	15	14	17	16	23	30	35	47	40	51	48
600	13	17	21	31	21	24	32	40	26	56	52	55	65
700	16	21	24	22	28	30	33	35	61	65	50	117	86
800	23	18	25	32	38	32	69	42	55	76	70	146	119
900	20	38	32	33	46	34	35	60	70	92	58	165	117
1000	20	35	51	27	31	42	52	93	63	99	59	168	114

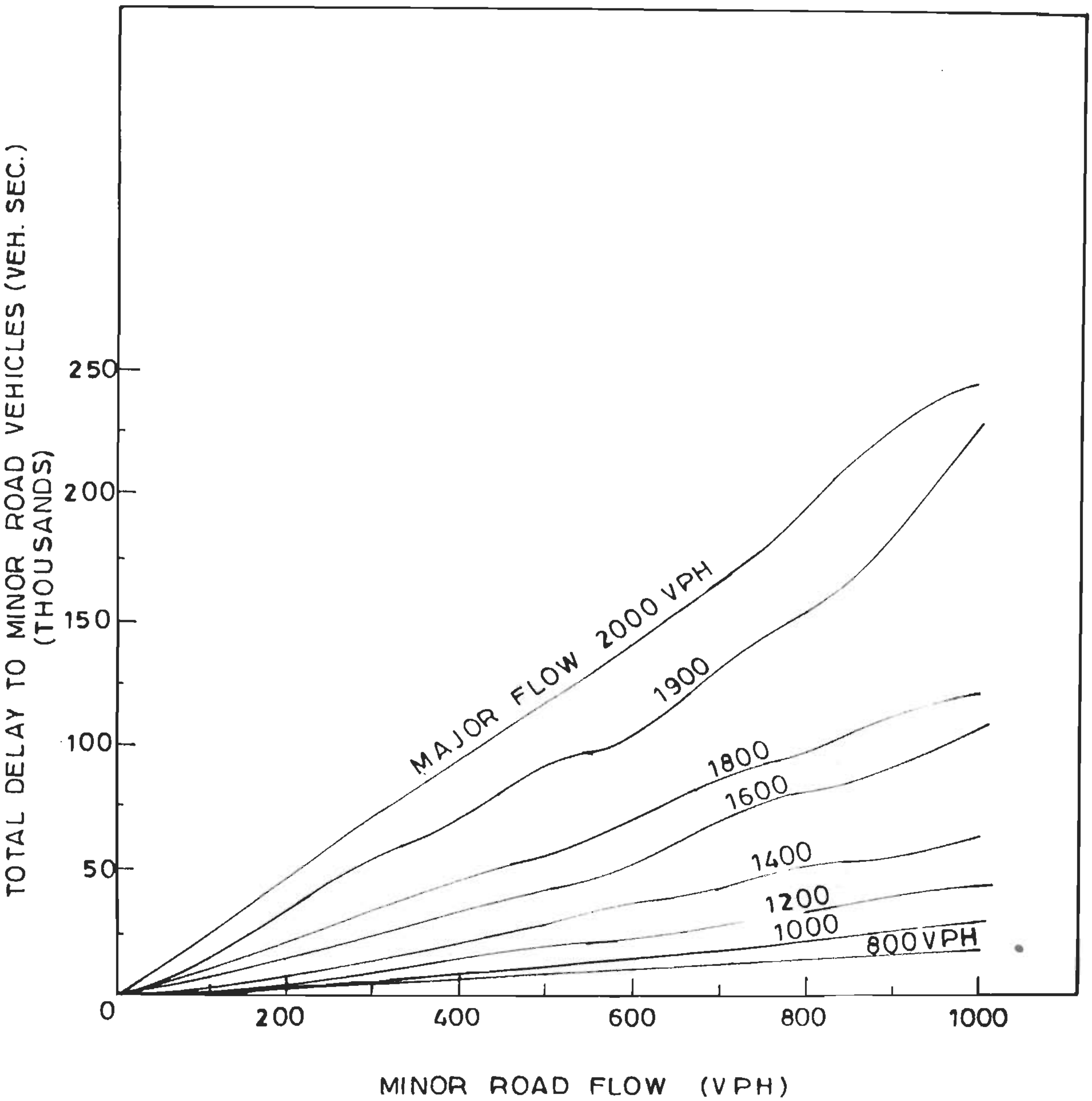


Fig. 6.7 Relationship between minor road flow and total delay to minor road vehicles

(SIMULATED RESULTS, 3-LEG INTERSECTION)

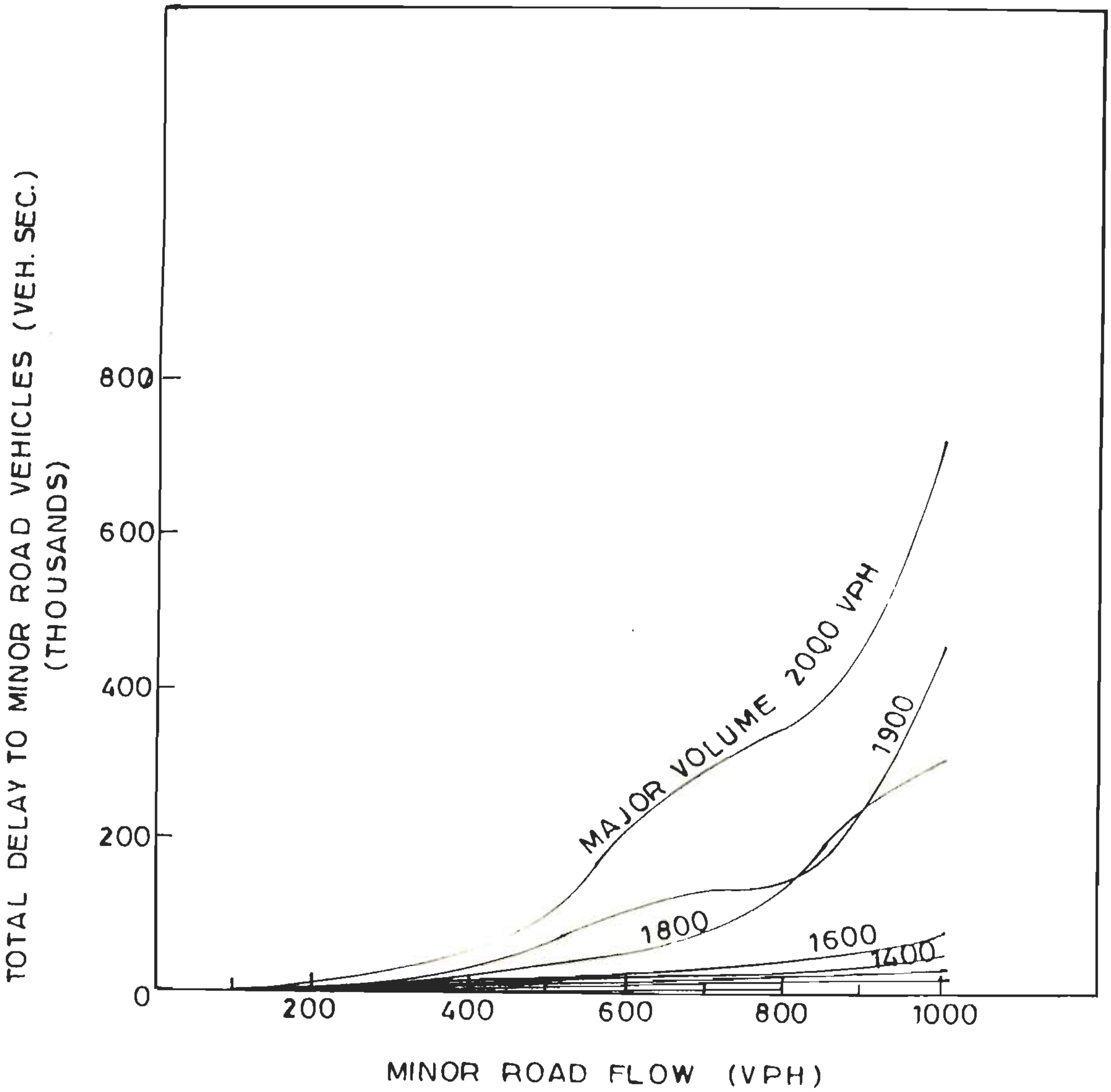


Fig. 6.8' Relationship between minor road flow and total delay to minor road vehicles

(SIMULATED RESULTS , 4 - LEG INTERSECTION)

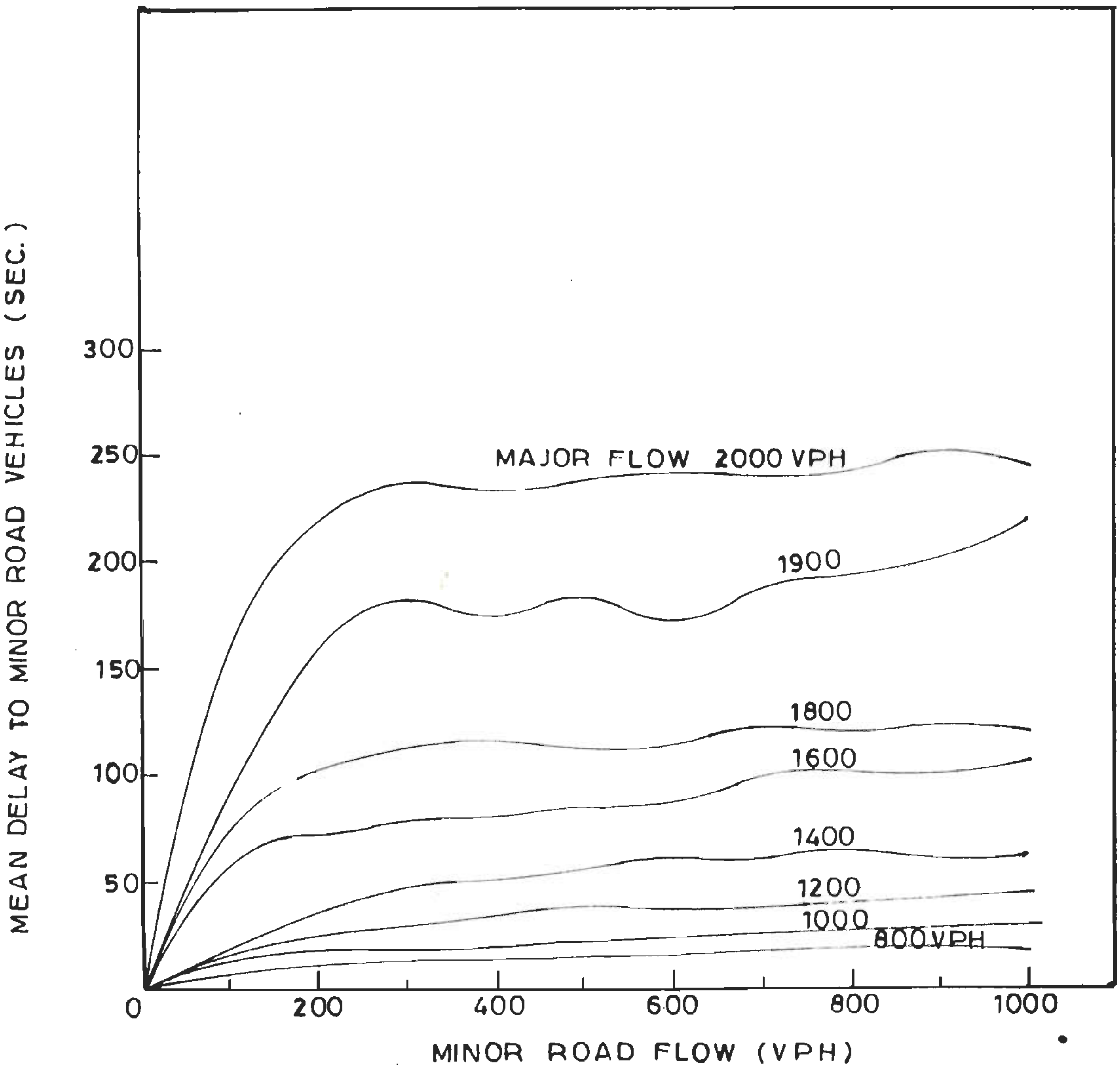


Fig. 6.9 Relationship between minor road flow and mean delay to minor road vehicles

(SIMULATED RESULTS, 3-LEG INTERSECTION)

TABLE 6.4 – RELATIONSHIPS BETWEEN MINOR ROAD FLOW AND TOTAL DELAY, MEAN DELAY AND QUEUE LENGTH ON MINOR ROAD (Simulated Results, 4-Leg Intersections)

Minor Volume (vph)	MAJOR VOLUME (VPH)												
	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH-SEC)												
100	577.20	441.20	689.40	705.80	677.10	708.50	804.50	1231.20	1188.50	1501.60	1447.70	1467.20	1668.90
200	1050.30	1195.90	2403.80	2273.90	1904.30	2224.50	3410.90	3869.80	4104.50	4174.70	3933.90	4643.60	13854.50
300	1319.40	1933.40	2401.40	2286.20	3377.10	3719.70	4106.10	5581.60	6384.70	6447.90	11232.20	16815.90	23139.70
400	2131.10	3752.90	4367.20	4051.90	4235.60	5734.40	8404.00	8685.70	13089.40	11148.10	21936.40	26407.10	55193.40
500	3022.00	4100.70	4538.70	7437.50	8399.70	9357.80	11066.30	14985.10	22996.90	20598.00	35310.80	65354.60	81517.60
600	4728.30	5716.90	7883.10	8371.30	9649.80	16579.10	20892.70	25512.10	22911.10	24568.60	53565.70	107304.10	226498.00
700	5676.70	9874.70	12376.90	10819.40	16001.10	19664.30	23982.70	28098.60	27253.30	30484.70	75573.90	141619.80	293812.30
800	6891.90	10823.50	14051.30	14667.90	21015.00	29049.20	29166.20	40065.50	46549.20	55480.20	127592.00	125595.70	354706.60
900		12276.60	17244.60	17509.60	21301.10	29693.20	30313.70	59735.80	44572.50	59603.30	255769.40	201907.30	412195.70
1000			19520.80	26664.50	32945.20	54191.30	49923.80	107198.40	79126.10	17271.80	308324.60	454154.00	718755.40
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)												
100	8.60	9.50	13.00	13.60	13.20	13.90	15.60	25.40	24.00	32.60	28.90	28.30	31.60
200	10.30	12.10	23.40	22.10	18.90	22.00	33.40	37.40	40.40	42.70	38.50	45.60	131.50
300	8.90	12.90	16.00	15.20	22.30	24.90	27.10	36.30	42.20	43.10	75.30	114.50	156.60
400	10.70	19.00	21.50	20.10	21.40	28.80	41.90	43.00	66.00	55.70	111.80	134.00	277.30
500	12.10	16.40	18.20	29.40	33.40	37.20	44.40	59.30	90.40	82.80	141.70	262.40	325.60
600	15.70	19.10	26.30	27.90	32.30	54.90	69.40	85.10	76.00	82.00	157.00	357.40	748.60
700	16.20	28.20	35.20	30.80	45.80	55.90	68.40	80.70	77.60	87.40	215.60	403.40	832.30
800	17.10	27.10	34.90	36.60	52.40	72.60	73.00	100.20	117.10	138.60	320.50	314.90	879.30
900		27.10	38.10	38.80	47.20	66.30	67.50	132.70	98.90	132.70	564.50	446.80	908.40
1000			38.90	53.20	65.50	108.40	100.40	212.70	158.10	344.40	612.60	901.00	782.10
	LENGTH OF QUEUE ON MINOR ROAD (NO. OF VEHICLES)												
100	2	2	2	2	2	3	2	3	2	3	3	3	3
200	3	2	4	4	4	3	4	4	5	5	4	4	7
300	2	4	4	4	5	4	7	6	8	8	14	17	19
400	5	7	5	4	5	8	8	10	17	10	23	22	28
500	8	8	6	8	8	9	13	14	14	15	23	35	36
600	8	8	12	13	18	20	23	31	22	19	46	55	57
700	8	17	9	12	20	26	28	27	17	19	46	59	72
800	7	18	9	16	30	37	35	34	39	38	59	69	82
900		10	16	19	22	36	33	48	41	41	72	78	97
1000			17	28	23	47	44	50	55	86	82	101	103

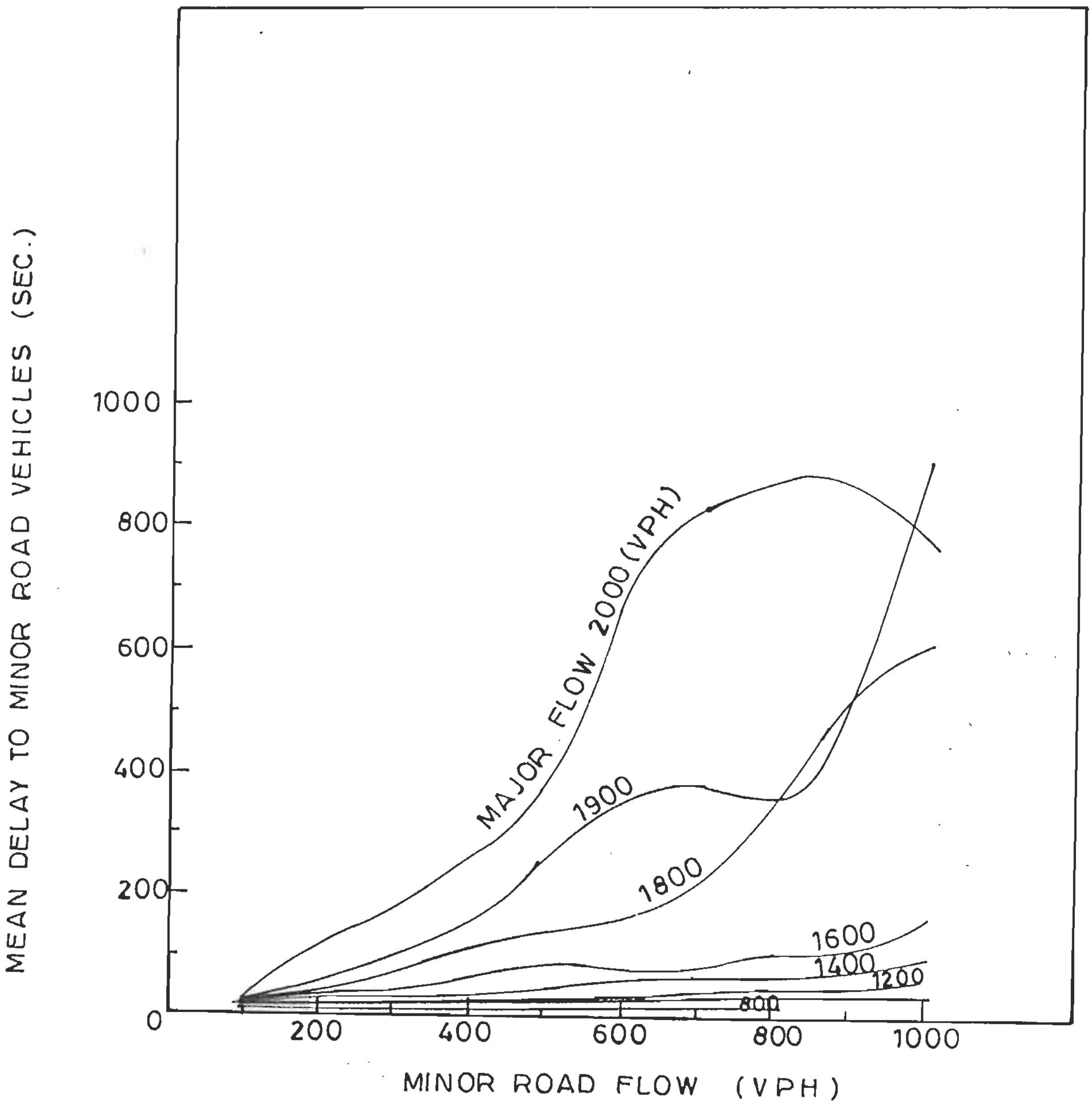


Fig.6.10 Relationship between minor road flow and mean delay to minor road vehicles

(SIMULATED RESULTS , 4-LEG INTERSECTION)

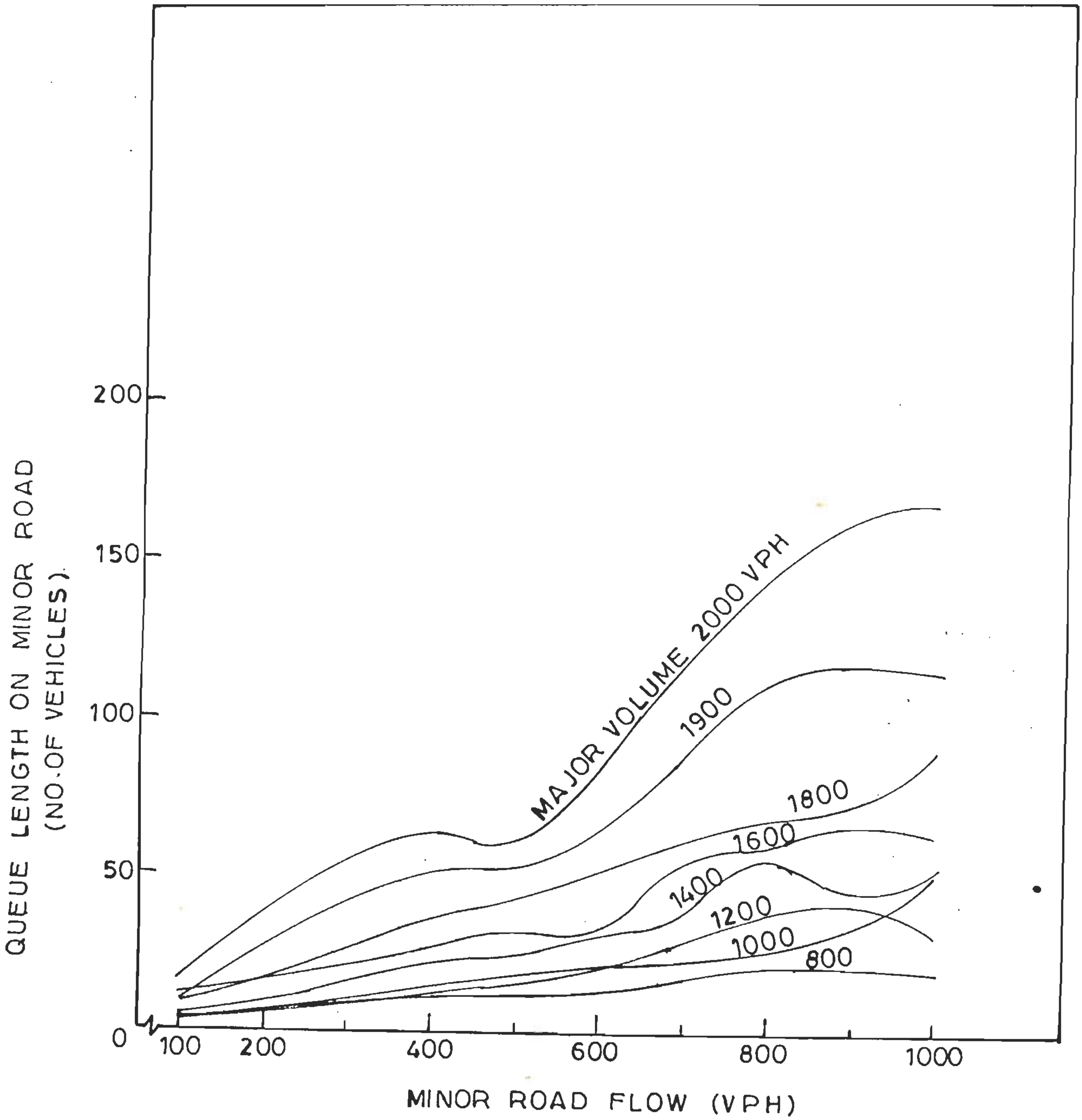


Fig. 6.11 Relationship between minor road flow and queue length on minor road

(SIMULATED RESULTS , 3-LEG INTERSECTION)

