DEVELOPMENT OF SIMULATION MODEL

CHAPTER-7

DEVELOPMENT OF SIMULATION MODEL

7.0 GENERAL

After the development of models for various components of the traffic system, the next stage is the integration of these building blocks into a model. A brief description of the traffic flow simulation model along with various components and validation of the model are presented in this chapter.

7.1 LANGUAGE SELECTION

The first step in the development of simulation model is the selection of language for writing the program code. In general, there are two alternatives to write computer code for simulation exercises. The computer code can be written in a general purpose language such as FORTRAN, PASCAL, C, C++ or using a special purpose simulation language such as SIMULA, GPSS, SIMSCRIPT, GASP, SIMPAC, DYNAMO etc. Even though the special purpose simulation languages have the advantages of less programming time and in-built error
checking routines, the advantages such as less flexibility and increased computer running times limit the suitability of these languages for traffic flow simulation applications. Many of the traffic simulation programs were written in general purpose languages: FORTRAN language (SOVT, TWOWAF, SOFOT, TRARR), C language (DRACULA, MICSTRAN), C++ (PLANSIM-T, SITRA-B). The VTI model was written in SIMULA, a special purpose simulation language. For the present work, C has been chosen as the programming language due to its many advantages, especially the ability to handle graphics and familiarity.

7.2 INTERNAL BOOK KEEPING

To achieve efficient operation of the simulation program it is essential to represent the roadway and vehicle characteristics in a logical form so that it requires minimum computer storage and time. The different systems generally used for representation of the system are: Physical representation, Memorandum representation, Mathematical notation, Modified mathematical notation and List processing or chaining. A detailed description of these representation systems is given in Gerlough and Huber (1965) and Drew (1968). All these methods have their own advantages and limitations. The modified mathematical notation technique and list processing technique are known to be superior to other techniques.

The concept of three-dimensional circular array used in the modified mathematical notation cannot be applied to mixed traffic flow, as the vehicles do not observe lane discipline. The system that uses vehicle-based arrays was thus used in mixed traffic simulation models. In the present study, the different characteristics of a vehicle were combined to form a structure. This structure
was assigned a number that indicates the position of the vehicle in queue. For continuous operation and to circumvent the problem of computer memory shortage, the Stack Data Structure was used. In this approach, once a vehicle leaves the test section, its related characteristics are popped out and the statistics of other vehicles are updated. Thus, the memory allocated to the leaving vehicle is freed and is allocated to the vehicle entering the test section. Fig 7.1 illustrates this. It should be noted that the characteristics of the leaving vehicle should not be assigned to the entering vehicle, as in circular track concept, which introduces stochastic feed back effects at higher flows (Luk 1976).

7.3 TIME FLOW MECHANISM

As it is hardly possible to monitor all the simulated vehicles simultaneously or continuously, it becomes necessary to scan the system (i.e. examine each vehicle in turn) at specified intervals of simulated time. The two basic approaches that could be adopted are time-based and event-based scanning. In mixed traffic, a large number of significant events such as changes in speeds, changes in position of vehicles, changes in state of vehicles take place simultaneously at a number of places. It is advantageous to use time based scanning technique under such situations.

The limitation of time scanning technique is that the events are assumed to take place at the end of the interval and so tends to give less accurate results. This limitation can be overcome by reducing the scan interval, but at the cost of increased simulation time. In general, one second scan interval was found satisfactory. The scanning interval is user selectable in the present model.
However, considering the complexity of the system and availability of high speed computers, a 0.3 sec scan interval was selected in this study.