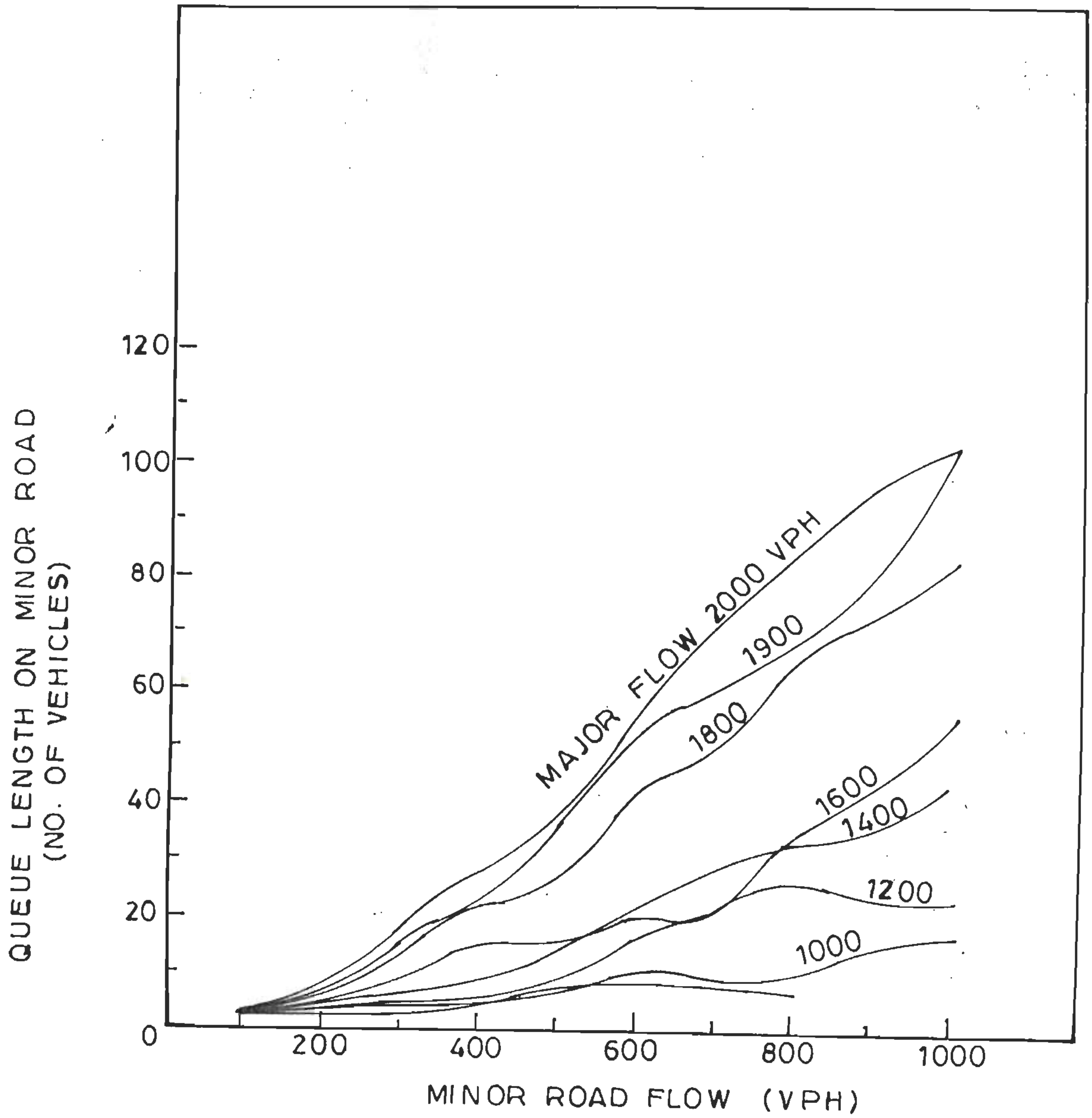


Fig. 6.12 Relationship between minor road flow and queue length on minor road

(SIMULATED RESULTS, 4-LEG INTERSECTION)

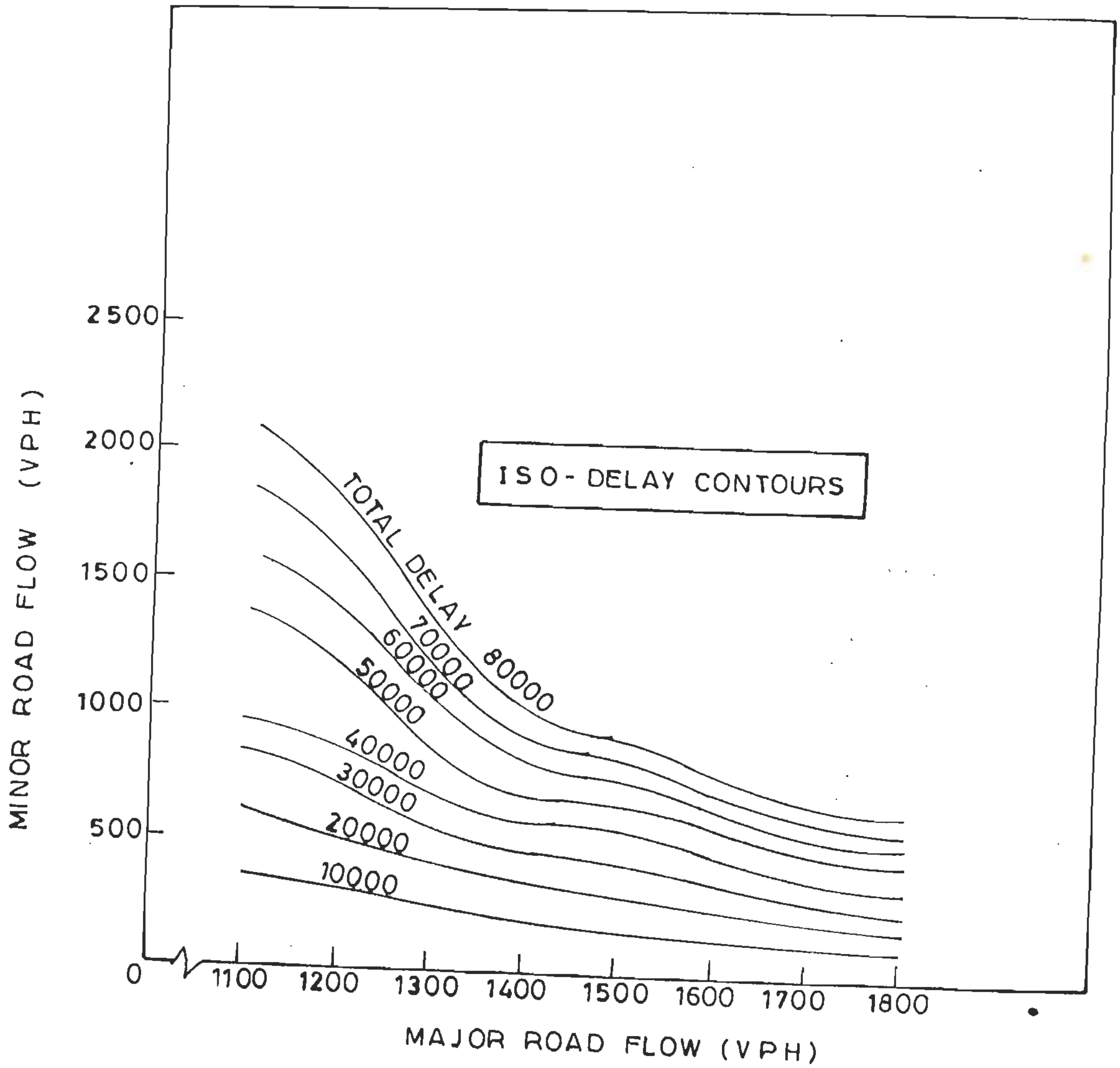


Fig. 6.13 Isometric graph of total delay for uncontrolled priority type intersection incorporating ISO - Delay curves
(BASED ON SIMULATION RESULTS , 3- LEG INTERSECTION)

Figs. 6.1 to 6.12

It is possible to suggest the acceptable and critical intersection volumes from the simulated results provided the tolerable and intolerable delay values are known for mixed traffic flow situations. But no such information being available, it was decided to adopt the tolerable and intolerable delay values as 30 seconds and 80 seconds respectively on the basis of experience. This means that the delay range from 0 to 30 seconds is tolerable, it is between tolerable (30 seconds) and intolerable (80 seconds) depending upon the prevailing traffic, roadway and environmental conditions at priority type uncontrolled intersections. A delay comes under intolerable limit once it crosses 80 seconds threshold value mark.

In the present research work, the various conclusions drawn and corresponding suggestions made from the results of different simulation experiments are based on these delay ranges.

One of the important methods of presenting the above simulated results is by portraying these results through the drawing of isometric or topographic graphs. Here the ordinate and abscissa are minor and major road volumes, respectively and the contour lines indicate levels of equal intersection delays. Such a graph is shown in Fig. 6.13. The contour lines were interpolated between adjacent delay points to get the 'ISO-delay' curves. The resulting topographic 'map' appears quite logical. At low levels of mior road volume, total delay increases slowly as major road volume increases, but as minor road volume increases, total delay increases rapidly.

It is possible to have a readily available information on total delays experienced by minor road vehicles by simply knowing the major and minor road flows from Fig. 6.13 and Table 6.5.

TABLE 6.5 – RELATIONSHIP BETWEEN MAJOR ROAD FLOW AND MINOR ROAD FLOW (Based on Simulated Results)(4-Leg Intersection)

TOTAL DELAY (VEHICLE SECOND)								
Major Road Flow (vph)	10000	20000	30000	40000	50000	60000	70000	80000
	MINOR ROAD FLOW (VPH)							
1800	120	190	260	340	440	510	560	630
1700	130	200	280	380	460	530	600	650
1600	150	270	370	470	580	640	690	770
1500	170	300	440	570	660	760	840	930
1400	220	350	470	580	670	780	870	940
1300	230	400	510	640	760	980	1100	1300*
1200	320	520	740	880	1230*	1440*	1660*	1850*
1100	350	600	840	960*	1380*	1600*	1850*	2100*

* Values computed through extrapolation

6.4.2 Mix Mode Traffic Experiments With SIMMTRA-345

The mixed mode traffic experiments are framed for -

a. Single mode experiments

b. Bimode experiments

c. Trimode experiments

d. Tetramode experiments

e. Pentamode experiments

f. Hexamode experiments

g. Septamode experiments.

Single mode traffic experiments were carried out to represent homogeneous traffic characteristics. Cars, buses, trucks, scooters/motor cycles, bicycles, pedal rickshaws and others are considered for single mode treatment. Holding all the other input parameters undisturbed, the model is run 7 times, everytime changing the mode of vehicle . The trends of total delay, mean delay and queue length for single mode traffic under constant approach volumes of 300 vph and 1000 vph on minor and major roads respectively are presented in Table 6.6 for 3-leg and 4-leg intersections.

TABLE 6.6 - SIMULATED RESULTS OF SINGLE MODE TRAFFIC EXPERIMENTS

Vehicle Type (100%)	3-Leg intersection Major=1000 & Minor=300(vph)			4-Leg intersection Major=1200 & Minor=800(vph)		
	Total Delay (veh.sec)	Mean Delay (sec)	Queue Length (No. of vehicles)	Total Delay (veh.sec)	Mean Delay (sec)	Queue Length (No. of vehicles)
Car	1877.32	6.26	6	4217.27	14.32	8
Bus	2802.15	9.34	9	6656.52	22.30	9
Truck	2802.15	9.34	9	6656.52	22.30	9
Scooter/ Motorcycle	2288.92	7.63	9	3462.41	11.62	7
Bicycle	10702.11	35.67	18	22159.17	74.61	34
Pedal rickshaw	10873.55	36.25	18	25881.83	87.42	36
Others	12260.74	40.87	18	29193.96	98.41	37

It has been found that incase of unimode traffic, among the motorised category, cars cause minimum interaction whereas the trucks or buses cause maximum interactions. On the other hand, among the non-motorised category bicycles cause minimum interactions and other vehicles cause maximum interactions at intersections. But when the interactions between slow moving vehicles (SMV) and fast moving vehicles (FMV) are compared it can be noticed that interactions rise sharply in case of SMV.

In bimode traffic experiments, the cars are mixed with all the remaining modes one by one. The interactions due to mixing of two type of vehicles have been studied by running the model 11 times for different percentage of cars, starting from 0 to 100.

Such sets of 11 runs each were accomplished for all the combinations of two vehicles as discussed above. The simulated results of this series of two vehicle mix experiments are presented in Table 6.7 and Figs. 6.14 to 6.16 for 3-leg intersection and in Table 6.8 and Figs. 6.17 to 6.19 for 4-leg intersection. It can be seen from the figures that as long as the traffic is homogeneous in character, means it consists only motorised vehicles, the delays are very low. But as soon as it is mixed with non-motorised vehicles (SMV), the delay increases considerably.

Incase of tromide traffic experiments, cars are mixed with buses and scooters. The model is run by varying proportion of the cars gradually at equally increasing rate. The proportion of the vehicles other than cars is reduced or increased equally for different runs as can be seen in Table 6.9.

TABLE 6.7 – INTERACTIONS DUE TO MIXING OF TWO VEHICLE TYPES ON MINOR ROAD (SIMULATED RESULTS 3-Leg , INTERSECTION)

MAJOR FLOW = 1000, MINOR FLOW = 300 (VPH) 2-VEHICLE MIX.

Proportion of Vehicles Other than Cars (percentage)	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH-SEC.)				
0	1877.32	1877.32	1877.32	1877.32	1877.32
10	2435.85	2395.60	4545.16	4545.61	4930.74
20	2545.59	2352.53	6836.99	6865.35	7651.54
30	2497.31	2376.23	7202.08	7427.35	8285.73
40	2660.95	2346.50	8749.76	8778.11	9924.25
50	2622.70	2384.57	9021.33	9126.78	10255.41
60	2637.83	2331.20	9458.45	9740.00	10979.08
70	2691.52	2309.51	10042.02	10136.65	11435.20
80	2685.53	2325.17	10283.81	10455.25	11741.23
90	2699.61	2288.26	10479.61	10651.05	11921.84
100	2802.15	2288.92	10702.11	10873.55	12260.74
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)				
0	6.26	6.26	6.26	6.26	6.26
10	8.12	7.99	15.15	15.15	16.44
20	8.49	7.84	22.79	22.88	25.51
30	8.32	7.92	24.01	24.76	27.62
40	8.87	7.82	29.17	29.26	33.08
50	8.74	7.95	30.07	30.43	34.18
60	8.79	7.77	31.53	32.47	36.60
70	8.97	7.70	33.47	33.79	38.12
80	8.98	7.75	34.28	34.85	39.14
90	9.00	7.62	34.93	35.50	39.74
100	9.34	7.63	35.67	36.25	40.87
	LENGTH OF QUEUE ON MINOR ROAD (NO. OF VEHICLES)				
0	6	6	6	6	6
10	9	9	11	11	11
20	9	9	16	16	16
30	9	9	16	16	16
40	9	9	17	17	17
50	9	9	18	18	18
60	9	9	18	18	18
70	9	9	18	18	18
80	9	9	18	18	18
90	9	9	18	18	18
100	9	9	18	18	18

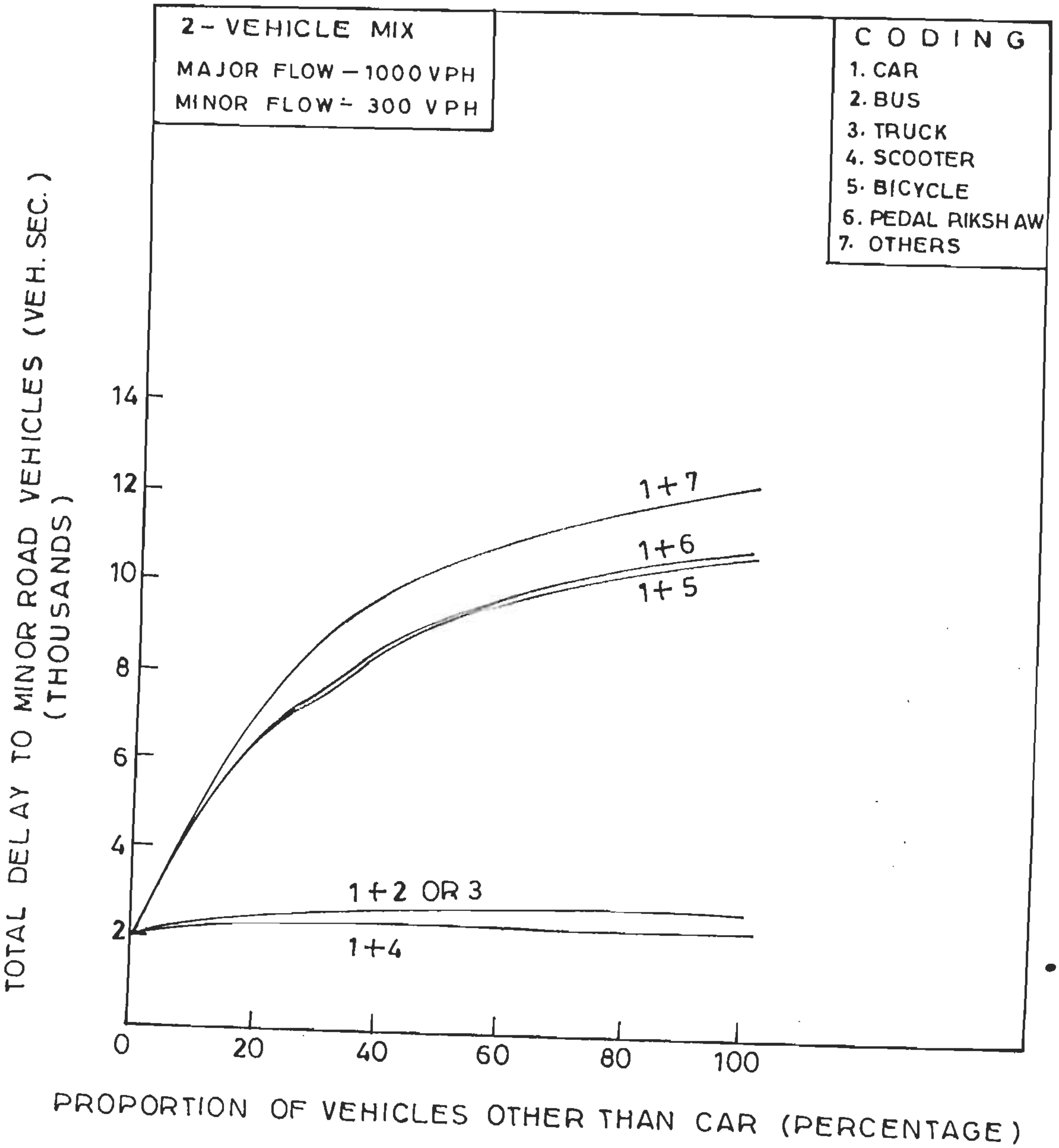


Fig. 6.14 Relationship between proportion of vehicles other than car in the traffic stream on minor road and total delay to minor road vehicles

(SIMULATED RESULTS , 3-LEG INTERSECTION)

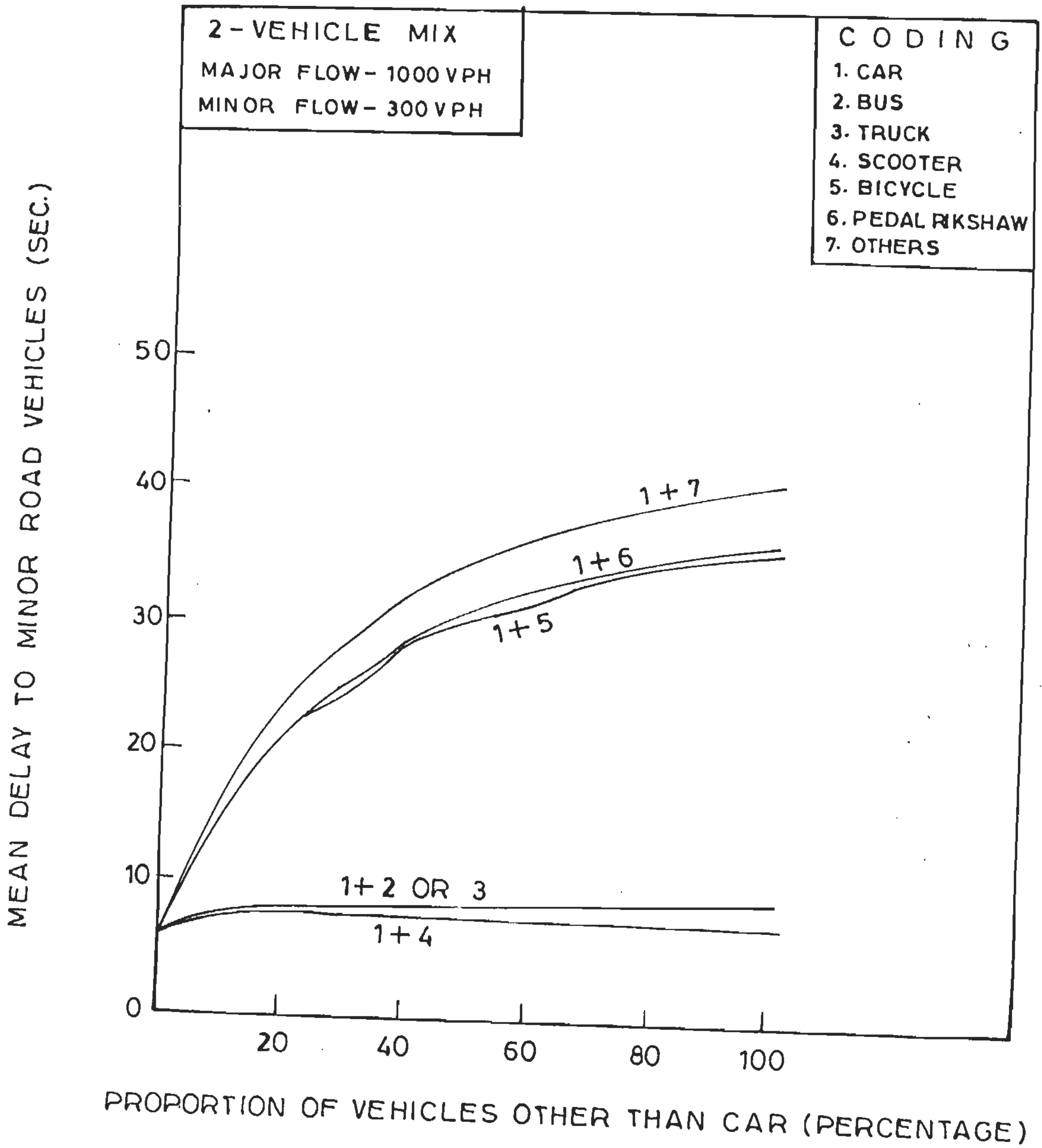


Fig. 6.15 Relationship between proportion of vehicles other than car in the traffic stream on minor road and mean delay to minor road vehicles (2-VEHICLE MIX)

(SIMULATED RESULTS , 3-LEG INTERSECTION)

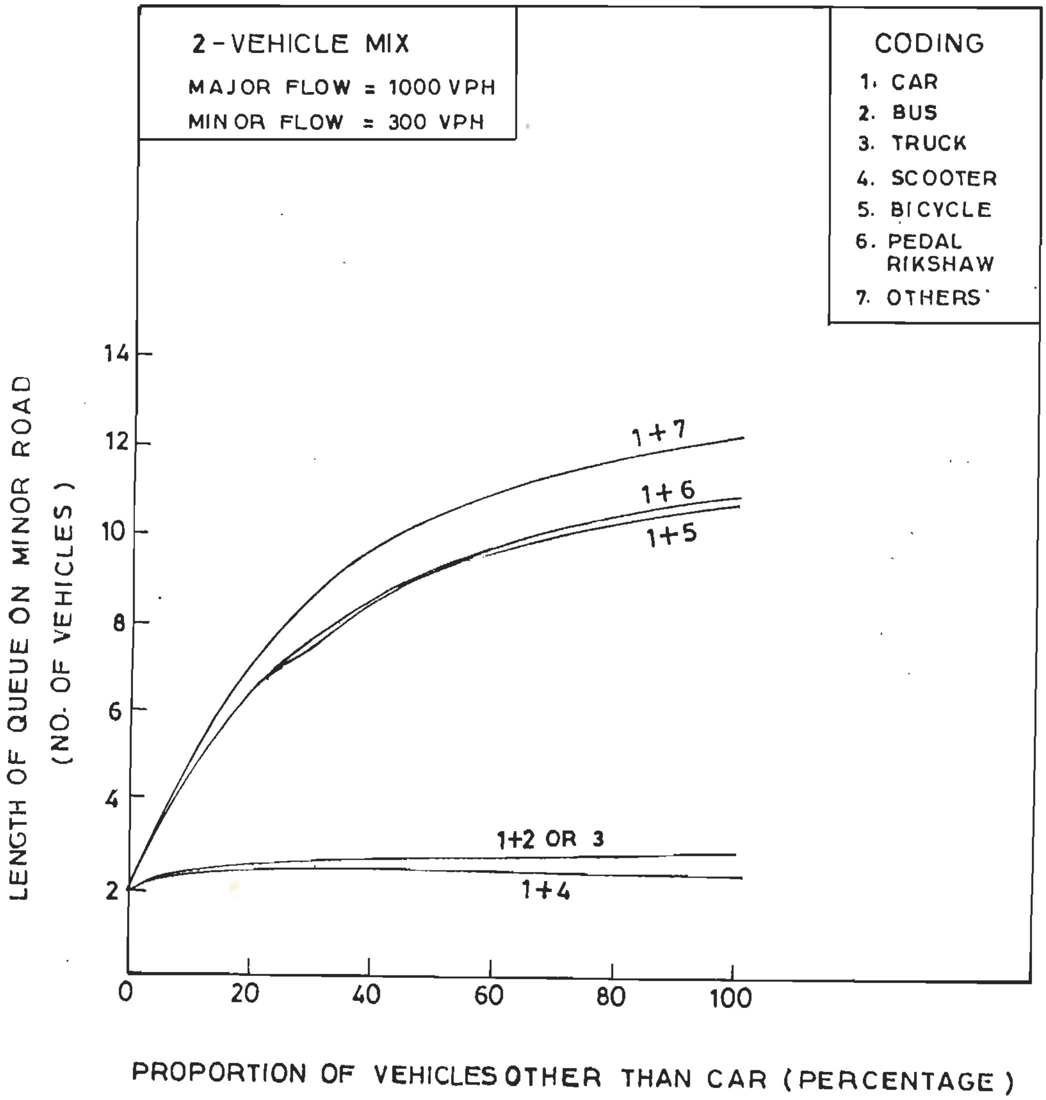


Fig.6.16 Relationship between proportion of vehicles other than car in the traffic stream on minor road and length of queue on minor road (2-VEHICLE MIX)
(SIMULATED RESULTS, 3-LEG INTERSECTION)

TABLE 6.8 – INTERACTION DUE TO MIXING OF TWO MODE VEHICLES (SIMULATED RESULTS, 4-ARM INTER SECTION)

MAJOR FLOW = 1200; MINOR FLOW = 600 (VPH)

Vehicle Other Than Car (Percent)	TOTAL DELAY ON MINOR ROAD (VEH-SEC)				
0	4217.79	4217.79	4217.79	4217.79	4217.79
10	4490.13	4269.46	5194.25	5227.33	5734.12
20	4709.21	4187.96	5661.09	5980.63	6408.15
30	5123.12	4580.16	7202.44	7213.42	11010.86
40	5237.36	4045.72	10106.66	11824.82	13265.44
50	6421.67	4683.75	10687.03	10841.26	16076.71
60	5589.41	3891.68	12726.90	14610.47	16623.81
70	6029.51	3665.06	13260.93	17651.92	23206.11
80	6251.84	3721.78	19478.92	21405.41	24458.73
90	6448.71	3592.67	18675.66	20777.42	27176.53
100	6656.02	3456.02	22159.02	25881.02	29193.02
	MEAN DELAY (SEC.)				
0	14.32	14.32	14.32	14.32	14.32
10	15.03	14.29	17.39	17.00	19.16
20	15.75	14.02	18.93	19.96	21.39
30	17.21	15.31	23.95	23.99	36.35
40	17.55	13.54	39.60	39.60	44.43
50	21.41	15.58	36.27	36.27	54.05
60	18.75	13.04	48.96	48.96	55.65
70	20.23	12.27	59.63	59.63	78.35
80	20.97	12.47	72.14	72.14	82.30
90	21.63	12.10	70.28	70.28	91.27
100	22.30	11.62	81.82	87.42	98.41
	QUEUE LENGTH (NO. OF VEHICLES)				
0	8	8	8	8	8
10	8	8	11	11	12
20	8	8	11	12	13
30	9	9	12	12	13
40	8	8	22	27	27
50	9	8	19	19	26
60	8	8	25	29	29
70	8	7	22	25	27
80	9	8	32	34	35
90	9	8	30	33	41
100	9	7	34	36	37

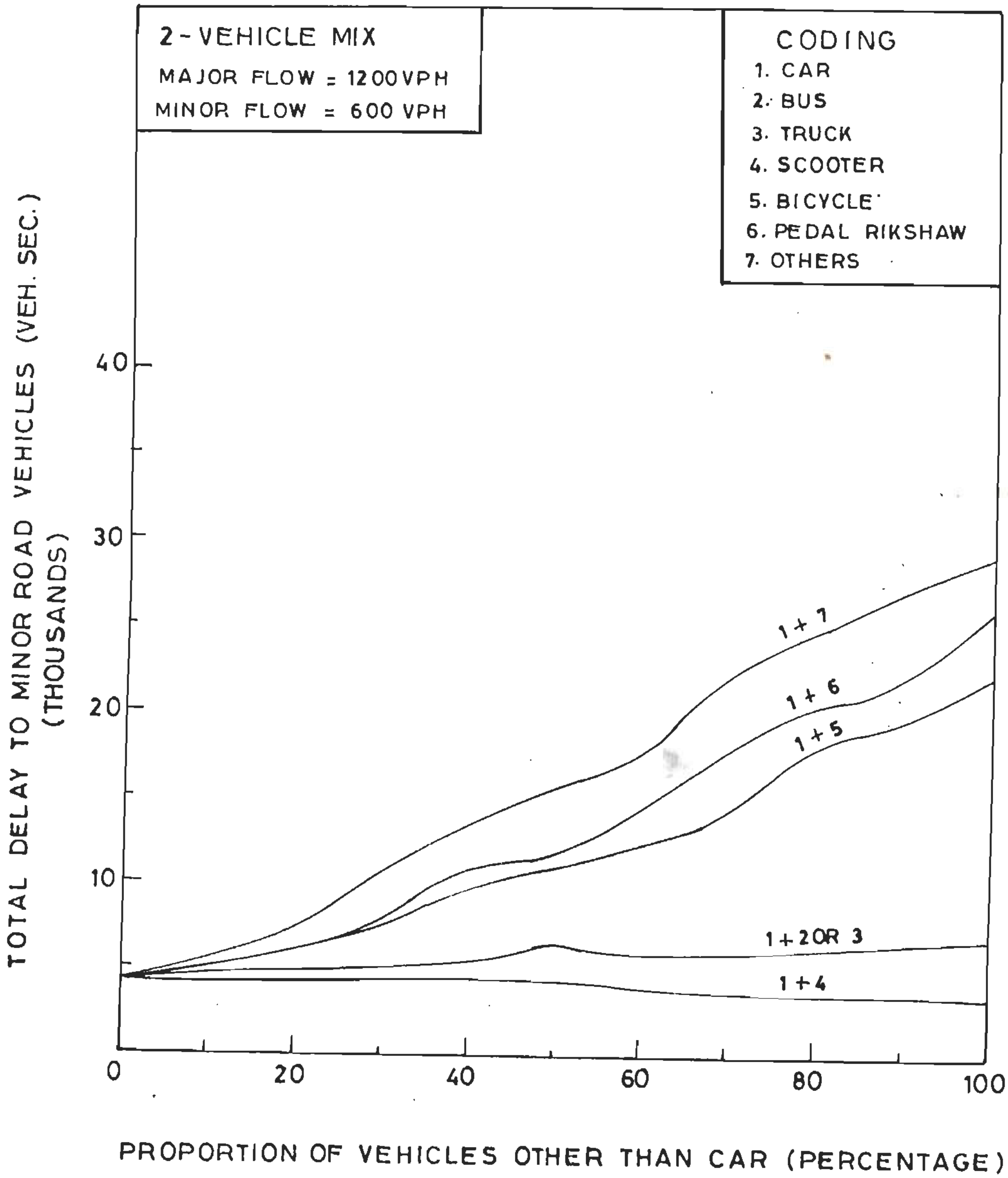


Fig.6.17 Interactions due to mixing of two vehicle types on minor road (TOTAL DELAY)
(SIMULATED RESULTS, 4-LEG INTERSECTION)

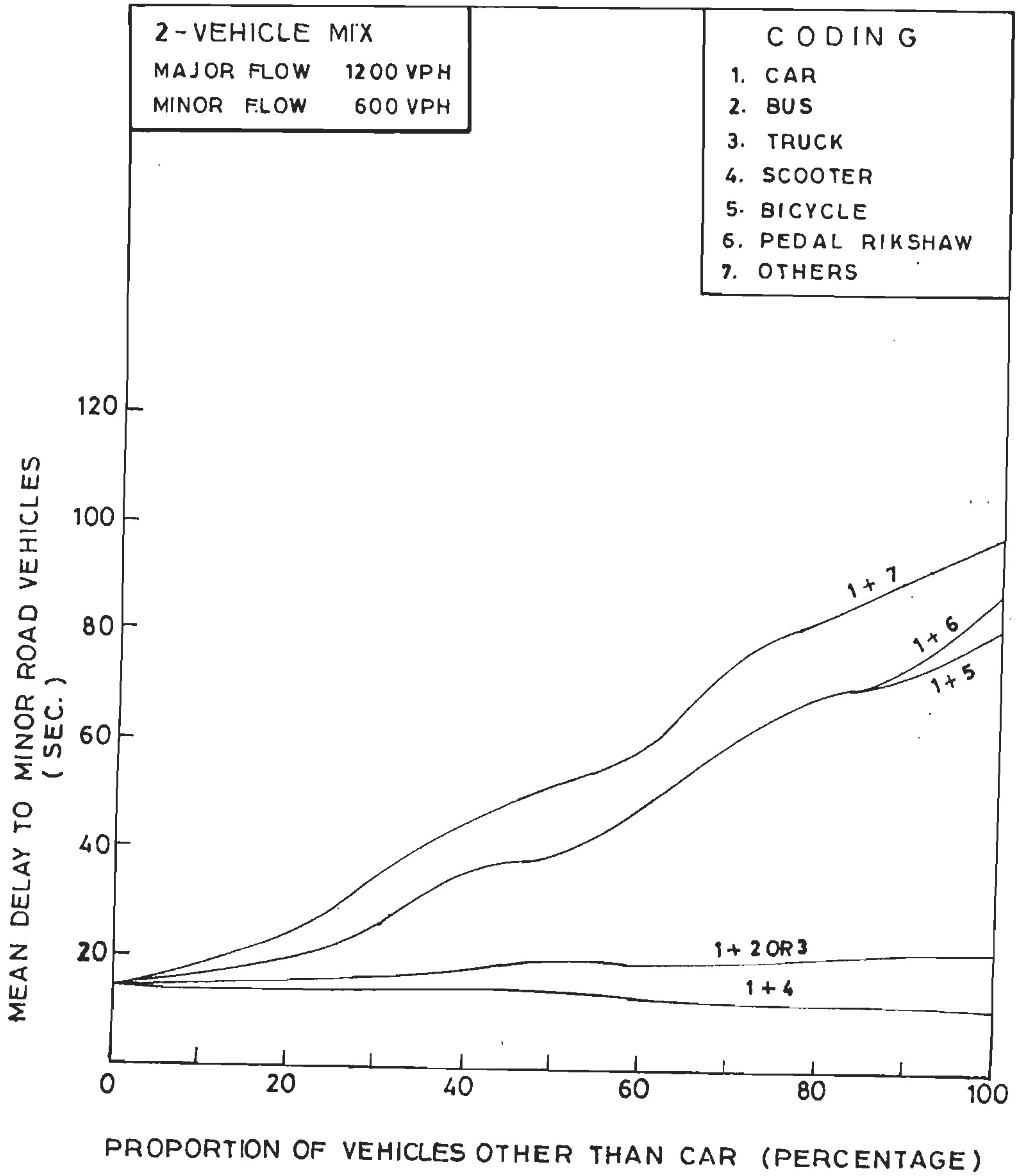


Fig.6.18 Interactions due to mixing of two vehicle types on minor road (MEAN DELAY)

(SIMULATED RESULTS, 4-LEG INTERSECTION)

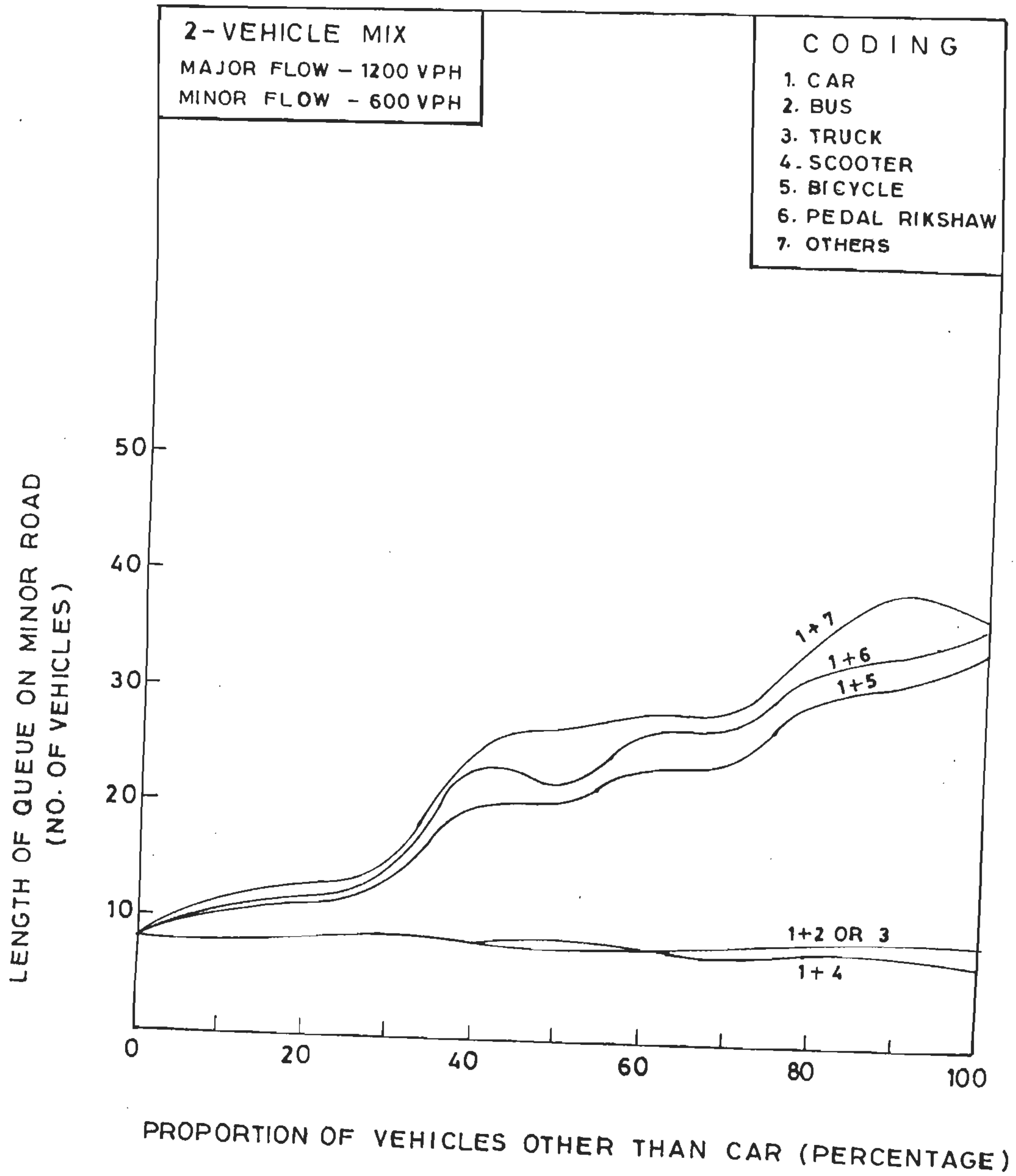


Fig. 6.19 Interactions due to mixing of two vehicle types on minor road (QUEUE LENGTH)

(SIMULATED RESULTS, 4-LEG INTERSECTION)

TABLE 6.9 – NORMAL INPUT VARIATIONS IN VEHICLE PROPORTIONS CONSIDERED FOR SIMULATION RUNS (3-Leg Intersection)

		VOLUMES			Minor = 300 (vph) Major = 1000 (vph)			
	CAR,	BUS,	SCOOTER,	BICYCLES	& PEDAL RICHSKAW			
Simu-lation run no.	% CAR	% BUS	% SCOOTER	% BICYCLE	% PED. RIKSH.	TOTAL DELAY	MEAN DELAY	QUEUE LENGTH
1	0	25.00	25.00	25.00	25.00	8759.18	29.20	14
2	10	22.50	22.50	22.50	22.50	7477.04	24.92	13
3	20	20.00	20.00	20.00	20.00	8472.27	28.24	14
4	30	17.50	17.50	17.50	17.50	7414.07	24.71	11
5	40	15.00	15.00	15.00	15.00	7773.12	25.91	14
6	50	12.50	12..50	12.50	12.50	6777.03	22.59	13
7	60	10.00	10.00	10.00	10.00	5331.08	17.77	10
8	70	7.50	7.50	7.50	7.50	4900.06	16.33	10
9	80	5.00	5.00	5.00	5.00	3678.96	12.26	8
10	90	2.50	2.50	2.50	2.50	3366.00	11.22	6
11	100	0.00	0.00	0.00	0.00	1877.32	6.26	6

Similarly for tetramode, pentamode, hexamode and septamode traffic experiments, the interactions are measured in terms of simulated delays and queue lengths between cars, buses, trucks, and scooters (4 modes), between cars, buses, trucks, scooters and bicycles (5 modes), between cars, buses, trucks, scooters, bicycles and pedal rickshaws (6 modes) and between cars, buses, trucks, scooters, bicycles, pedal rickshaws and others (7 modes) respectively. The interactive simulated results are presented through Table 6.10 and Figs. 6.20 to 6.22 for 3-leg intersections and through Table 6.11 and Figs. 6.23 to 6.25 for 4-leg inter-

TABLE 6.10 – INTERACTIONS DUE TO MIXING OF MULTI MODE VEHICLES ON MINOR ROAD (SIMULATED RESULTS, 3-Leg INTERSECTIONS).

VOLUMES MINOR = 300 & MAJOR = 1000 (vph)

Vehicles Other than Cars (Percent)	TOTAL DELAY TO MINOR ROAD VEHICLES (VEH-SEC)					
0	2622.65	2622.65	2622.65	2622.65	2622.65	2622.65
10	2435.85	2663.19	2641.73	4401.70	3366.00	5170.00
20	2545.59	2641.14	2620.67	2976.38	3678.90	5684.22
30	2497.31	2638.37	2714.12	4970.60	4900.06	6314.70
40	2660.95	2768.32	2670.72	4951.88	5331.08	7181.09
50	2622.70	2981.99	2847.74	6298.70	6777.03	7312.41
60	2637.83	2752.65	2744.57	6979.19	7773.12	7346.64
70	2691.52	2949.25	2810.84	6902.82	7414.07	9433.30
80	2685.53	2893.92	2695.86	7388.55	8472.27	9656.18
90	2699.61	2986.25	2820.41	5954.04	7477.04	8795.14
100	2802.15	3097.09	2852.90	7026.51	8759.18	10063.94
	MEAN DELAY TO MINOR ROAD VEHICLES (SEC.)					
0	8.74	8.74	8.74	8.74	8.74	8.74
10	8.12	8.88	8.81	14.67	11.22	17.23
20	8.49	8.80	8.74	9.92	12.26	18.95
30	8.32	8.79	9.05	16.57	16.33	21.05
40	8.87	9.23	8.90	16.51	17.77	23.94
50	8.74	9.94	9.49	21.00	22.59	24.37
60	8.79	9.18	9.15	23.26	25.91	24.49
70	8.97	9.83	9.37	23.01	24.71	31.44
80	8.98	9.65	8.99	24.63	28.24	32.19
90	9.00	9.95	9.40	19.85	24.92	29.32
100	9.34	10.32	9.51	23.42	29.20	33.55
	LENGTH OF QUEUE ON MINOR ROAD (NO. OF VEHICLES)					
0	6	6	6	6	6	6
10	9	6	6	13	6	13
20	9	6	6	7	8	13
30	9	6	6	10	10	13
40	9	6	6	10	10	13
50	9	7	7	10	13	14
60	9	6	6	14	14	13
70	9	7	7	13	11	15
80	9	6	6	14	14	15
90	9	7	7	13	13	14
100	9	7	7	13	14	14

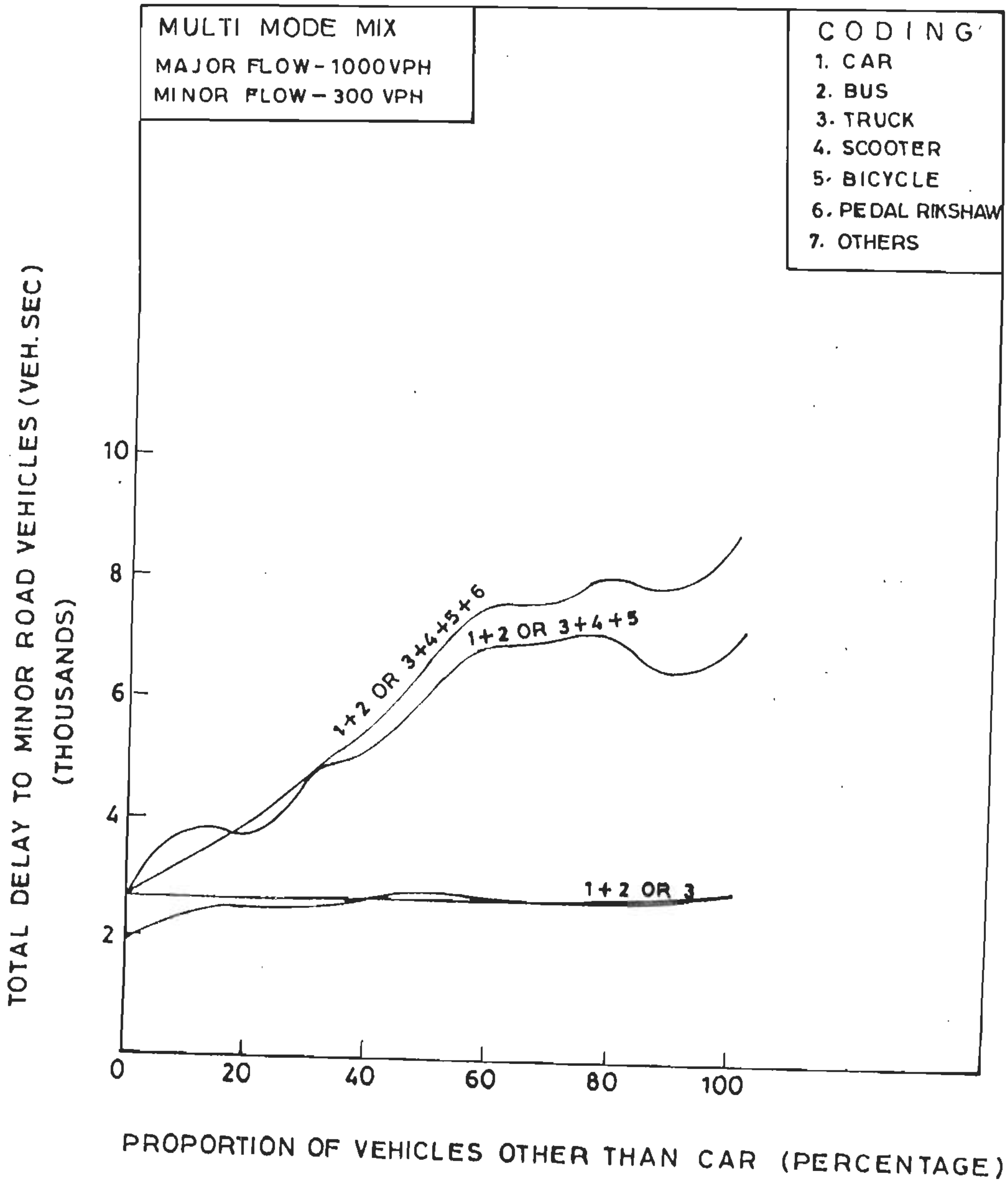


Fig.6.20 Relationship between proportion of vehicles other than car in the traffic stream on minor road and total delay to minor road vehicles (MULTI MODE MIX)
(SIMULATED RESULTS, 3-LEG INTERSECTION)