![Flowchart](image)

**Fig 7.1 Stack Data Structure**

### 7.4 GENERAL DESCRIPTION OF THE MODEL

The simulation model consists of a main program, which acts as master for the rest of the subroutines, which define the various component models. The submodels include the input module, output module and processing module. The structure of the model is presented in Fig. 7.2.
START

Read Input

Y

Randomise Seed Numbers

Randomise seed numbers

N

Is total proportion of vehicles = 1.0

N

Give Error Message

END

Y

Generate Graphics Display

Create image of road
Generate vehicle images
Draw road

N

Initialise Parameters

Calculate cumulative percentage composition of vehicle classes

Sim_Clock = 0

A

Y

Sim_Clock = Sim_time

END

B

Fig 7.2 Structure of Simulation Model (contd.)
Fig 7.2 Structure of Simulation Model
7.4.1 Input Module

The input subroutine reads the needed inputs from different files. Inputs to the model can be grouped into four categories:

- Road characteristics (length and width of road, length of the road to be displayed),
- Vehicle characteristics (Dimensions, mean and standard deviation of free flow speeds, maximum acceleration/deceleration values, default path of vehicles),
- Stream characteristics (entry flow, percentage composition of different vehicles),
- Data for various models (neural network weights/regression coefficients of desired frontal spacings, lateral clearances, car-following models, acceleration/deceleration models, free lateral placement, etc.) and
- General data (simulation time, scanning interval, duration of sampling period for recording the outputs, serial number of vehicle whose characteristics are to be stored, option to randomise seed numbers for random number generation).

The road width can be varied (need not be in terms of lanes) as per the requirement of the simulation experiment. The length of the road is also a variable in the model. However, the length of the road and the section where the observations have to be taken depend on the length of warm-up zone. The model is capable of accommodating up to ten types of vehicles.

7.4.2 Random Numbers

Road traffic systems with the driver-vehicle unit being one of the basic elements are characterised by many stochastic processes. Generation of random numbers
is a fundamental element in simulation of stochastic systems. The random number generator used in this study is the linear congruential random number generator proposed by Park and Miller (1988) with Bays – Durham shuffling algorithm. The random number generator gives a uniform random deviate between 0.0 and 1.0.

In simulation of complex systems such as traffic systems, it is often necessary to deal with several independent random processes. Random numbers are required to create these random processes. If the random numbers required for generating different random processes are taken from a single series of random numbers, then the random variates generated for a particular process will lack the required characteristics. To overcome this problem, separate seed numbers were used to generate the sequences of random numbers required for different processes. For example, separate sequences of random numbers were used to assign the desired speeds of different classes of vehicles generated. The program has the capability of generating 100 sequences of random numbers.

The random number generator generates the same sequence of random numbers for a given seed number. This results in the same conditions being simulated for a given set of input values. In simulation of stochastic systems it becomes necessary to generate various possible scenarios for the specified set of conditions. At the same time, during the debugging of program, it is necessary to generate the same sequence of random numbers so that the error identification will be easy. An option was provided in the program to randomise the seed numbers so that different random numbers will be generated for a particular process on each trail.
7.4.3 Generation of Non Uniform Variates

The general requirement in simulation is for a sequence of random numbers, which follow the distribution that best describes the process under study. Uniformly distributed random numbers, generated as described in the previous article, are used for generating such numbers. Other variates needed in the present study are the exponential variates and normal variates. The inverse transformation method and the method based on central limit theorem were used to generate exponential variates and normal variates respectively.

7.4.4 Generation of Vehicle Arrivals

The arrival process consists of the generation of inter arrival times of the vehicles at the entry to the simulated stretch. The arrivals are generally simulated by sampling from specified headway distributions. It is well established that the headways in free flow conditions could be described by exponential distribution but it is not the same in platoon flow conditions. As no specific distribution will be able to describe the headways over all the ranges of flows in mixed traffic, the warm zone approach has been adopted in this study. In this approach, suitable length of hypothetical road is added before the simulated stretch. The vehicle arrival times at the entry to the warm-up zone were obtained by sampling from exponential distribution. The vehicles thus generated are moved through the warm-up zone as per the flow logic of the model.

7.5 VEHICLE CHARACTERISATION

After generating the arrival pattern, it is necessary to identify the type of vehicle that would be entering the test section and assign its characteristics. The vehicle type was identified on the basis of cumulative uniform distribution for the given
composition of traffic stream. For this purpose one sequence of random numbers was used. Identification of vehicle type is presented in Fig 7.3.

![Flowchart](image)

**Fig 7.3 Subroutine to Identify Vehicle Type**

The characteristics to be assigned to the generated vehicles include the physical dimensions, the free flow speeds, the acceleration and deceleration characteristics and the desired linear and lateral clearances.