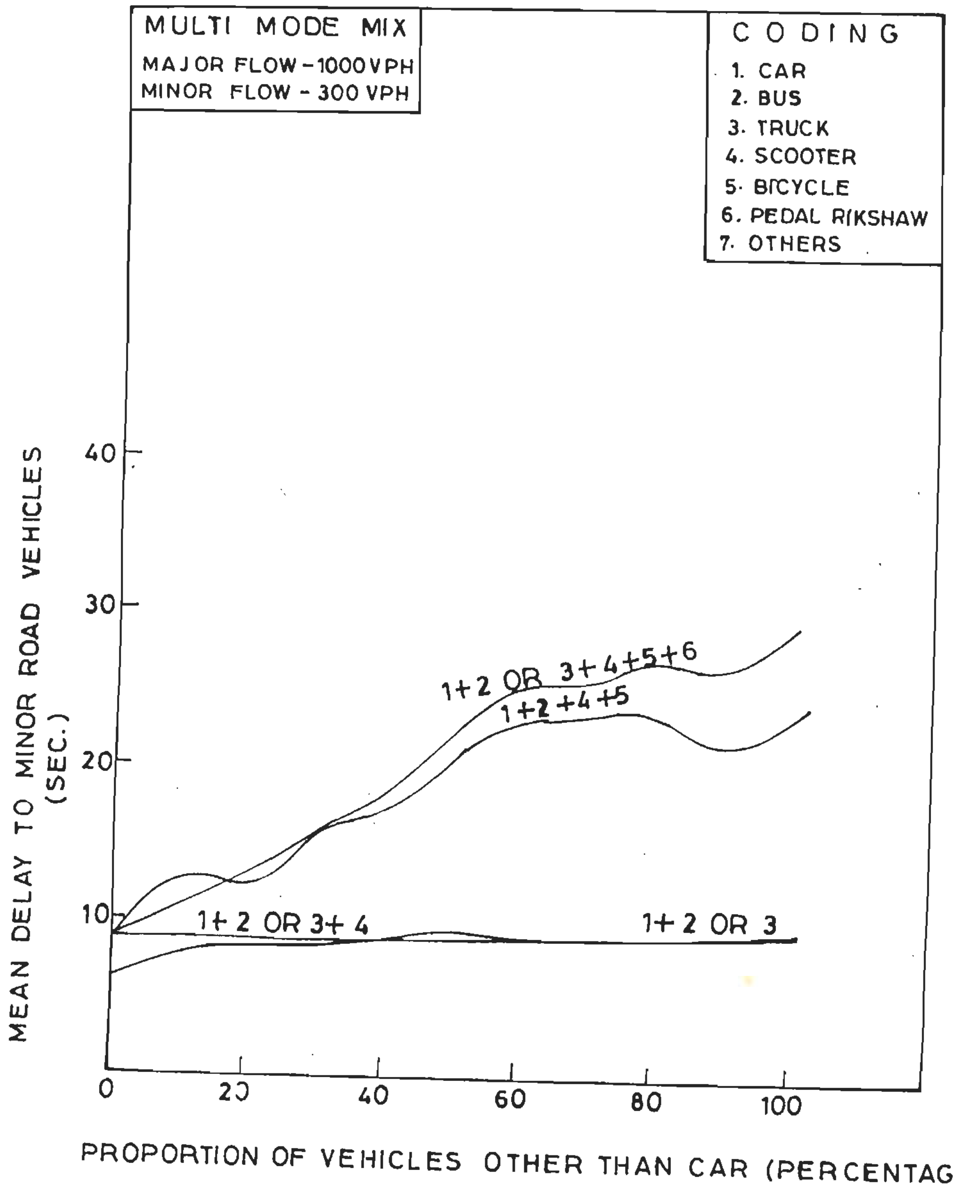


Fig. 6.21 Relationship between proportion of vehicles other than car in the the traffic stream on minor road and mean delay to minor road vehicles (MULTI MODE MIX)

(SIMULATED RESULTS, 3-LEG INTERSECTION)

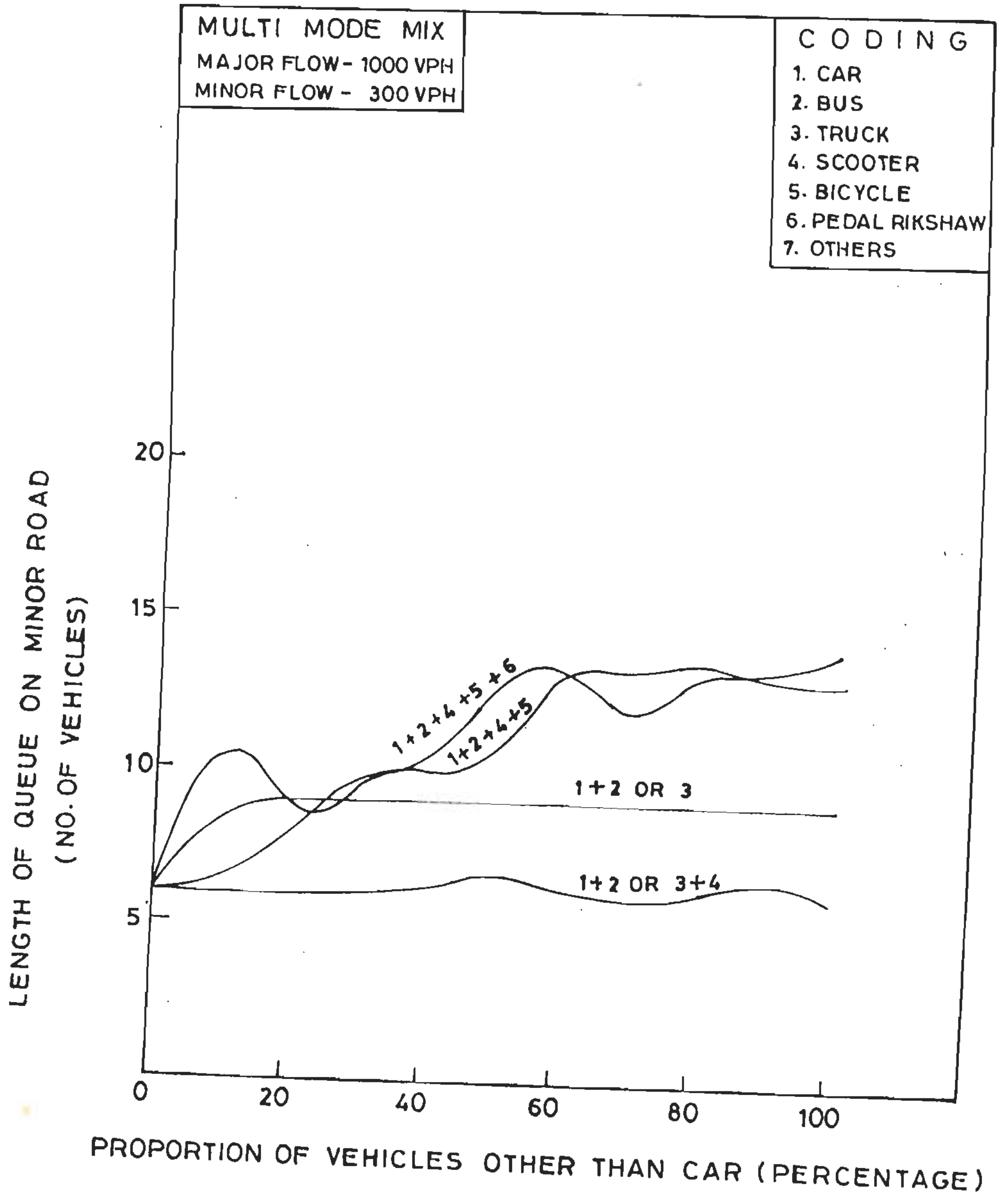


Fig. 6.22 Relationship between proportion of vehicles other than car in the traffic stream on minor road and queue length formed on minor road (MULTI MODE MIX)
(SIMULATED RESULTS, 3-LEG INTERSECTION)

TABLE 6.11 – INTERACTIONS DUE TO MIXING OF MULTI MODE VEHICLES ON MINOR ROAD (SIMULATED RESULTS, 4-Leg INTERSECTION)

VOLUMES : MINOR = 600 & MAJOR = 1200 (VPH)

Vehicle Other than Car (Percent)	TOTAL DELAY ON MINOR ROAD (VEH-SEC.)					
0	4217.84	4217.84	4217.84	4217.84	4217.84	4217.84
10	4490.53	4435.77	4454.68	4751.47	4691.58	5286.97
20	4709.12	4624.26	5129.23	4548.14	4836.51	5207.78
30	5123.23	5167.39	5032.36	7020.11	5591.78	5571.01
40	5237.71	5336.28	5029.93	6242.52	6694.76	9778.77
50	6421.88	6558.15	5784.44	6702.43	9375.69	10043.17
60	5589.67	5763.89	5100.23	7929.81	8047.07	9817.32
70	6029.38	6267.13	5603.82	7122.95	8030.46	10272.75
80	6251.69	6451.57	5364.96	9022.63	8539.29	10035.59
90	6448.97	6962.73	5696.04	7309.31	8025.44	12528.25
100	6656.85	7732.74	5627.69	8604.43	9872.39	11525.02

	MEAN DELAY ON MINOR ROAD (SEC.)					
0	14.12	14.12	14.12	14.12	14.12	14.12
10	15.03	14.83	14.89	15.81	17.18	17.72
20	15.75	15.47	17.16	15.22	16.16	17.42
30	17.12	17.31	16.81	23.28	18.82	18.58
40	17.55	17.85	16.85	20.78	22.52	32.48
50	21.41	21.85	19.28	22.35	31.31	33.59
60	18.75	19.33	17.07	26.31	26.91	32.58
70	20.23	21.03	18.79	23.83	26.71	34.19
80	18.36	21.61	17.97	29.87	28.49	33.55
90	21.63	23.37	19.08	24.52	26.91	49.94
100	22.31	25.84	18.85	28.89	32.69	38.43

	QUEUE LENGTH (NO. OF VEHICLES)					
0	8	8	8	8	8	8
10	8	8	8	9	8	10
20	8	8	9	9	9	9
30	9	9	9	8	10	10
40	8	8	9	11	16	16
50	9	10	9	10	18	18
60	8	7	8	15	16	14
70	8	8	8	7	11	12
80	9	8	8	17	16	17
90	9	10	8	16	15	29
100	9	9	8	12	18	21

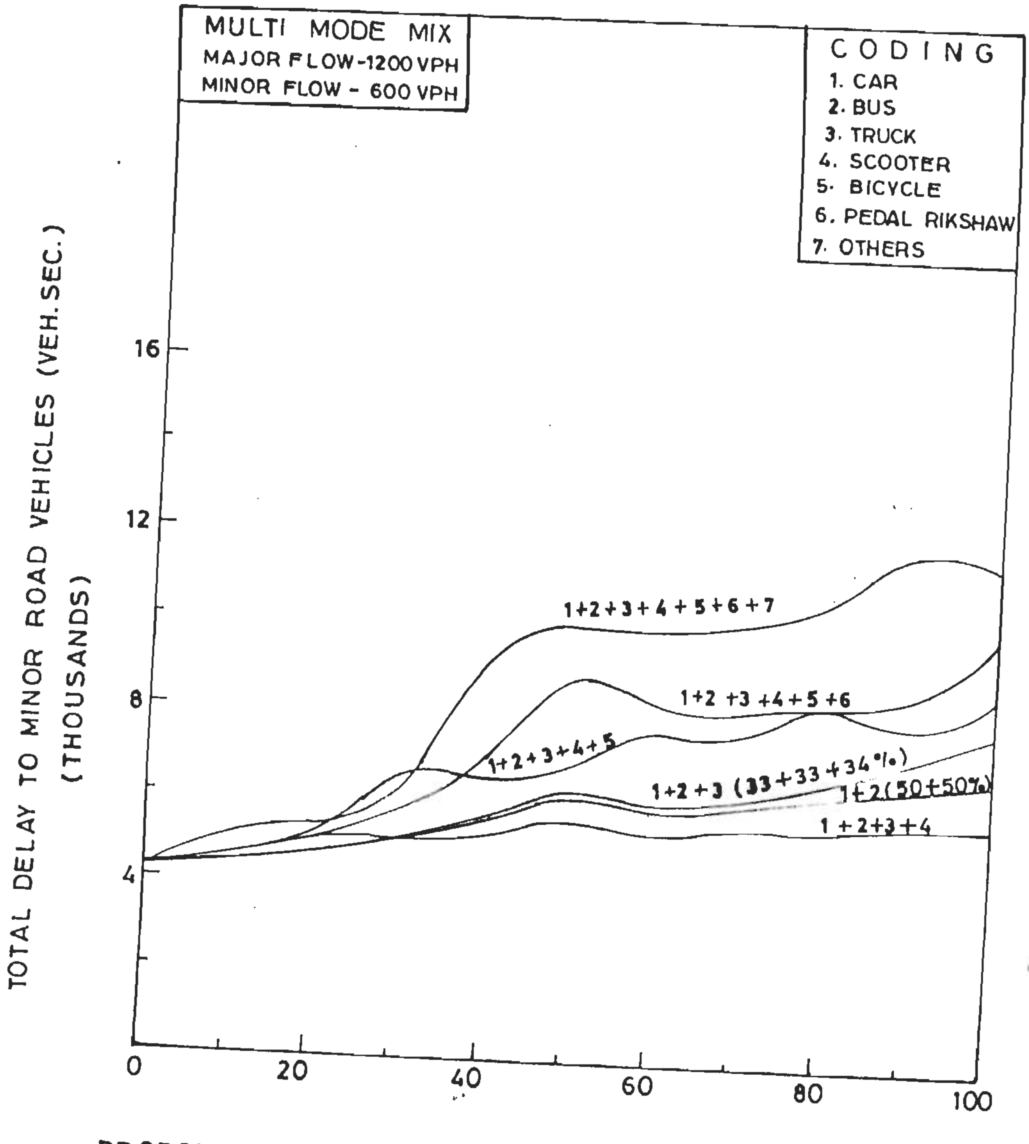


Fig. 6.23 Interactions due to mixing of multi mode vehicles on minor road (TOTAL DELAY)

(SIMULATED RESULTS, 4-LEG INTERSECTION)

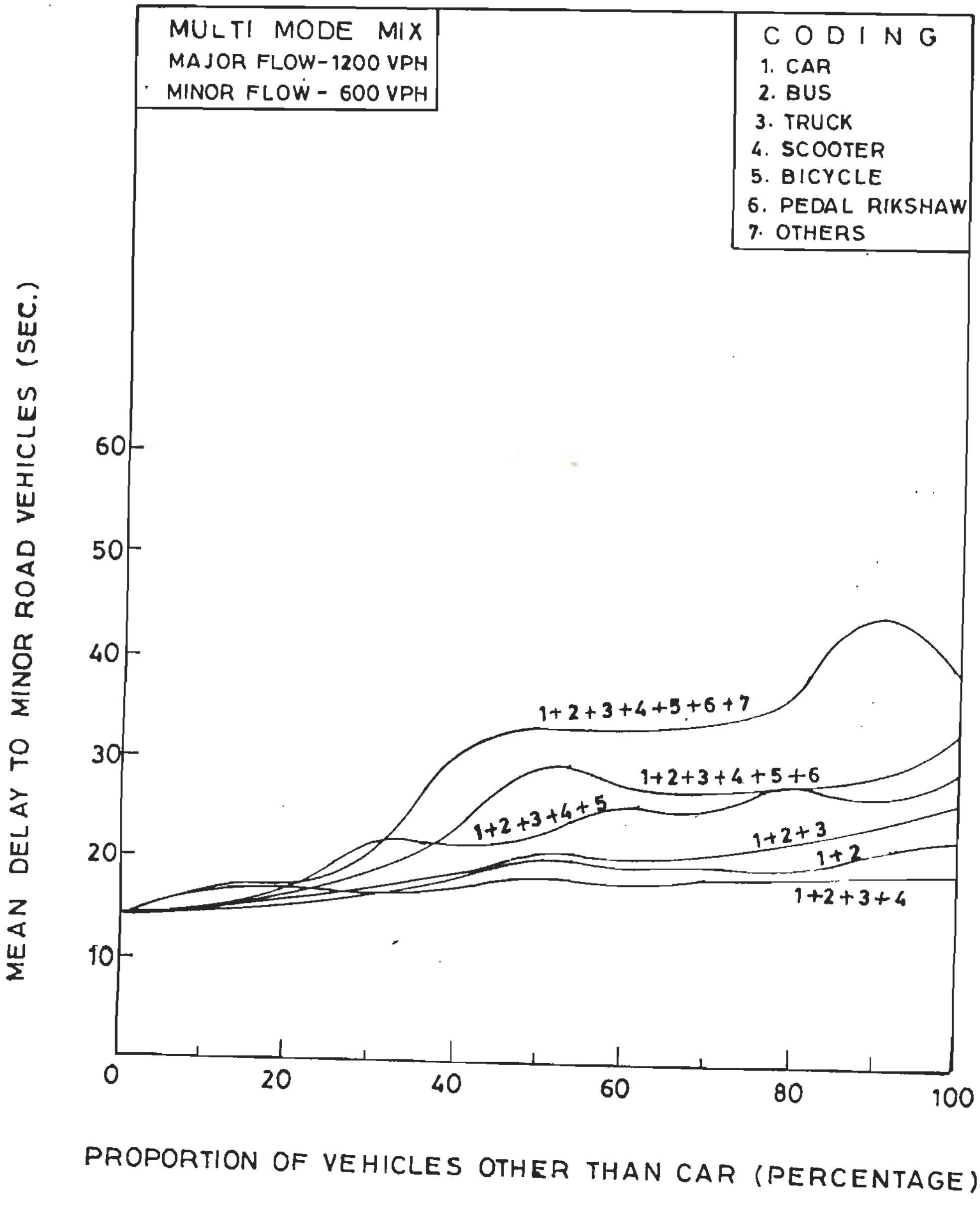


Fig. 6.24 Interactions due to mixing of multi mode vehicles on minor road (MEAN DELAY)

(SIMULATED RESULTS, 4-LEG INTERSECTION)

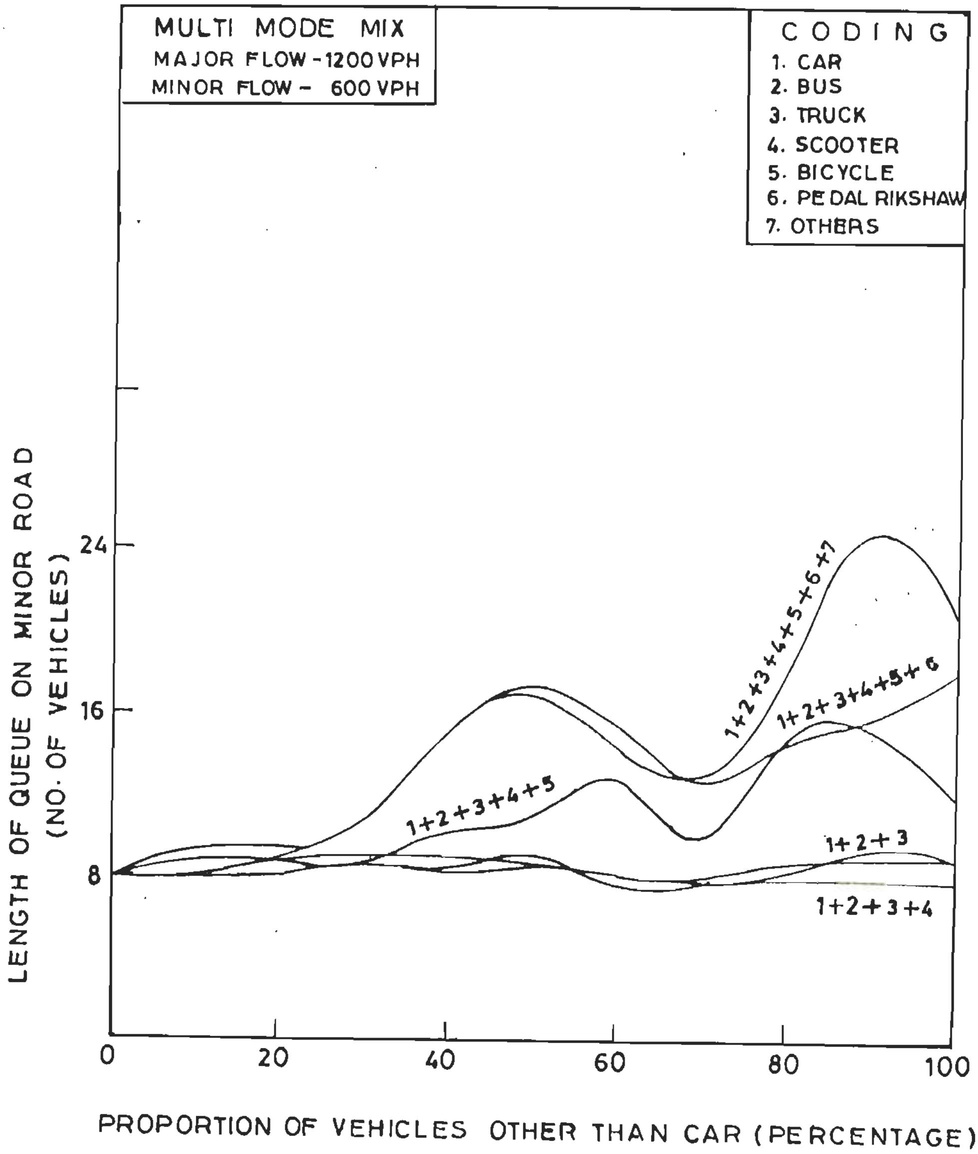


Fig . 6.25 Interactions due to mixing of multi mode vehicles on minor road (QUEUE LENGTH)

(SIMULATED RESULTS , 4-LEG INTERSECTION)

sections respectively. It is clear from the above figures that up to three vehicle mix (cars, buses and scooters), where all the three modes are motorised vehicles, there is a marginal increase in delays. It ccan be noticed that the delays show increased trend with every additional vehicle mode in approach traffic. Although the amount of this increased interactions (delays) is marginal when the approach traffic is composed of all motorised vehicles. But with addition of every slow moving vehicle mode, the interactions increase to a large extent. The basic reason beyond this may be fundamental differences in physical and operating characteristics of motorised and non-motorised vehicles.

6.4.3 Turning and Crossing Experiments with SIMMTRA-345

After completing the two series of runs, viz., series for traffic volume ranges and series for vehicle mode mixing, a further series of runs are made to evaluate the effect of turning movements. The approach volumes are held constant at various volume levels for both the major and minor roads while the percentage of turning or crossing traffic are varied.

As already stated in article 5.8.2.2, the left turn from all the approaches is permitted without delay as it does not come into the conflict with any other movement as can be seen from Table 6.12 and Fig. 6.26 & 6.27. The permitted left turn has been incorporated in the model SIMMTRA-345 considering the current Indian traffic regulation rules in practice.

There are no turn restrictions, that is all turns are permitted from all approaches. But there is a provision to introduce the turn res-

TABLE 6.12 - RELATIONSHIP BETWEEN NON-CONFLICTING TRAFFIC FROM MINOR ROAD AND TOTAL DELAY AND QUEUE LENGTH ON MINOR ROAD (SIMULATED RESULTS, 3-Leg INTERSECTION)

Left Going %				TOTAL DELAY (VEH.SEC.)				
0	892.92	4458.90	9572.40	15506.28	20472.48	44133.44	97899.08	132898.70
10	842.79	3882.96	8966.49	13552.96	18419.99	33870.12	75716.48	111116.50
20	693.26	3456.17	8324.74	11868.15	16267.24	30238.21	62620.34	87169.09
30	637.61	2856.68	7247.97	11368.13	13419.91	27575.98	59373.70	83485.67
40	545.32	2648.90	6209.00	9424.08	11398.63	25160.49	56758.08	77516.09
50	440.14	2042.78	5313.32	6925.02	9552.01	21876.24	54371.70	72820.70
60	396.56	1604.16	4654.92	5992.85	6182.43	15172.18	37349.02	57261.71
70	356.58	1393.17	4378.43	4712.10	5055.33	14534.20	19078.75	25136.86
80	283.60	708.61	3806.60	3917.41	4353.19	12290.09	15279.89	18240.23
90	238.61	630.34	3107.59	3197.72	3034.46	10668.16	11098.88	16888.85
100	0	0	0	0	0	0	0	0
				QUEUE LENGTH (NO. OF VEHICLES)				
0	136	8	18	19	24	49	118	136
10	37	8	18	19	24	26	34	37
20	37	8	18	19	19	26	34	37
30	37	8	18	19	19	26	33	37
40	37	8	18	19	19	25	26	37
50	11	3	3	8	6	13	13	11
60	3	3	5	3	3	5	3	3
70	3	2	5	3	3	3	3	3
80	3	2	5	3	3	3	3	3
90	3	2	5	3	3	3	3	3
100	0	0	0	0	0	0	0	0

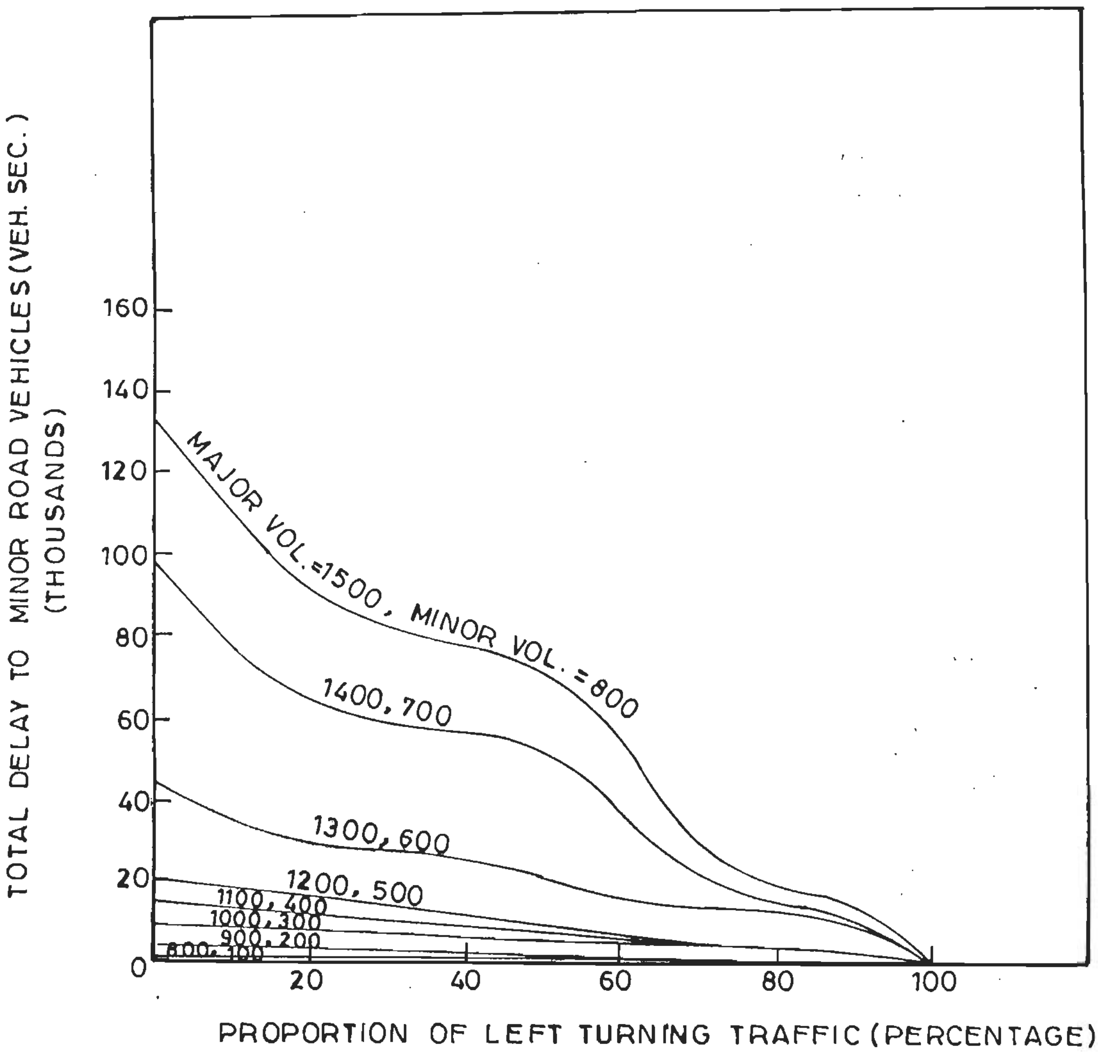


Fig. 6.26 Relationship between left turning traffic from minor road and total delay to minor road vehicles

(SIMULATED RESULTS, 3-LEG INTERSECTION)

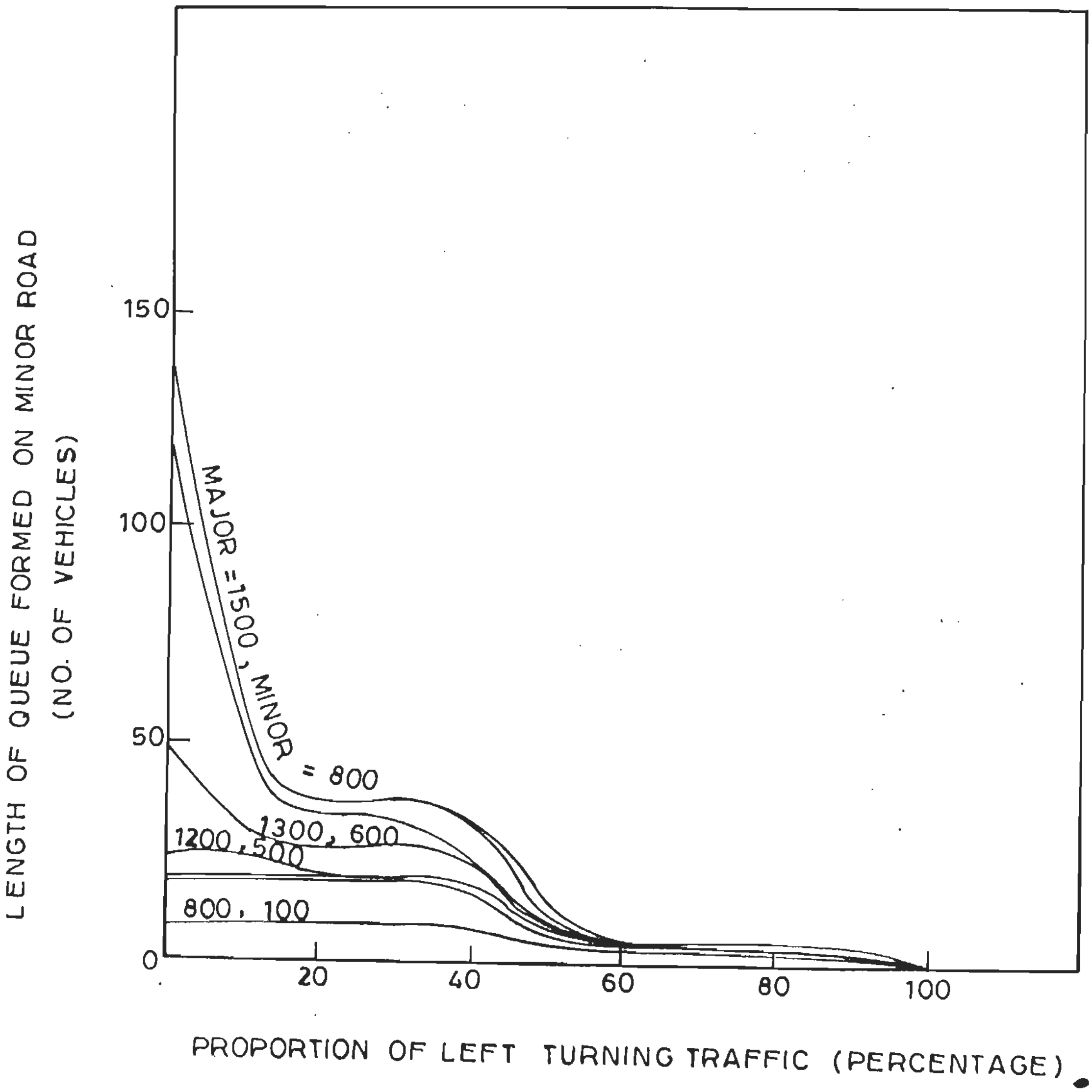


Fig. 6.27 Relationship between left turning traffic from minor road and queue length formed on minor road

(SIMULATED RESULTS, 3-LEG INTERSECTION)

trictions in the model if needed.

In order to observe the effects of turning traffic , the model was operated for over 100 times. The simulated results of this series of runs are presented in Table 6.13 and through Figs. 6.28 to 6.30. It is evident from the figures that the delays increase with increased proportion of right turning traffic. Although this increase is marginal upto minor flow of 500 vph and major flow 1200 vph. But delays increase considerably with increased conflict traffic for the minor and major volume levels exceeding jointly 500 vph and 1200 vph respectively.

Further effect of conflict traffic is evaluated by keeping the proportion of conflict traffic constant at various percentage of conflict traffic for both major and minor roads while the combination of approach volumes for minor and major roads is varied. The simulated results of this series of runs are presented graphically in Fig. 6.31. It can be deduced that the delays are within tolerable limits up to 50 percentage conflict traffic for the combination of major/minor volumes from 800 (major)/100(minor)to 1500(major)/800(minor)vph.But the delays rise very sharply once the conflict traffic crosses 50 percentage mark for the above major/minor volume combinations.

6.5 DEVELOPMENT OF EQUIVALENT PASSENGER CAR VALUES (EPCV) FOR PRIORITY TYPE SEMI-URBAN INTERSECTIONS

6.5.1 Introduction

The capacity of a any road intersection is determined by the capacities of the individual critical approaches to the intersection. In turn the capacity of an approach is affected by two types of factors viz.,

TABLE 6.13 – RELATIONSHIPS BETWEEN CONFLICTING TRAFFIC ON MINOR ROAD AND TOTAL DELAY, MEAN DELAY AND QUEUE LENGTH ON MINOR ROAD (Simulated Results, 3-Leg Intersection)

Major Flow (vph)	800	900	1000	1100	1200	1300	1400	1500
Minor Flow (vph)	100	200	300	400	500	600	700	800
Right Going Traffic (Percent)	TOTAL DELAY ON MINOR ROAD (VEH.SEC.)							
0	0	0	0	0	0	0	0	0
10	238.61	630.34	3107.59	3197.72	3034.46	10668.16	11098.88	16888.85
20	283.60	708.61	3865.60	3917.41	4353.19	12290.09	15279.69	18240.23
30	356.58	1393.17	4375.43	4712.10	5055.33	14534.20	19078.75	25136.86
40	396.56	1604.16	4654.92	5992.85	6182.43	15172.18	37349.02	57261.71
50	440.14	2042.78	5313.32	6925.02	9552.01	21876.24	54371.70	72820.70
60	545.32	2648.90	6209.00	9424.08	11398.63	25160.49	56758.08	77516.09
70	637.61	2856.68	7247.97	11368.13	13419.91	27575.98	59373.70	83485.67
80	693.26	3456.17	8324.74	11868.15	16267.24	30238.21	62620.34	87169.09
90	842.79	3882.96	8965.49	13552.96	18419.99	33870.12	75716.48	111116.5
100	892.92	4458.90	9572.40	15505.28	20472.48	44133.44	97899.08	132898.7
	MEAN DELAY (SEC.)							
0	0	0	0	0	0	0	0	0
10	2.39	3.15	10.36	7.99	6.07	17.78	15.86	21.11
20	2.84	3.54	12.69	9.79	8.71	20.48	21.83	22.80
30	3.57	6.97	14.59	11.78	10.11	24.22	27.26	31.42
40	3.97	8.02	15.52	14.98	12.36	25.29	53.36	71.58
50	4.40	10.21	17.71	17.31	19.10	36.46	77.67	91.03
60	5.45	13.24	20.70	23.56	22.80	41.93	81.08	96.90
70	6.38	14.28	24.16	28.42	26.84	45.96	84.84	104.36
80	6.93	17.28	27.75	29.67	32.53	50.40	89.46	108.96
90	8.43	19.41	29.89	33.88	36.84	56.45	108.17	138.90
100	8.93	22.29	31.91	38.77	40.94	73.56	139.86	6166.12
	QUEUE LENGTH (NO. OF VEHICLES)							
0	0	0	0	0	0	0	0	0
10	3	2	5	3	3	3	3	3
20	3	2	5	3	3	3	3	3
30	3	2	5	3	3	3	3	3
40	3	3	5	3	3	5	3	3
50	11	3	3	8	6	13	13	11
60	37	8	18	19	19	25	26	37
70	37	8	18	19	19	26	33	37
80	37	[illegible]	18	19	19	26	34	37
90	37	8	18	19	24	26	34	37
100	136	8	18	19	24	49	118	136

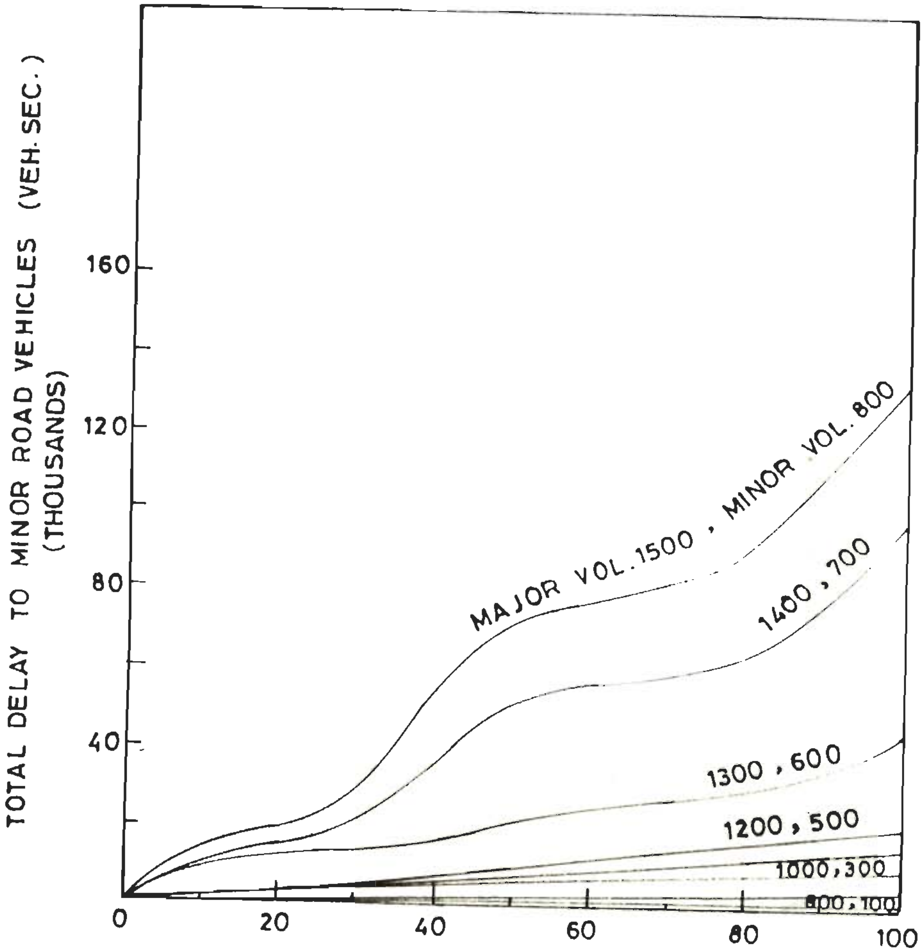


Fig. 6.28 Relationship between right turning traffic from minor road and total delay to minor road vehicles

(SIMULATED RESULTS, 3-LEG INTERSECTION)

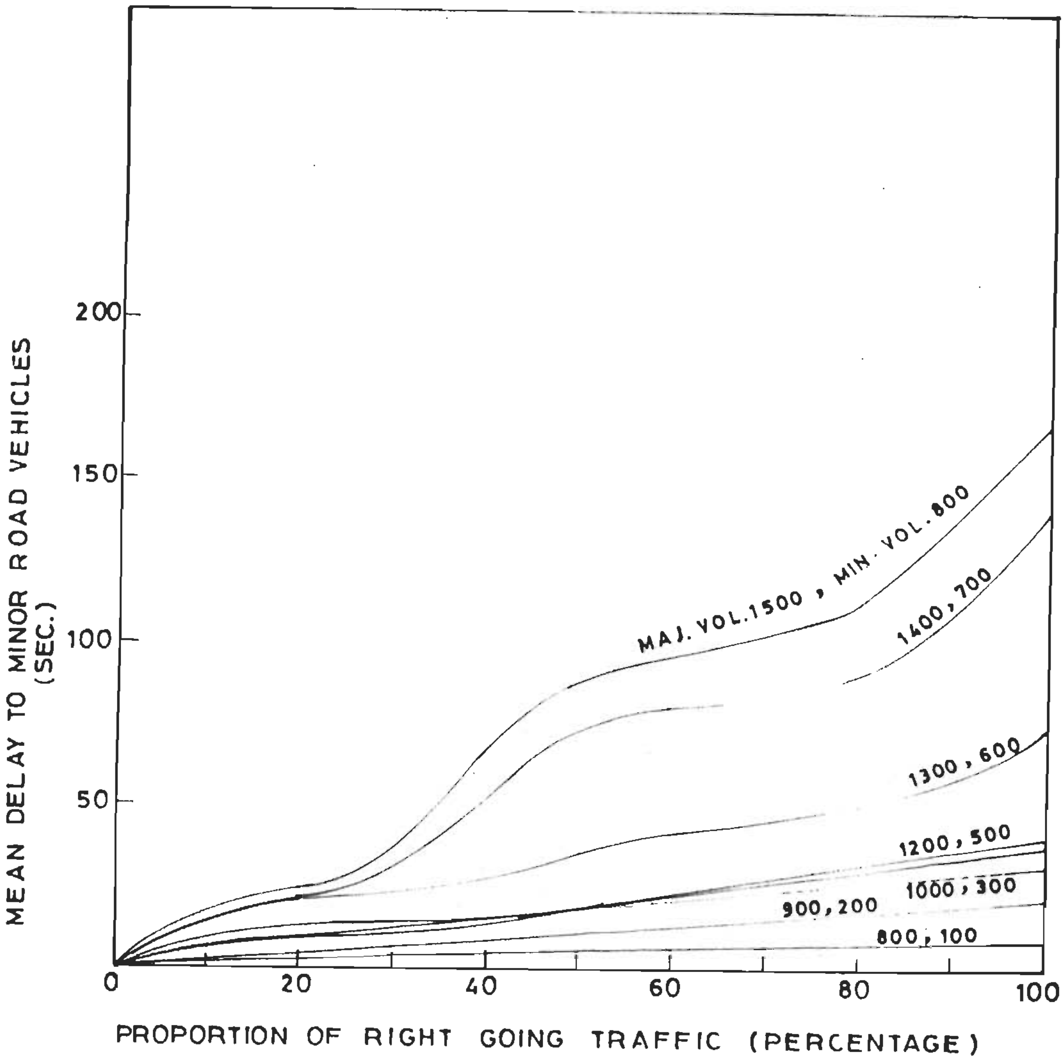


Fig. 6.29 Relationship between right turning traffic from minor road to **mean** delay to minor road vehicles

(SIMULATED RESULTS , 3-LEG INTERSECTION)

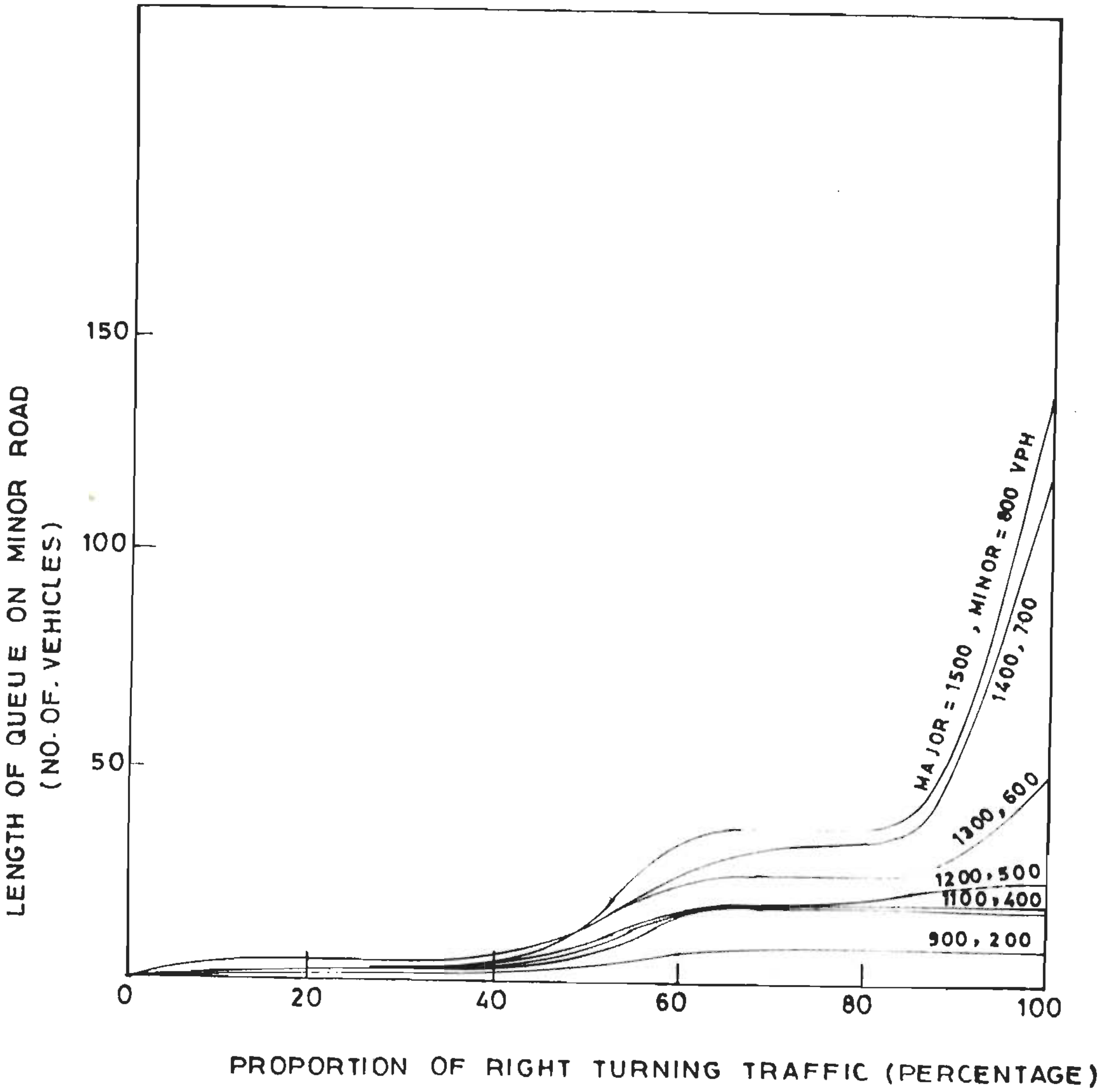


Fig.6.30 Relationship between right going traffic from minor road and queue length formed on minor road

(SIMULATED RESULTS, 3-LEG INTERSECTION)

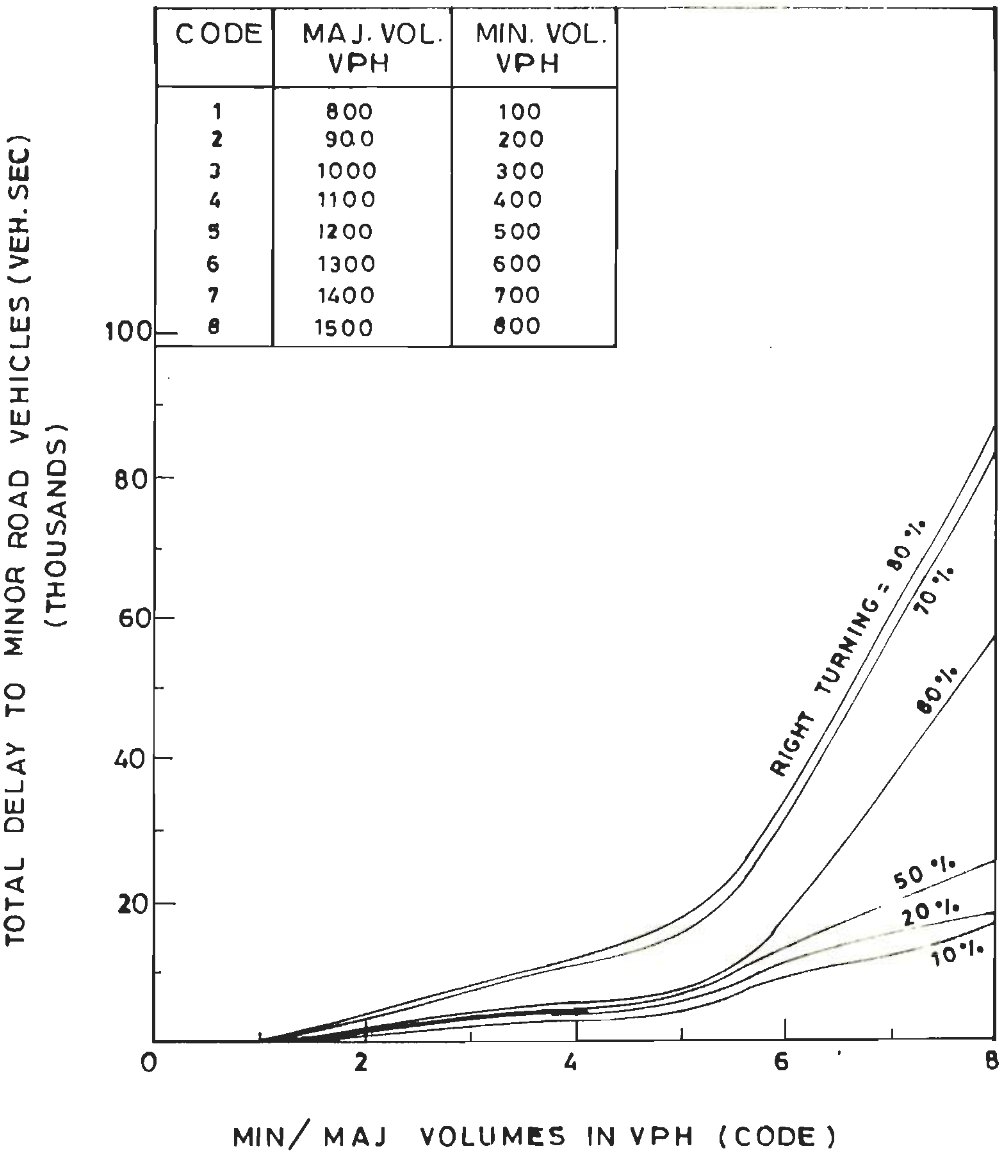


Fig.6.31 Relationship between volumes on major & minor roads and total delay to minor road vehicles

(SIMULATED RESULTS, 3-LEG INTERSECTION)

roadway and environmental factors, and traffic and control factors (180). Roadway and environmental factors include the physical layout of an intersection, lane widths, lane type, gradients etc. Traffic and control factors include the approaching volumes and composition of the traffic flow and the type of movements being carried out.

In computing the capacity of any intersection, the effect of traffic factors on the capacity of the intersection is allowed for by the use of standard equivalent passenger cars which represent the effect of the various vehicles and movement types relative to a car. The capacity of the roadway is available only in terms of passenger car units till to date. It provides common base for comparison purposes. More desired so in the case of mixed traffic where in different types of modes are involved. Under the circumstances, the only logical approach from the point of view of practical applicability is the prediction of heterogeneous or mixed traffic flow in terms of equivalent passenger car traffic flow.

Several attempts have been to compute EPCU for road sections (181, 182, 183, 184, 185, 186, 187), considering different vehicular and traffic parameters. Ramanayya (188) used simulation technique to develop equivalent design vehicle units (EDVU) for the road section under mixed traffic conditions. Marwah (149) developed interaction factors through simulation technique for the straight stretch of road for mixed traffic flow. Gupta (104), in his dissertation work has developed equivalent passenger car values (EPCV) on the basis of traffic composition, operating speeds and flow levels for heterogeneous traffic flow. Indian roads congress (189) has recommended the equivalency factors for use in rotary design for Indian traffic situation. Reddy (150) and Katti (109) have attempted to develop the PCU values for signalised and priority type intersections respectively. But all the above equivalency factors are not applicable for the intersections under the study.

6.5.2 Initial Equivalent Passenger Car Values (EPCV)

The initial EPCV were computed for the intersection on the basis of the area of a vehicle and the average time it takes to cross an intersection.

$$EPCV = \frac{A_v}{A_c} \times \frac{t_v}{t_c} \qquad (6.1)$$

where,

A_v = area of vehicle in sq.m

A_c = area of car in sq.m

t_v = average crossing time (straight) for a vehicle

t_c = average crossing time (straight) for a car

In the above relationship, as the average crossing time of a vehicle has been considered, it automatically accounts for the various vehicular characteristics except an area of a vehicle which has been considered separately as is evident from equation 6.1. The initial EPCV, thus determined, are presented in Table 6.14. So far the geometric factors of an interaction, affecting EPCV, are concern, this effect is supposed to be the common for all type of vehicles. Hence no geometric factors of an intersection have been considered for computing EPCV.

In the above relationship (Eqn. 6.1) no traffic factors such as, composition of traffic and proportion of conflicting traffic, have been taken into account which would affect the EPCV to a great extent. Therefore

TABLE 6.14 – DETERMINATION OF INITIAL EQUIVALENT PASSENGER CAR VALUES (EPCV)

Sl.No.	Vehicle type	Area (sqm)	Average crossing time (straight) (sec)	Initial EPCV
1.	Car	6.88	4.00	1.00
2.	Bus	22.2	4.40	3.55
3.	Truck	22.2	6.10	4.89
4.	Scooter/ Motorcycle	1.37	4.40	0.22
5.	Bicycle	0.92	7.70	0.27
6.	Pedal rickshaw	2.44	9.10	0.80
7.	Others	*	24.00	6.0 (202, 208)

* Area of other vehicles vary to a great extent.

an attempt has been made, in the following articles, to develop the composition factors and conflict factors for investigating final equivalent passenger car values exclusively for priority intersections.

6.5.3 Development of Composition Factors

The composition factors have been developed on the basis of simulated mean delays. The composition factors have been developed for all type of vehicles and for vehicular composition from 0 to 100 percentage. Holding the approach volumes, turning and crossing proportion of the vehicles and all the other parameters constant, the proportion of non-motorised vehicles is varied gradually from 0 to 100 percentage with an increasing step of 10 percentage.

As for example, if we want to compute the composition factor for a car, the proportion of non-motorised vehicles in an approach volume are varied starting from zero percentage to hundred percentage, whereas in the motorised vehicles only cars are considered. Simulation model SIMMTRA-345 is run 11 times to get the average delay for 11 proportions of cars in traffic streams of all approaches.

Similarly average delays were found out by running the model for all type of vehicles included in the study. The only worth mentioning point here is that while computing composition factor for say, bus, under morotised vehicles 100 percentage buses have been considered, in the all approach traffic streams.

The composition delay values are then determined from the graph drawn between traffic composition versus mean delay. One such graph is shown in Fig. 6.32 for vehicle type 'others'. The above computed composition delay values are divided by 100 and the resulting values are taken as the composition factors which are to be added to the initial equivalent passenger car values. The revised EPCV, thus determined, accounts, for the proportion of vehicle type in the traffic mix.

6.5.4 Development of Conflict Factors

Working along the same line, the conflict factors are computed for various type of vehicles for different percentage of conflict traffic. This time the parameters like approach volumes, percentage of the vehicle whose conflicting factor is to be found, etc., are held constant and proportion of conflict traffic is varied from 0 to 100 percentage with stepping up of 10 percentage. This way the conflict factors are computed on the

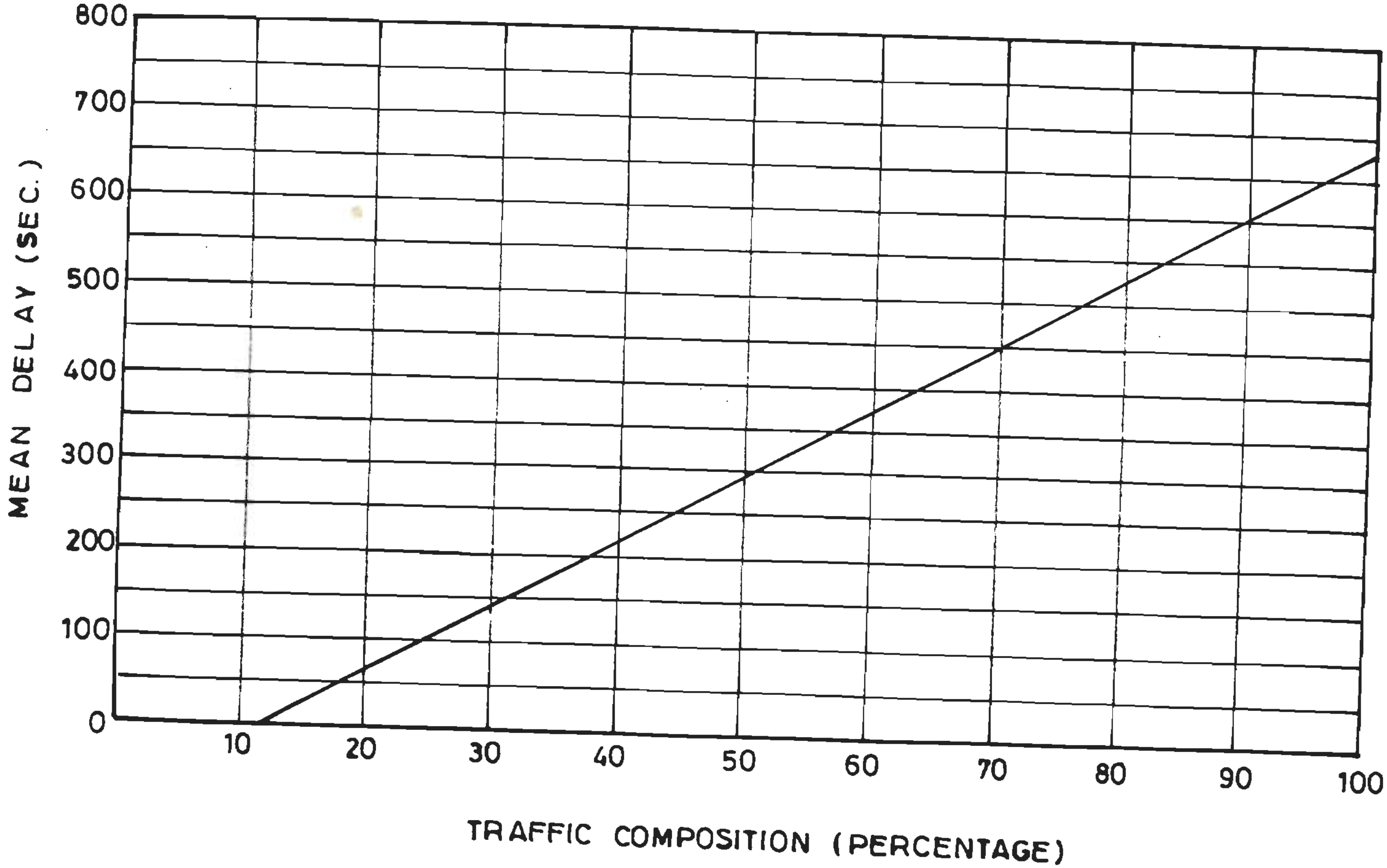


Fig. 6.32 Determination of composition factors for vehicle type 'others'

TABLE 6.15 – DETERMINATION OF CONFLICT AND COMPOSITION FACTORS FOR COMPUTING EPCV BASED ON MEAN DELAY

%Age Conflict Traffic	100% CARS			%Age Non-Motorised Traffic	MOTORIZED VEHICLES CARS ONLY		
	Mean Delay (SEC)	Conflict Factor (ADD)	Revised EPCV		Mean Delay (SEC)	Composition Factor (ADD)	Revised EPCV
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	0	0	1	0	20.44	0.16	1.16
10	3.51	0.03	1.03	10	16.61	0.18	1.21
20	4.18	0.04	1.04	20	16.89	0.21	1.25
30	5.51	0.06	1.06	30	28.66	0.23	1.29
40	8.53	0.09	1.09	40	28.61	0.26	1.35
50	12.41	0.12	1.12	50	22.57	0.28	1.40
60	20.23	0.2	1.20	60	32.67	0.31	1.51
70	22.19	0.22	1.22	70	28.67	0.33	1.55
80	25.16	0.25	1.25	80	26.31	0.36	1.61
90	29.01	0.29	1.29	90	38.16	0.38	1.67
100	41.81	0.42	1.42	100	51.11	0.41	1.83
	100% BUSES				MOTORIZED VEHICLES BUSES ONLY		
0	0	0	3.55	0	15.37	0.15	3.70
10	4.11	0.04	3.59	10	19.34	0.18	3.77
20	5.71	0.06	3.61	20	18.89	0.20	3.81
30	7.94	0.08	3.63	30	24.26	0.22	3.85
40	12.16	0.12	3.67	40	23.09	0.25	3.92
50	20.01	0.20	3.75	50	33.45	0.27	4.02
60	29.19	0.29	3.84	60	28.96	0.29	4.13
70	33.51	0.34	3.89	70	25.02	0.32	4.21
80	42.84	0.43	3.98	80	30.91	0.34	4.32
90	54.82	0.55	4.10	90	25.56	0.36	4.46
100	71.42	0.71	4.26	100	51.11	0.38	4.64
	100% TRUCKS				MOTORIZED VEHICLES TRUCKS ONLY		
0	0	0	4.89	0	15.77	0.16	5.05
10	4.11	0.04	4.93	10	22.19	0.18	5.11
20	5.71	0.06	4.95	20	22.89	0.21	5.16
30	7.94	0.08	4.95	30	20.39	0.23	5.20
40	12.16	0.12	5.01	40	25.24	0.26	5.27
50	20.01	0.20	5.09	50	34.55	0.28	5.37
60	29.19	0.29	5.18	60	28.88	0.32	5.50
70	33.51	0.34	5.23	70	23.61	0.34	5.57
80	42.84	0.43	5.32	80	33.03	0.37	5.69
90	54.82	0.55	5.44	90	37.96	0.39	5.83
100	71.42	0.71	5.60	100	51.11	0.42	6.02
	100% SCOOTERS				MOTORIZED VEHICLES SCOOTER/MOTOR CYCLES ONLY		
0	0	0	0.22	0	23.91	0.22	0.44
10	3.27	0.03	0.25	10	24.62	0.24	0.49
20	3.30	0.03	0.25	20	23.65	0.25	0.50
30	4.56	0.04	0.26	30	28.22	0.26	0.52
40	7.22	0.07	0.29	40	28.29	0.28	0.57
50	10.92	0.11	0.33	50	31.01	0.29	0.62
60	18.42	0.18	0.40	60	24.89	0.30	0.70
70	20.25	0.20	0.42	70	27.04	0.31	0.73
80	23.23	0.23	0.45	80	26.01	0.33	0.78
90	35.93	0.25	0.47	90	27.73	0.34	0.81
100	36.71	0.36	0.58	100	51.11	0.35	0.93

(Contd.........)

Table 6.15 (Contd.......)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	100%	BICYCLES		VEHICLES BICYCLE ONLY			
0	0	0	0.27	0	35.77	0.40	0.67
10	9.04	0.09	0.36	10	44.51	0.41	0.77
20	16.85	0.16	0.43	20	44.37	0.42	0.85
30	51.37	0.51	0.78	30	51.72	0.43	1.21
40	84.68	0.84	1.11	40	44.14	0.44	1.55
50	279.56	1.79	2.06	50	28.65	0.45	2.51
60	220.34	2.20	2.47	60	60.16	0.46	2.93
70	252.24	2.52	2.79	70	28.52	0.47	3.26
80	557.76	5.57	5.84	80	50.87	0.48	6.32
90	663.63	6.63	6.90	90	55.63	0.49	7.39
100	827.19	8.23	8.54	100	51.11	0.50	9.04
100%	PEDAL	RICKSHAW		VEHICLE PEDAL RICKSHAW ONLY			
0	0	0	0.80	0	26.09	0.39	1.19
10	9.04	0.09	0.89	10	43.63	0.395	1.29
20	16.85	0.16	0.96	20	46.91	0.40	1.36
30	51.54	0.51	1.31	30	51.49	0.405	1.71
40	86.46	0.86	1.60	40	41.19	0.41	2.01
50	289.09	1.89	2.69	50	36.79	0.415	3.10
60	261.91	2.61	3.41	60	39.59	0.42	3.83
70	567.01	5.67	6.47	70	41.04	0.425	6.89
80	658.97	6.58	7.38	80	28.11	0.43	7.81
90	844.62	8.40	9.20	90	42.22	0.435	9.73
100				100	51.11	0.40	
	100%	OTHERS			VEHICLES	OTHERS	
0	0	0	6	0	0	0	6
10	22.56	0.22	6.22	10	71.56	0	6.22
20	25.16	0.25	6.25	20	73.17	0.65	6.90
30	108.26	1.08	7.08	30	102.86	1.40	8.48
40	140.72	1.40	7.40	40	130.91	2.20	9.60
50	326.37	3.20	9.20	50	204.77	3.00	12.2
60	492.06	4.90	10.90	60	276.73	3.70	14.60
70	550.45	5.50	11.50	70	352.97	4.50	16.00
80	682.08	6.80	12.80	80	562.63	5.20	18.00
90	840.52	8.40	14.40	90	698.28	6.00	20.40
100	1025.15	10.20	16.20	100	773.56	6.70	22.90

basis of mean delay. Here it is to be noted that if conflict factor of car is to be determined, there will be 100 percentage cars in the approach volumes. The final revised EPCV can be had from the Table 6.15 dependig upon the proportion of non-motorised vehicles available in approach volume and percentage of conflicting traffic. For instance, suppose on minor road of a particular intersection the conflict traffic is 60 percentage and proportion of non-motorised vehicles is 30 percentage. Then consulting the table 6.15, the EPCV can be selected for difeferent type of vehicles as presented in Table 6.16.

TABLE 6.16 – COMPUTATION OF FINAL EPCV FOR 60% CONFLICT TRAFFIC AND 30% SLOW MOVING VEHICLES (SMV)

Vehicle type	Initial EPCV	Conflict factor for 60% traffic	Composition factor for 30% SMV	Finally selected EPCV
Car	1.00	0.20	0.23	1.43
Bus	3.55	0.29	0.22	4.06
Truck	4.89	0.29	0.23	5.41
Scooter/ Motorcycle	0.22	0.18	0.26	0.66
Bicycle	0.27	2.20	0.43	2.90
Pedal rickshaw	0.80	2.61	0.41	3.82
Others	6.00	4.90	1.40	12.30

6.6 HOMOGENISING AND HETEROGENISING EFFECTS THROUGH SIMMTRA-345

One special series of simulation runs was accomplished to assess the homogenising and heterogenising effects of mixed traffic flow in terms of simulated mean delays. The simulated delays and queue lengths for this series of runs are tabulated in Table 6.17 for 4-leg intersection.

TABLE 6.17 - ANALYSIS OF HETEROGENISING AND HOMOGENISING EFFECTS THROUGH SIMMTRA-345 (4-Leg INTERSECTION, SIMULATED RESULTS)

Slow moving Vehicles (percent)	Total Delay (Veh.Sec)	Mean Delay (Sec)	Queue Length (No. of vehicles)
0	2422.27	14.08	3
10	3155.18	18.24	5
20	3631.33	20.93	7
30	5199.54	32.59	7
40	3622.38	23.37	6
50	4308.12	29.93	8
60	6140.75	41.77	11
70	3853.62	26.41	8
80	8348.92	54.92	21
90	4837.29	46.06	
100	4327.51	50.91	7

It was found that under homogeneous (all motorised) traffic conditions the vehicular interactions are minimum. But as the non-motorised vehicles get mixed with motorised vehicles or the amount of heterogenity in the approaching traffic streams increases, the intervehicular interactions also increase. This causes large delays to the vehicles. Thus the increasing trend in delay was observed with increased proportion of slow moving vehicles in the traffic stream.

Although the maximum simulated delays were observed when there are 80% SMV in the traffic stream, it is understood that as the whole process is random, it might have been so happened that at that particular time the suitable gaps could not have been available in the major traffic stream. This could have caused more delays to minor road vehicles at 80% SMV rather than 100% SMV as the arrival times of vehicles on all approaches are generated randomly.

6.7 ANALYSIS OF VEHICULAR INTERACTIONS DUE TO ROADWAY FACTORS THROUGH SIMMTRA-345

There are several roadway factors that directly affect the vehicular interactions in an intersection area. Most of these factors have been accounted for in the model SIMMTRA-345. Now the effects of approach widths and intersection angles will be studied through the developed simulation model.

6.7.1 Effect of Approach Widths

As already stated in article 5.6.3.2, the three categories of approach widths were considered in the present research work, viz.; one category for major road and 2 categories for minor road, viz; 3.5 m (category 1) and 7.0 m (category 2). The simulation model was run once for each category of minor road approach widths. Holding all the other input parameters constant only approach width category for minor road was changed in the second run. The simulated results of these two runs are presented in Table 6.18. It was found that the delays to minor road vehicles reduce as the approach width of minor road increases. This is for the simple reason that due to availability of large approach width, the internal conflict between minor road approaching vehicles is reduced, specially between left turning and other vehicles, which enable them to complete their manoeuvre bit quickly.

6.7.2 Effect of Angle of Intersection

Due to the change in the angle of intersection the turning radius of crossing paths varies and as a result the distances to be crossed for different manoeuvres also vary. All the above logics have been incorporated in the model. In order to assess the effect of angle of intersection on delays to minor road vehicles, the model was run for three times with varying the angle but all the other input parameters were held unchanged. The angles considered were 90, 60 and 45 degrees. The results of three simulation runs have been recorded and presented in Table 6.18.

TABLE 6.18 - EFFECT OF APPROACH WIDTH AND ANGLE OF INTERSECTION ON MINOR ROAD DELAYS (SIMULATED RESULTS, 3-Leg INTERSECTION)

Volumes : Major = 550 and Minor = 200 (vph)

Roadway Factors		Total Delay (veh.sec)	Mean Delay (sec.)	Queue Length (No. of vehicles)
Approach width (m)	3.50	987.57	9.88	3
	7.00	788.73	7.89	3
Angle of intersection (Degrees)	90	19.46	0.19	1
	60	20.87	0.21	1
	45	23.51	0.23	2

Analysing the results, it was found that as an angle of intersection decreases there is a marginal increase in the delays to minor road vehicles. It is understandably so as the angle effects the two variables in intersection operation :

1. Distance to be covered while different turning manoeuvres, and
2. Speed with which the turning distances are negotiated.

It is widely accepted fact that as the angle of intersecion increases the turning distances either reduce or increase depending upon the type of turn. In case, for a particular turn, the turning distance is reduced, then its turning speed will also reduce. On the other hand if the turning distance is increased for a particular turn, then its speed to negotiate the turn would also increase.

From the above disucssions we can come to the point that the effect of the change of an intersection angle is more or less nullified by either increased distance and increased speed or by reduced distance and reduced turning speed. It can therefore be concluded that the crossing times are only marginally affected by change of an intersection angle. This is what has been observed in the simulated results, marginal increase in delays with reduced angle of intersection.

6.8 ANALYSIS OF VEHICULAR INTERACTIONS FOR MAJOR ROAD TRAFFIC FLOW

The overall performance of any at-grade intersection is always closely associated with the performance of minor road of the intersection. Yet sometimes it is necessary and interesting to analyse the vehicular interactions at major road too.

As has been already discussed that in the model SIMMTRA-345, the priority has been given to major road vehicles, that is to say that no major road vehicle manoeuvre is influenced by minor road vehicle manoeuvres.

A possibility of any vehicular interactions among major road vehicles arises only when there is a conflicting traffic on the major road approaches. The effect of conflicting traffic on major road delays was studied through SIMMTRA-345, by running the model several times for different proportions of conflicting traffic on major road approaches. The simulated results of the eleven runs are shown in Table 6.19. It is evident from

TABLE 6.19 – VEHICULAR INTERACTIONS ON MAJOR ROAD DUE TO MAJOR ROAD CONFLICTING TRAFFIC (SIMULATED RESULTS) (T-INTERSECTION, MAJOR VOLUME = 1000, MINOR = 300 vph)

Conflicting traffic on major road (Percentage)	Total Delay (veh.sec)	Mean Delay (sec.)	Queue Length (No. of vehicles)
	ON	MAJOR	ROAD
0	0.00	0.00	0
10	121.01	0.24	1
20	283.33	0.57	2
30	486.06	0.97	2
40	611.79	1.22	3
50	887.66	1.77	4
60	1126.96	2.24	4
70	1360.82	2.71	5
80	1571.36	3.31	5
90	1874.31	3.75	5
100	2986.26	6.02	9

the table that amount of vehicular interaction on major road depends upon the proportion of conflicting traffic in the major traffic streams.

6.9 LEVEL-OF-SERVICE CRITERIA FOR PRIORITY TYPE INTERSECTIONS THROUGH SIMMTRA-345

6.9.1 Introduction

Generally the capacity and level-of-service of an uncontrolled intersection would rarely be critical or of practical consideration. In practice, by the time approach volumes have increased to a critical stage signals would be installed, and the level-of-service of an uncontrolled intersection considered to be of academic interest only.

The various type of controls at uncontrolled intersection such as, no control, yield, and stop-sign, all have an effect on the level-of-service and operations of intersection.

As discussed earlier, the major road traffic is given priority over minor road traffic. Hence with sufficient traffic on the major road the minor road traffic may theoretically fall off to zero. Thus any measure of level-of-service can relate only to the minor road traffic in relation to major road traffic.

Total delay or mean delay has been widely accepted in theory as an appropriate objective measure of effectiveness for uncontrolled intersections. Level-of-service criteria for uncontrolled intersection has been stated in very general terms, and has been related to general delay ranges (123).

If the existing or projected traffic demand is greater than the calculated capacity, failure or breakdown condition occurs. This is not level-of-service 'F'. Level-of-service 'F' occurs when the major road traffic backs up from a down stream conditions and blocks the minor road such that the minor road vehicles cannot enter the intersection.

A minor road approach operating at or near capacity has very long traffic delays and lengthy queues.

The difference between the capacity figure and the existing or projected flows is defined as the reserved capacity. Traffic delays and the resulting level-of-service for uncontrolled intersections are directly related to the magnitude of the reserve capacity. Suggested ranges of reserve capacities for the various levels-of-service (190) have been presented in Table 6.20.

TABLE 6.20 – LEVEL-OF-SERVICE AND EXPECTED DELAYS FOR RESERVE CAPACITY RANGES

Reserve Capacity	Level-of-service	Expected traffic delay
400 or more	A	Little or no delay
300 to 399	B	Short traffic delays
200 to 299	C	Average traffic delays
100 to 199	D	Long traffic delays
0 to 99	E	Very long traffic delays
Less than 0	E	Failure-extreme congestion
(Any value)	F	Intersection blocked by external causes

6.9.2 Level-of-Service Through SIMMTRA-345

In the present work an attempt has been made to relate the simulated mean delays with various levels-of-service under mixed traffic conditions. The methodology adopted has been discussed step wise as under.

Conditions :

1. Input parameters for major road remain unchanged during the simulation runs.

2. Number of cars or mixed vehicles and the total equivalent passenger car values (EPCV) for the above mixed vehicles remain same with about five percentage variation for all runs.

3. The EPCV should be selected from table 6.15 for all type of vehicless for predecided percentage of conflicting traffic, (70% are considered for the present experiments). These percentage of conflicting traffic should be held constant for all simulation runs.

The simulation model SIMMTRA-345 is run several times subject to the above conditions.

On minor road the approach volume is considered 600 vph. In the first run only cars are considered on the minor road and equivalent passenger car values for 70% conflicting traffic are 732 (600 x 1.22).

In second run, buses are mixed with cars in such a way that number of vehicles are exactly 600 and total EPCV remain around 732.

Similarly the simulation runs for three vehicles mix (cars, buses and scooters), four vehicle mix (cars, buses, scooters and bicycles), five vehicle mix (cars, buses, scooters, bicycles and pedal rickshaws and six vehicle mix (cars, buses, scooters, bicycles, pedal rickshaws and others) are accomplished subject to the above conditions.

The mean delay were recorded for all runs and used to correlate with level-of-service under different heterogenity conditions. The relationship developed between level-of-service and average queue delay (123, 191) for uncontrolled intersections has been used as a basis for developing relationship between mean delay and level-of-service in the present study. A summary of these runs has been presented in the Table 6.21 in the form of relationship between level-of-service and average delays.

TABLE 6.21 - DEVELOPMENT OF LEVEL-OF-SERVICE THROUGH SIMMTRA-345 FOR MIXED TRAFFIC CONDITIONS

		AVERAGE DELAY RANGES (SEC.)						
	LOS	Only cars	2-veh. mix	3-veh. mix	4-veh. mix	5-veh. mix	6-veh. mix	Reserve Capa-city (EPCV)
Simulated average delays (sec.)		6.26	7.63	9.20	23.01	28.24	32.20	
Proportio-nately extending the simu-lated average delay to established delay ranges	I	10	12	15	36	45	50	400
	II	10-20	12-24	15-30	36-72	45-90	50-100	300-400
	III	20-30	24-36	30-45	72-108	90-135	100-150	200-300
	IV	> 30	> 36	> 45	> 108	> 135	> 150	100-200

The suggested relationships are considered to represent the mixed traffic behaviour in a better way.

6.10 SUMMARY

The vehicular interactions in mixed traffic streams have been presented in this chapter. The various experiments have been accomplished with simulation model SIMMTRA-345. Vehicular interactions have been computed in terms of simulated delays, queue lengths, approach volumes, traffic composition, conflict traffic etc. The simulated results have been presented in form of tables and nomograms. Further the composition and conflict factors have been established to determine EPCV exclusively for uncontrolled, priority type intersections under mixed traffic conditions. The homogenising and heterogenising effects have been studied under mixed traffic flow conditions. The effects of roadway factors on minor road vehicles have been evaluated.

Lastly an attempt has been made to establish the delay ranges for various levels-of-service under mixed traffic flow.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS AND SCOPE FOR FUTURE WORK

7.1 CONCLUSIONS

The objective of this research programme has been to analyse and interpret the vehicular interactions under heterogeneous traffic flow at semi-urban type uncontrolled (priority) at - grade intersections. The road interactions being the major bottlenecks in the road network, the congestion primarily begins at intersections. There are not many publications on traffic analysis at uncontrolled intersections ask under mixed traffic flow. This is probably the first time that a simulation model has been developed which is capable to simulate the traffic at 3-leg, 4-leg and 5-leg uncontrolled intersections under mixed traffic conditions of the type obtaining on Indian roads. The present research work has considered delay as measure-of-effectiveness. Within this broad framework the salient results obtained on the basis of extensive field studies and simulation experiments carried through the simulation model SIMMTRA-345, and the conclusions so derived are listed below.

7.1.1 Field Data Collection Programme

1. The experimental field programme designed and carried out has provided useful data and it could be used to advantage in the subsequent analysis. This can be a model guideline for similar other programmes.

2. The video recording techniques (VRT) used in this research programme is an extensive work of its kind in a planned research programme, and the values provided through tedious and long data

analysis are specially suited to a study of the present type and must be recommended for future studies, due to the following salient features.

(i) All features of vehicular interactions are recorded on a permanent basis for future analysis, as well as, in case of doubts in analysis, the data can be reproduced and reanalysed. Further a large number of variables can be simultaneously recorded. This could not be possible with any other form of field data collection procedures. The additional cost involved is off-set by the additional benefits derived and the possibility of data reproducibility and varied analysis.

(ii) The special attachments like video-rama and other recording and projecting aids and equipments are ideal for data analysis from video recording field studies.

7.1.2 Characteristics of Mixed Traffic

Following descriptions are provided for the mixed traffic features, observed at the various semi-urban or semi-rural type uncontrolled intersections which were finally selected in the state of Uttar Pradesh of India.

7.1.2.1 Characteristics of time-headways in mixed traffic

Time-headways in mixed traffic flow followed Poisson distribution model which can be adopted up to an approach volume of 200 vph. The shifted exponential distribution model was found to suit to mixed traffic flows up to 500 vph.

7.1.2.2 Models of mixed traffic speed distribution

It was found that the normal distribution represents the speed behaviour of mixed traffic flow in a reasonable way, especially due to lower speed ranges.

7.1.2.3 Gap acceptance behaviour in mixed traffic

Gap acceptance behaviour of mixed traffic flow has been incorporated in the simulation model in the form of actual crossing speeds and crossing distances, which ultimately decide the gap to be accepted. The effect of the gap acceptance phenomeon, therefore has been indirectly incorporated.

7.1.3 Mixed Traffic Flow Mechanism

7.1.3.1 Proposed volume limits

Simulation findings show that at a total volume (entering on all approaches) of 1000 vph the delays are small and in most cases they are acceptable (up to 30 sec) at a total intersection volume of about 1700 vph incase of 4-leg intersections and about 1500 vph incase of 3-leg intersections, under mixed traffic conditions. However, the critical volumes, above which delays increase rapidly and traffic jams are formed,are suggested as under.

For 4-leg intersections - 2600 vph.

For 3-leg intersections - 2400 vph.

7.1.3.2 Mixed mode results

The traffic was analysed through several runs of SIMMTRA-345 simulation model. The following conclusions are drawn for mixed mode traffic situation.

1. When unimode traffic is considered, the cars cause minimum interaction whereas trucks cause maximum intersection in motorised traffic flow situation. Incase of non-motorised traffic flow, the bicycle cause least interactions whereas hand and animal drawn carts (others) cause maximum interactions.

2. The vehicular interaction increase to a great extent when slow moving vehicles (SMV) start mixing with fast moving vehicles (FMV).

3. There is a marginal increase in delays with every additional FMV mode getting mixed in motorised traffic flow.

4. The delay to minor road vehicles rises sharply with every additional SMV mode getting mixed in motorised traffic stream.

The above results are considered to be logically justified due to the physical and operating characteristics of SMV; they cause delays to FMV and these delays are maximum when there are only SMV in the traffic stream.

7.1.3.3 Conflicting traffic results

The turning movements from minor road were evaluated through

7.1.3.4 Development of equivalent passenger car values (EPCV)

The equivalent car values are developed exclusively for semi-urban uncontrolled, priority type at-grade intersections. For this purpose initially the composition factors and conflicting factors for all seven type of vehicles have been established by making use of simulation model SIMMTRA-345. Later on the EPCV were computed based on

(i) Area of the vehicle

(ii) Its crossing time

(iii) Percentage of SMV available in traffic stream, and

(iv) Percentage of conflicting traffic.

It is concluded that the EPCV for the particular vehicle increases with increased proportion of SMV and conflicting traffic.

7.1.3.5 Interactions due to roadway factors

The vehicular traffic was analysed for two roadway factors; viz.; approach width and angle of intersection.

The simulated findings show that the amount of interactions and ultimately the delays to minor road vehicles reduce with increased approach width. Also a marginal variation was observed in delays with different intersection angles.

7.1.3.6 Major road vehicular interactions

While analysing the major road vehicular traffic through SIMMTRA-345, it was found that the conflicting traffic available in major traffic simulation model SIMMTRA-345 for 3-leg intersection. The following conclusions were deduced.

1. No left turning vehicle is subjected to delay as this manoeuvre does not come in to conflict with any other manoeuvre.

2. The minor road vehicles are subjected to tolerable delays (upto 30 seconds) for single lane approach width of 3.5 m, under following traffic situations.

Conflicting traffic	$\ngtr$	70%
Major road volume	$\ngtr$	1200 vph
Minor road volume	$\ngtr$	500 vph

The delays become intolerable (more than 80 seconds) when

Conflicting traffic	>	50%
Major road volume	>	1400 vph
Minor road volume	>	700 vph

Thus it can be seen that some compromising values of conflicting traffic proportion and intersection traffic volume (major and minor road volumes) are to be found out for optimum performance of an uncontrolled intersection. These values are recommended as

Conflicting traffic	=	55%
Major road volume	=	1300 vph
Minor road volume	=	600 vph

stream causes the interactions to the major road traffic. These interactions increase with increased proportion of conflicting traffic.

7.1.3.7 Level-of-service (LOS) concept

The four levels-of-service have been established for uncontrolled priority type intersections. The various delay values have been developed for each LOS depending upon the number of vehicle types available in the traffic stream. It is deduced that the level-of-service, offered by an intersection to the users, deteriorate with addition of each additional vehicle mode in traffic stream. The rate of deterioration of LOS rise sharply with addition of each SMV mode in a traffic flow. It is therefore concluded that under the mixed traffic conditions, as are prevailing in India, the level-of-service and the capacity of semi-urban, uncontrolled intersections is low in comparision to the Western and European countries. One of the most important aspect of the simulation model SIMMTRA-345 is its requirement of input data which is very simple and can be collected easily in the field.

7.2 RECOMMENDATIONS AND SCOPE FOR FUTURE WORK

The present research has answered many questions. However, it has also uncovered several areas that warrant further research. These areas include :

(i) An analysis of pedestrian flows at semi-urban uncontrolled priority type intersections under mixed traffic flow.

(ii) An analysis of relationship between vehicular flows and pedestrians flows along and accross the flows.

(iii) Detailed combined gap acceptance behaviour is to be analysed to understand the mixed traffic flow in the still better way.

(iv) This research work can be extended to incorporate more types of vehicles in the model and evaluate their influence on intersection performance.

(v) It is possible to extend the work to suggest the volume warrants for introducing the type of control at uncontrolled intersection under mixed traffic conditions.

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VITAE

T.L. POPAT

1.	Date and Place of Birth	:	July 4, 1948, Bantwa (Gujarat)
2.	Educational Qualifications	:	B.E. (Civil), Gujarat University, Ahmedabad 1974 M. Tech. (Transport Engg.) R.E.C., Kakatiya University Warangal (A.P.) 1982
3.	Membership of Professional Institutes/Societies	:	i) Member, Indian Society of Technical Education ii) Member, Indian Roads Congress
4.	Professional Experience	:	Worked as Supervisor and Junior Engineer in Gujarat State P.W.D. for about one year. Since January 1975 employed by Director of Tech. Edu. Gujarat State, Gandhinagar.
5.	Teaching Experience	:	i) Worked as a Asstt. Lecturer in Civil Engg. Deptt., L.D. College of Engineering, Ahmedabad (Gujarat) 1975 - 1982 ii) As a Lecturer in Civil Engg. Deptt., L.E. College, Morbi (Gujarat) 1982 - 1985 iii) Currently working as a Asstt. Prof. in Civil Engg., L.E. College, Morbi (Gujarat) 1985 - to date
6.	Research Experience	:	Since 1987 associated with the Traffic Engg. Research at the Centre of Transportation Engineering, Civil Engg. Deptt., University of Roorkee, Roorkee (U.P.).
7.	Publication	:	
	Research Paper	:	9, in various National and International Journals/Conferences/Bulletins.
	Technical Discussions	:	5, in various Seminars, Symposiums, Research Project Meetings etc.
8.	Matiral Status	:	Married, having one daughter and one son.

APPENDIX A

PROFORMA FOR FIELD DATA COLLECTION FOR DIRECTIONAL VEHICULAR TRAFFIC AT ROAD INTERSECTION

Date and Day :

Intersection Identification :

Method :

Name of Enumerator :

Weather :

Type :

Approach Name & No. : Minor & 1

Starting Time : 17.00

Ending Time : 18.00

Approach From	Approach To	Time of Count	Vehicle Type → Cars, Jeeps Vans, 3-wheeler, Tractors etc.	Busses & Mini bus	Trucks, Mini trucks, Tractors cum Troiles etc.	Scooters Motor-cycles, Mopeds	Bicycle	Pedal Rickshaw	Others	Remark
		17.00 - 17.10								
		17.10 - 17.20								
		17.20 - 17.30								
	2	17.30 - 17.40								
		17.40 - 17.50								
		17.50 - 17.80								
		17.00 - 17.10								
		17.10 - 17.20								
1	3	17.20 - 17.30								
		17.30 - 17.40								
		17.40 - 17.50								
		17.50 - 17.80								
		17.00 - 17.10								
		17.10 - 17.20								
		17.20 - 17.30								
	4	17.30 - 17.40								
		17.40 - 17.50								
		17.50 - 17.80								

APPENDIX B

DETAILS OF SUBROUTINE 'RANDU' TO GENERATE RANDOM REAL NUMBERS

```
SUBROUTINE RANDU

PURPOSE
   COMPUTES UNIFORMLY DISTRIBUTED RANDOM REAL NUMBERS BETWEEN
   0 AND 1.0 AND RANDOM INTEGERS BETWEEN ZERO AND
   2**31. EACH ENTRY USES AS INPUT AN INTEGER RANDOM NUMBER
   AND PRODUCES A NEW INTEGER AND REAL RANDOM NUMBER.

USAGE
   CALL RANDU(IX,TY,YFL)

DESCRIPTION OF PARAMETERS
   IX - FOR THE FIRST ENTRY THIS MUST CONTAIN ANY ODD INTEGER
        NUMBER WITH NINE OR LESS DIGITS. AFTER THE FIRST ENTRY,
        IX SHOULD BE THE PREVIOUS VALUE OF IY COMPUTED BY THIS
        SUBROUTINE.
   TY - A RESULTANT INTEGER RANDOM NUMBER REQUIRED FOR THE NEXT
        ENTRY TO THIS SUBROUTINE. THE RANGE OF THIS NUMBER IS
        BETWEEN ZERO AND 2**31
   YFL- THE RESULTANT UNIFORMLY DISTRIBUTED, FLOATING POINT,
        RANDOM NUMBER IN THE RANGE 0 TO 1.0

REMARKS
   THIS SUBROUTINE IS SPECIFIC TO SYSTEM/360 AND WILL PRODUCE
   2**29 TERMS BEFORE REPEATING.  THE REFERENCE BELOW DISCUSSES
   SEEDS (65539 HERE), RUN PROBLEMS, AND PROBLEMS CONCERNING
   RANDOM DIGITS USING THIS GENERATION SCHEME.  MACLAREN AND
   MARSAGLIA, JACM 12, P. 83-89, DISCUSS CONGRUENTIAL
   GENERATION METHODS AND TESTS.  THE USE OF TWO GENERATORS OF
   THE RANDU TYPE, ONE FILLING A TABLE AND ONE PICKING FROM THE
   TABLE, IS OF BENEFIT IN SOME CASES.  65549 HAS BEEN
   SUGGESTED AS A SEED WHICH HAS BETTER STATISTICAL PROPERTIES
   FOR HIGH ORDER BITS OF THE GENERATED DEVIATE.
   SEEDS SHOULD BE CHOSEN IN ACCORDANCE WITH THE DISCUSSION
   GIVEN IN THE REFERENCE BELOW.  ALSO, IT SHOULD BE NOTED THAT
   IF FLOATING POINT RANDOM NUMBERS ARE DESIRED,AS ARE
   AVAILABLE FROM RANDU, THE RANDOM CHARACTERISTICS OF THE
   FLOATING POINT DEVIATES ARE MODIFIED AND IN FACT THESE
   DEVIATES HAVE HIGH PROBABILITY OF HAVING A TRAILING LOW
   ORDER ZERO BIT IN THEIR FRACTIONAL PART.

SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
   NONE

METHOD
   POWER RESIDUE METHOD DISCUSSED IN IBM MANUAL C20-8011,
   RANDOM NUMBER GENERATION AND TESTING

..................................................................

      SUBROUTINE RANDU(IX,TY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=TY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

APPENDIX C

TYPICAL OUTPUT OF SIMULATION MODEL SIMMTRA-345
(3-Leg Intersection, Approach No. 1, Km. 20.000)

TABLE-DELAY for Approach No.1

S.No.	Vehicle Type	Turning	Arrival Time (Sec)	Headway (Sec)	Delay (Sec)	Length of Que	Headway same veh. (Sec)	
1.	5	2	64.47	9.83	.00	0	.00	7.371
2.	1	3	74.30	15.67	.00	0	.00	1.232
3.	4	2	89.97	22.27	.23	1	.00	1.980
4.	1	3	112.24	.57	.00	0	37.94	1.232
5.	4	2	112.82	37.66	.00	0	22.84	1.980
6.	3	3	150.47	10.02	.00	0	.00	1.941
7.	1	2	160.49	49.22	.00	0	48.25	2.121
8.	1	3	209.71	21.21	.00	0	49.22	1.232
9.	1	2	230.93	40.79	.00	0	21.21	2.121
10.	4	3	271.72	32.81	.00	0	158.90	1.030
11.	3	2	304.53	25.12	2.08	1	154.05	2.607
12.	1	3	329.64	37.78	.00	0	98.72	1.232
13.	4	2	367.42	12.07	.00	0	95.71	1.980
14.	1	3	379.49	30.35	.00	0	49.85	1.232
15.	1	2	409.84	1.78	.00	0	30.35	2.121
16.	1	3	411.62	18.50	.00	0	1.78	1.232
17.	4	2	430.12	18.28	.00	0	62.70	1.980
18.	3	3	448.40	7.69	.00	0	143.88	1.941
19.	1	2	456.09	.29	3.32	1	44.47	2.121
20.	4	3	456.38	51.80	.00	0	26.26	1.030
21.	1	2	508.19	7.43	.00	0	52.09	2.121
22.	5	3	515.61	10.83	.00	0	451.14	2.567
23.	3	3	526.44	13.83	.00	0	78.04	1.941
24.	1	3	540.28	32.59	.00	0	32.09	1.232
25.	5	2	572.87	17.36	27.79	1	57.26	7.371
26.	1	3	590.23	1.76	.00	0	49.95	1.232
27.	4	2	591.99	16.06	8.67	1	135.61	1.980
28.	1	3	608.05	5.73	.00	0	17.82	1.232
29.	5	2	613.79	10.73	.00	0	40.92	7.371
30.	3	3	624.52	7.32	.00	0	98.07	1.941
31.	1	2	631.83	3.75	1.99	1	23.78	2.121
32.	4	3	635.58	5.90	.00	0	43.59	1.030
33.	1	3	641.48	33.42	.00	0	9.64	1.232
34.	4	3	674.90	2.03	.00	0	39.32	1.030
35.	2	3	676.93	8.52	.00	0	.00	1.941
36.	1	3	685.45	34.58	.00	0	43.97	1.232
37.	4	2	720.03	29.46	.00	0	45.13	1.980
38.	1	3	749.49	11.68	.00	0	64.04	1.232
39.	4	3	761.17	1.90	.00	0	41.15	1.030
40.	1	3	763.07	62.68	.00	0	13.58	1.232
41.	3	3	825.75	6.96	.00	0	201.24	1.941
42.	3	3	832.72	8.78	.00	0	6.96	1.941
43.	1	3	841.50	9.88	.00	0	78.43	1.232
44.	4	3	851.38	20.78	.00	0	90.21	1.030
45.	1	3	872.17	9.48	.00	0	30.66	1.232
46.	5	3	881.64	35.45	.00	0	267.86	2.567
47.	3	3	917.09	5.93	.00	0	84.37	1.941
48.	1	3	923.02	47.02	.00	0	50.86	1.232
49.	4	3	970.04	.58	.00	0	118.66	1.030
50.	1	3	970.62	40.50	.00	0	47.60	1.232

51.	4	3	1011.12	22.94	.00	0	41.08	1.030
52.	1	3	1034.06	25.54	.00	0	63.43	1.232
53.	5	3	1059.60	5.35	.00	0	177.95	2.567
54.	3	3	1064.95	12.57	.00	0	147.86	1.941
55.	1	3	1077.52	22.34	.00	0	43.47	1.232
56.	4	3	1099.87	2.25	.00	0	88.74	1.030
57	1	3	1102.12	.20	.00	0	24.59	1.232
58.	4	3	1102.32	19.80	.00	0	2.45	1.030
59.	4	3	1122.12	5.19	.00	0	19.80	1.030
60.	1	3	1127.31	1.04	.00	0	25.19	1.232
61.	3	3	1128.35	8.30	00	0	63.40	1.941
62.	1	3	1136.65	8.76	.00	0	9.34	1.232
63.	5	3	1145.42	8.39	.00	0	85.82	2.567
64.	4	3	1153.81	16.05	.00	0	31.69	1.030
65.	1	3	1169.86	5.42	.00	0	33.21	1.232
66.	3	3	1175.28	20.47	.00	0	46.93	1.941
67.	1	3	1195.76	.50	.00	0	25.90	1.232
68.	4	3	1196.26	19.37	.00	0	42.45	1.030
69.	1	3	1215.63	23.70	.00	0	19.87	1.232
70.	4	3	1239.33	13.50	.00	0	43.07	1.030
71.	4	3	1252.83	6.08	.00	0	13.50	1.030
72.	1	3	1258.91	5.86	.00	0	43.28	1.232
73.	2	3	1264.76	25.18	.00	0	587.83	1.941
74.	1	3	1289.94	47.15	.00	0	31.03	1.232
75.	3	3	1337.09	1.40	.00	0	161.81	1.941
76.	4	3	1338.49	11.80	.00	0	85.66	1.030
77.	1	3	1350.29	7.19	.00	0	60.35	1.232
78.	3	3	1357.48	42.35	.00	0	20.39	1.941
79.	1	3	1399.84	11.20	.00	0	49.54	1.232
80.	5	3	1411.04	4.57	.00	0	265.62	2.567
81.	1	3	1415.61	11.86	.00	0	15.77	1.232
82.	4	3	1427.47	10.76	.00	0	88.98	1.030
83.	4	3	1438.23	8.85	.00	0	10.76	1.030
84.	1	3	1447.08	14.68	.00	0	31.47	1.232
85.	3	3	1461.75	3.48	.00	0	104.27	1.941
86.	1	3	1465.23	14.48	.00	0	18.16	1.232
87.	5	3	1479.72	37.67	.00	0	68.68	2.567
88.	4	3	1517.39	10.28	.00	0	79.16	1.030
89.	1	3	1527.66	11.19	.00	0	62.43	1.232
90.	3	3	1538.86	3.99	.00	0	77.10	1.941
91.	1	3	1542.84	46.44	.00	0	15.18	1.232
92.	4	3	1589.28	37.39	.00	0	71.89	1.030
93.	1	3	1626.67	6.14	.00	0	83.83	1.232
94.	5	3	1632.81	10.32	.00	0	153.09	2.567
95.	4	3	1643.13	14.48	.00	0	53.85	1.030
96.	1	3	1657.62	38.21	.00	0	30.95	1.232
97.	3	3	1695.83	21.50	.00	0	156.97	1.941
98.	1	3	1717.33	4.28	.00	0	59.71	1.232
99.	4	3	1721.61	23.63	.00	0	78.48	1.030
100.	4	3	1745.23	10.89	.00	0	23.63	1.030
101.	1	3	1756.13	19.24	.00	0	38.80	1.232
102.	3	3	1775.37	15.51	.00	0	79.55	1.941
103.	1	3	1790.88	11.39	.00	0	34.76	1.232
104.	5	3	1802.28	15.99	.00	0	169.47	2.567
105.	1	3	1818.26	3.10	.00	0	27.38	1.232
106.	4	3	1821.36	12.04	.00	0	76.13	1.030
107.	4	3	1833.40	26.69	.00	0	18.04	1.030
108.	1	3	1860.10	5.66	.00	0	41.84	1.232
109.	2	3	1865.76	5.14	.00	0	600.99	1.941
110.	1	3	1870.90	53.08	.00	0	10.80	1.232
111.	3	3	1923.98	18.42	.00	0	148.61	1.941
112.	4	3	1942.40	13.87	.00	0	109.00	1.030
113.	1	3	1956.28	41.18	.00	0	85.38	1.232
114.	3	3	1997.46	69.00	.00	0	73.48	1.941
115.	1	3	2066.46	.72	.00	0	110.18	1.232
116.	4	3	2067.18	7.72	.00	0	124.78	1.030

117.	1	3	2074.90	1.77	.00	0	8.44	1.232
118.	4	3	2076.67	16.60	.00	0	9.49	1.030
119.	4	3	2093.27	.53	.00	0	16.60	1.030
120.	1	3	2093.79	24.07	.00	0	18.89	1.232
121.	3	3	2117.86	38.35	.00	0	120.40	1.941
122.	1	3	2156.21	25.92	.00	0	62.42	1.232
123.	4	3	2182.13	17.04	.00	0	88.87	1.030
124.	4	3	2199.17	20.62	.00	0	17.04	1.030
125.	1	3	2219.79	4.19	.00	0	63.58	1.232
126.	4	3	2223.98	12.02	.00	0	24.81	1.030
127.	1	3	2236.00	23.36	.00	0	16.21	1.232
128.	3	3	2259.35	3.32	.00	0	141.49	1.941
129.	5	3	2262.68	1.83	.00	0	460.40	2.567
130.	1	3	2264.50	26.84	.00	0	28.51	1.232
131.	4	3	2291.34	9.18	.00	0	67.36	1.030
132.	1	3	2300.52	4.99	.00	0	36.02	1.232
133.	3	3	2305.51	15.61	.00	0	46.16	1.941
134.	1	3	2321.13	17.75	.00	0	20.61	1.232
135.	5	3	2338.87	18.70	.00	0	76.20	2.567
136.	4	3	2357.57	38.01	.00	0	66.23	1.030
137.	1	3	2395.58	16.58	.00	0	74.45	1.232
138.	4	3	2412.16	.13	.00	0	54.59	1.030
139.	1	3	2412.29	10.59	.00	0	16.71	1.232
140.	3	3	2422.89	.98	.00	0	117.38	1.941
141.	4	3	2423.87	3.29	.00	0	11.71	1.030
142.	1	3	2427.16	78.50	.00	0	14.86	1.232
143.	5	3	2505.66	29.95	.00	0	166.78	2.567
144.	1	3	2535.61	32.15	.00	0	108.45	1.232
145.	2	3	2567.75	7.03	.00	0	702.00	1.941
146.	1	3	2574.79	14.39	.00	0	39.18	1.232
147.	4	3	2589.18	24.34	.00	0	165.31	1.030
148.	3	3	2613.52	2.59	.00	0	190.63	1.941
149.	1	3	2616.11	.19	.00	0	41.33	1.232
150.	4	3	2616.30	18.97	.00	0	27.13	1.030
151.	1	3	2635.27	4.40	.00	0	19.16	1.232
152.	3	3	2639.67	.09	.00	0	26.15	1.941
153.	4	3	2639.76	6.50	.00	0	23.46	1.030
154.	1	3	2646.26	6.49	.00	0	10.99	1.232
155.	4	3	2652.76	5.75	.00	0	12.99	1.030
156.	1	3	2658.50	11.70	.00	0	12.24	1.232
157.	3	3	2670.20	2.42	.00	0	30.53	1.941
158.	1	3	2672.62	13.87	.00	0	14.12	1.232
159.	5	3	2686.49	39.95	.00	0	180.83	2.567
160.	4	3	2726.44	11.91	.00	0	73.68	1.030
161.	1	3	2738.35	14.13	.00	0	65.74	1.232
162.	4	3	2752.48	6.83	.00	0	26.05	1.030
163.	1	3	2759.31	.94	.00	0	20.96	1.232
164.	3	3	2760.25	.46	.00	0	90.06	1.941
165.	4	3	2760.71	12.55	.00	0	8.23	1.030
166.	1	3	2773.26	20.27	.00	0	13.95	1.232
167.	4	3	2793.53	30.44	.00	0	32.82	1.030
168.	1	2	2823.97	3.29	.00	0	50.71	2.121
169.	3	3	2827.26	98.79	.00	0	67.01	1.941
170.	1	2	2926.06	15.95	.00	0	102.08	2.121
171.	4	3	2942.01	1.86	.00	0	148.47	1.030
172.	4	3	2943.87	37.01	.00	0	1.86	1.030
173.	1	3	2980.87	1.59	.00	0	54.82	1.232
174.	3	3	2982.46	.61	.00	0	155.20	1.941
175.	1	3	2983.07	61.31	.00	0	2.20	1.232
176.	3	3	3044.38	2.15	.00	0	61.91	1.941
177.	1	3	3046.53	25.35	.00	0	63.46	1.232
178.	1	2	3071.88	1.38	1.53	1	25.35	2.121
179.	4	3	3073.26	9.52	.00	0	129.40	1.030
180.	1	2	3082.78	50.26	2.04	1	10.90	2.121
181.	1	3	3133.04	251.03	.00	0	50.26	1.232
182.	2	3	3384.07	217.01	.00	0	816.32	1.941

APPENDIX D

OBSERVED DATA USED FOR VALIDATION OF MODEL SIMMTRA-345

SL. NO.	VEHICLE TYPE	ARRIVAL TIME
1	5	45
2	1	48
3	2	62
4	1	64
5	1	67
6	1	92
7	4	133
8	1	158
9	3	193
10	1	223
11	1	302
12	1	306
13	1	311
14	1	315
15	5	324
16	3	371
17	3	374
18	1	377
19	1	381
20	1	391
21	4	435
22	4	470
23	4	493
24	1	508
25	3	515
26	5	563
27	1	600
28	4	737
29	4	757
30	4	766
31	4	767
32	5	822
33	1	859
34	4	870
35	1	883
36	4	898
37	4	900
38	3	920
39	1	924
40	1	951
41	1	964
42	1	1013
43	1	1017
44	1	1043
45	3	1049
46	1	1059
47	4	1071
48	3	1077
49	4	1080
50	1	1105
51	5	1145
52	5	1167
53	1	1177
54	4	1190
55	1	1192
56	1	1195
57	3	1211

60	4	1221
61	1	1226
62	4	1230
63	4	1234
64	1	1256
65	1	1257
66	4	1260
67	1	1281
68	1	1284
69	2	1299
70	1	1300
71	4	1324
72	3	1423
73	3	1426
74	5	1452
75	4	1491
76	1	1531
77	4	1556
78	1	1610
79	1	1648
80	3	1673
81	3	1679
82	4	1704
83	4	1705
84	4	1734
85	1	1763
86	4	1810
87	4	1811
88	4	1824
89	1	1833
90	4	1896
91	5	1903
92	4	1942
93	1	1951
94	3	1965
95	1	1966
96	4	2014
97	3	2027
98	1	2031
99	4	2036
100	3	2044
101	4	2052
102	5	2076
103	1	2135
104	2	2180
105	1	2186
106	1	2190
107	3	2192
108	1	2201
109	4	2203
110	3	2252
111	1	2287
112	1	2304
113	3	2332
114	4	2355
115	2	2380
116	4	2388
117	1	2413
118	1	2439
119	3	2475
120	3	2485
121	1	2487
122	3	2505
123	1	2507

126	1	2533
127	1	2536
128	4	2539
129	4	2550
130	4	2559
131	5	2568
132	4	2582
133	1	2663
134	4	2718
135	1	2729
136	3	2769
137	4	2815
138	5	2857
139	1	2858
140	5	2861
141	4	2870
142	1	2883
143	4	2907
144	1	2934
145	1	2958
146	5	2976
147	4	3019
148	1	3051
149	4	3066
150	3	3070
151	1	3088
152	1	3117
153	3	3161
154	5	3177
155	1	3189
156	4	3205
157	4	3209
158	5	3213
159	5	3289
160	1	3291
161	1	3307
162	3	3362
163	5	3375
164	4	3383
165	1	3412
166	1	3414
167	4	3436
168	1	3491
169	3	3508
170	3	3512
171	5	3513
172	4	3522
173	3	3538
174	1	3543
175	1	3547
176	4	3570
177	2	3572
178	3.	3577
179	1	3578
180	1	3580
181	6	3589
182	5	3590
183	4	3592

APPENDIX E

THE TYPICAL DETAILED TABULAR OUTPUT OF SIMMTRA-345 WITH GIVEN OBSERVED DATA (3-Leg Intersection, Approach No. 1, Minor Road, Km. 20.000)

TABLE-DELAY for Approach No. 1

S.No.	Vehicle Type	Turning	Arrival Time (Sec)	Headway (Sec)	Delay (Sec)	Length of Que	Headway same veh. (Sec)	
1.	5	2	45.00	3.00	1.14	1	.00	7.371
2.	1	3	48.00	14.00	.00	0	.00	1.232
3.	2	3	62.00	2.00	.00	0	.00	1.941
4.	1	3	64.00	3.00	.00	0	16.00	1.232
5.	1	2	67.00	25.00	.00	0	3.00	2.121
6.	1	3	92.00	41.00	.00	0	25.00	1.232
7.	4	2	133.00	25.00	.00	0	.00	1.980
8.	1	3	158.00	35.00	.00	0	66.00	1.232
9.	3	2	193.00	30.00	.00	0	.00	2.607
10.	1	3	223.00	79.00	.00	0	65.00	1.232
11.	1	2	302.00	4.00	1.70	1	79.00	2.121
12.	1	3	306.00	5.00	.00	0	4.00	1.232
13.	1	2	311.00	4.00	.00	0	5.00	2.121
14.	1	3	315.00	9.00	.00	0	4.00	1.232
15.	5	2	324.00	47.00	.00	0	279.00	7.371
16.	3	3	371.00	3.00	.00	0	178.00	1.941
17.	3	3	374.00	3.00	.00	0	3.00	1.941
18.	1	3	377.00	4.00	.00	0	62.00	1.232
19.	1	2	381.00	10.00	.00	0	4.00	2.121
20.	1	3	391.00	44.00	.00	0	10.00	1.232
21.	4	2	435.00	35.00	.00	0	302.00	1.980
22.	4	3	470.00	23.00	.00	0	35.00	1.030
23.	4	2	493.00	15.00	.00	0	23.00	1.980
24.	1	3	508.00	7.00	.00	0	117.00	1.232
25.	3	3	515.00	48.00	.00	0	141.00	1.941
26.	5	3	563.00	37.00	.00	0	239.00	2.567
27.	1	2	600.00	137.00	.00	0	92.00	2.121
28.	4	3	737.00	20.00	.00	0	244.00	1.030
29.	4	2	757.00	9.00	.00	0	20.00	1.980
30.	4	3	766.00	1.00	.00	0	9.00	1.030
31.	4	2	767.00	55.00	.00	0	1.00	1.980
32.	5	3	822.00	37.00	.00	0	259.00	2.567
33.	1	2	859.00	11.00	.00	0	259.00	2.121
34.	4	3	870.00	13.00	.00	0	103.00	1.030
35.	1	3	883.00	15.00	.00	0	24.00	1.232
36.	4	3	898.00	2.00	.00	0	28.00	1.030
37.	4	2	900.00	20.00	1.14	1	2.00	1.980
38.	3	3	920.00	4.00	.00	0	405.00	1.941
39.	1	3	924.00	27.00	.00	0	41.00	1.232
40.	1	3	951.00	13.00	.00	0	27.00	1.232
41.	1	3	964.00	49.00	.00	0	13.00	1.232
42.	1	3	1013.00	4.00	.00	0	49.00	1.232
43.	1	3	1017.00	26.00	.00	0	4.00	1.232
44.	1	3	1043.00	6.00	.00	0	26.00	1.232
45.	3	3	1049.00	10.00	.00	0	129.00	1.941
46.	1	3	1059.00	12.00	.00	0	16.00	1.232
47.	4	3	1071.00	6.00	.00	0	171.00	1.030
48.	3	3	1077.00	3.00	.00	0	28.00	1.941
49.	4	3	1080.00	25.00	.00	0	9.00	1.030
50.	1	3	1105.00	40.00	.00	0	46.00	1.232
51.	5	2	1145.00	22.00	.00	0	323.00	7.371
52.	5	3	1167.00	10.00	.00	0	22.00	2.567
53.	1	3	1177.00	13.00	.00	0	72.00	1.232
54.	4	3	1190.00	2.00	.00	0	110.00	1.030

55.	1	3	1192.00	3.00	.00	0	15.00	1.232
56.	1	3	1195.00	16.00	.00	0	3.00	1.232
57.	3	3	1211.00	3.00	.00	0	134.00	1.941
58.	3	3	1214.00	5.00	.00	0	3.00	1.941
59.	1	3	1219.00	2.00	.00	0	24.00	1.232
60.	4	3	1221.00	5.00	.00	0	31.00	1.030
61.	1	3	1226.00	4.00	.00	0	7.00	1.232
62.	4	3	1230.00	4.00	.00	0	9.00	1.030
63.	4	3	1234.00	22.00	.00	0	4.00	1.030
64.	1	3	1256.00	1.00	.00	0	30.00	1.232
65.	1	3	1257.00	3.00	.00	0	1.00	1.232
66.	4	3	1260.00	21.00	.00	0	26.00	1.030
67.	1	3	1281.00	3.00	.00	0	24.00	1.232
68.	1	3	1284.00	15.00	.00	0	3.00	1.232
69.	2	3	1299.00	1.00	.00	0	1237.00	1.941
70.	1	3	1300.00	24.00	.00	0	16.00	1.232
71.	4	3	1324.00	99.00	.00	0	64.00	1.030
72.	3	3	1423.00	3.00	.00	0	209.00	1.941
73.	3	3	1426.00	26.00	.00	0	3.00	1.941
74.	5	3	1452.00	39.00	.00	0	285.00	2.567
75.	4	3	1491.00	40.00	.00	0	167.00	1.030
76.	1	3	1531.00	25.00	.00	0	231.00	1.232
77.	4	3	1556.00	54.00	.00	0	65.00	1.030
78.	1	3	1610.00	38.00	.00	0	79.00	1.232
79.	1	3	1648.00	25.00	.00	0	38.00	1.232
80.	3	3	1673.00	6.00	.00	0	247.00	1.941
81.	3	3	1679.00	25.00	.00	0	6.00	1.941
82.	4	3	1704.00	1.00	.00	0	148.00	1.030
83.	4	3	1705.00	29.00	.00	0	1.00	1.030
84.	4	3	1734.00	29.00	.00	0	29.00	1.030
85.	1	3	1763.00	47.00	.00	0	115.00	1.232
86.	4	3	1810.00	1.00	.00	0	76.00	1.030
87.	4	3	1811.00	13.00	.00	0	1.00	1.030
88	4	3	1824.00	9.00	.00	0	13.00	1.030
89.	1	3	1833.00	63.00	.00	0	70.00	1.232
90.	4	3	1896.00	7.00	.00	0	72.00	1.030
91.	5	3	1903.00	39.00	.00	0	451.00	2.567
92.	4	3	1942.00	9.00	.00	0	46.00	1.030
93.	1	3	1951.00	14.00	.00	0	118.00	1.232
94.	3	3	1965.00	1.00	.00	0	286.00	1.941
95.	1	3	1966.00	48.00	.00	0	15.00	1.232
96.	4	3	2014.00	13.00	.00	0	72.00	1.030
97.	3	3	2027.00	4.00	.00	0	62.00	1.941
98.	1	3	2031.00	5.00	.00	0	65.00	1.232
99.	4	3	2036.00	8.00	.00	0	22.00	1.030
100.	3	3	2044.00	8.00	.00	0	17.00	1.941
101.	4	3	2052.00	24.00	.00	0	16.00	1.030
102.	5	3	2076.00	59.00	.00	0	173.00	2.567
103.	1	3	2135.00	45.00	.00	0	104.00	1.232
104.	2	3	2180.00	6.00	.00	0	881.00	1.941
105.	1	3	2186.00	4.00	.00	0	51.00	1.232
106.	1	3	2190.00	2.00	.00	0	4.00	1.232
107.	3	3	2192.00	9.00	.00	0	148.00	1.941
108.	1	3	2201.00	2.00	.00	0	11.00	1.232
109.	4	3	2203.00	49.00	.00	0	151.00	1.030
110.	3	3	2252.00	35.00	.00	0	60.00	1.941
111.	1	3	2287.00	17.00	.00	0	86.00	1.232
112.	1	3	2304.00	28.00	.00	0	17.00	1.232
113.	3	3	2332.00	23.00	.00	0	80.00	1.941
114.	4	3	2355.00	25.00	.00	0	152.00	1.030
115.	2	3	2380.00	8.00	.00	0	200.00	1.941
116.	4	3	2388.00	25.00	.00	0	33.00	1.030
117.	1	3	2413.00	26.00	.00	0	109.00	1.232
118.	1	3	2439.00	36.00	.00	0	26.00	1.232
119.	3	3	2475.00	10.00	.00	0	143.00	1.941
120.	3	3	2485.00	2.00	.00	0	10.00	1.941

121.	1	3	2487.00	18.00	.00	0	48.00	1.232
122.	3	3	2505.00	2.00	.00	0	20.00	1.941
123.	1	3	2507.00	12.00	.00	0	20.00	1.232
124.	1	3	2519.00	4.00	.00	0	12.00	1.232
125.	1	3	2523.00	10.00	.00	0	4.00	1.232
126.	1	3	2533.00	3.00	.00	0	10.00	1.232
127.	1	3	2536.00	2.00	.00	0	3.00	1.232
128.	4	3	2538.00	12.00	.00	0	150.00	1.030
129.	4	3	2550.00	8.00	.00	0	12.00	1.030
130.	4	3	2558.00	10.00	.00	0	8.00	1.030
131.	5	3	2568.00	15.00	.00	0	492.00	2.567
132.	4	3	2583.00	80.00	.00	0	25.00	1.030
133.	1	3	2663.00	55.00	.00	0	127.00	1.232
134.	4	3	2718.00	4.00	.00	0	135.00	1.030
135.	1	3	2722.00	46.00	.00	0	59.00	1.232
136.	3	3	2768.00	47.00	.00	0	263.00	1.941
137.	4	3	2815.00	42.00	.00	0	97.00	1.030
138.	5	3	2857.00	1.00	.00	0	289.00	2.567
139.	1	3	2858.00	3.00	.00	0	136.00	1.232
140.	5	3	2861.00	9.00	.00	0	4.00	2.567
141.	4	3	2870.00	13.00	.00	0	55.00	1.030
142.	1	3	2883.00	24.00	.00	0	25.00	1.232
143.	4	3	2907.00	27.00	.00	0	37.00	1.030
144.	1	3	2934.00	24.00	.00	0	51.00	1.232
145.	1	3	2958.00	18.00	.00	0	24.00	1.232
146.	5	3	2976.00	43.00	.00	0	115.00	2.567
147.	4	3	3019.00	32.00	.00	0	112.00	1.030
148.	1	3	3051.00	15.00	.00	0	93.00	1.232
149.	4	3	3066.00	4.00	.00	0	47.00	1.030
150.	3	3	3070.00	18.00	.00	0	302.00	1.941
151.	1	3	3088.00	29.00	.00	0	37.00	1.232
152.	1	3	3117.00	44.00	.00	0	29.00	1.232
153.	3	3	3161.00	16.00	.00	0	91.00	1.941
154.	5	3	3177.00	12.00	.00	0.	201.00	2.567
155.	1	3	3189.00	16.00	.00	0	72.00	1.232
156.	4	3	3205.00	4.00	.00	0	139.00	1.030
157.	4	3	3209.00	4.00	.00	0	4.00	1.030
158.	5	3	3213.00	76.00	.00	0	36.00	2.567
159.	5	3	3289.00	2.00	.00	0	76.00	2.567
160.	1	3	3291.00	16.00	.00	0	102.00	1.232
161.	1	3	3307.00	55.00	.00	0	16.00	1.232
162.	3	3	3362.00	13.00	.00	0	201.00	1.941
163.	5	3	3375.00	8.00	.00	0	86.00	2.567
164.	4	3	3383.00	29.00	.00	0	174.00	1.030
165.	1	3	3412.00	2.00	.00	0	105.00	1.232
166.	1	3	3414.00	22.00	.00	0	2.00	1.232
167.	4	3	3436.00	55.00	.00	0	53.00	1.030
168.	1	3	3491.00	17.00	.00	0	77.00	1.232
169.	3	3	3508.00	4.00	.00	0	146.00	1.941
170.	3	3	3512.00	1.00	.00	0	4.00	1.941
171.	5	3	3513.00	9.00	.00	0	138.00	2.567
172.	4	3	3522.00	10.00	.00	0	86.00	1.030
173.	3	3	3532.00	11.00	.00	0	20.00	1.941
174.	1	3	3543.00	4.00	.00	0	52.00	1.232
175.	1	3	3547.00	23.00	.00	0	4.00	1.232
176.	4	3	3570.00	2.00	.00	0	48.00	1.030
177.	2	3	3572.00	5.00	.00	0	1192.00	1.941
178.	3	3	3577.00	1.00	.00	0	45.00	1.941
179.	1	3	3578.00	2.00	.00	0	31.00	1.232
180.	1	3	3580.00	9.00	.00	0	2.00	1.232
181.	6	2	3589.00	1.00	20.80	1	.00	7.541
182.	5	2	3590.00	2.00	19.80	2	77.00	7.371
183.	4	3	3592.00	2.00	.00	0	22.00	1.030