### 7.5.1 Physical Dimensions of the Vehicles

The physical dimensions of the vehicles to be specified in simulation model include the length and the width of the vehicles. The physical dimensions of the design vehicle of different classes as recommended by Indian Roads Congress (IRC SP - 41, 1994) were used in this study. After identifying the type of vehicle, the dimensions of vehicles are assigned based on type of vehicle.
7.5.2 Free Flow Speeds

The next part in the vehicle characterisation is to assign the free flow speeds to the generated vehicles. Free flow speed is the speed at which a vehicle is driven when it is not under the influence of any other vehicles. No vehicle will be allowed to exceed the assigned free flow speed. Each vehicle generated was assigned the free flow speed sampled from normal distribution with the mean and standard deviations values as presented in Table. 4.14. Separate random number sequences were used for determining the free flow speeds of different classes of vehicles. Illustration of assignment of various characteristics to the generated vehicle is given in Fig. 7.4.

7.5.3 Free Lateral Placement

Each of the generated vehicles has to be assigned the position it is likely to occupy across the width of road in case it is not under the influence of any other vehicle. The free lateral position was determined using the regression models developed based on field observations and incorporating a random component to reflect the driver dependent variability.

7.5.4 Vehicle Placement

A generated vehicle is placed at the beginning of the simulation stretch after considering actual time of arrival at entry and nearest updating time. The available and required linear clearances are also being taken into consideration before fixing the longitudinal position of a vehicle at the time of entry into the simulation stretch. If the available clearance is less than the required clearance, the speed of vehicle is reduced depending on the available clearance. If the available clearance is still insufficient, the vehicle is placed before the entry point.
The lateral position of a vehicle at entry is fixed randomly and taking into consideration the available and required lateral clearances.

```
Serial No. of seed = vehicle type
Generate 12 random numbers
Find sum of 12 random numbers
Calculate free flow speed, using mean & standard deviation of free flow speed for given vehicle type
```

Fig 7.4 Subroutine to Assign Characteristics

As presented earlier, the simulated system is scanned and updated after each increment of simulated time. Processing of all the vehicles, from the first vehicle to the last vehicle, in the simulated system is carried out at every scanning of the system. If a vehicle’s longitudinal position is greater than the length of simulated stretch then that vehicle will be removed from the list and all other vehicles are updated in the list. Thus, as and when a vehicle leaves the simulated stretch, the memory allocated for that vehicle is freed and is allocated to the next vehicle in the list. The first vehicle is moved with its desired speed and its lateral position is
determined based on flow logic. All subsequent vehicles are moved through the simulated system as described in the vehicle manoeuvring logic.

7.6 VEHICLE MANOEUVRING LOGIC

The processing of the vehicles through the simulated traffic system forms the core of the simulation model. For each vehicle, the vehicles in the surrounding are determined. In case of lane disciplined traffic it is done on the basis of lane occupied. In case of heterogeneous traffic consisting of vehicles of different dimensions, it is a tough task to find the vehicles in the surroundings. This is done considering the lateral space (sum of required clearance on left, width of vehicle and required right clearance) required for the vehicle to continue at the present speed. For each vehicle, the vehicle on the front, the vehicle on front left, the vehicle on the front right, the vehicle on the left, the vehicle on the right, the vehicle at the back, the vehicle at back left and the vehicle at back right are determined. Consider the vehicles shown in Fig. 7.5. Let R be the subject vehicle. B is the vehicle in front, C is the vehicle on front left, D is the vehicle on front right, E is the vehicle on the left, F is the vehicle on the right, G is the vehicle on the back left, H is the vehicle on the back, I is the vehicle on the back right.

Fig 7.5 Schematic Representation of Positions of Vehicles
The headway with respect to the nearest front vehicle is determined and if it is
greater than the threshold headway the vehicle is considered to be in the free
flowing regime. In this case, if the vehicle's current speed is lower than its desired
speed, it accelerates at the normal acceleration rate to achieve its desired speed;
if the current speed is higher than the desired speed, the vehicle decelerates with
the normal deceleration rate to slow down. Also, a free flowing vehicle moves
towards its free lateral position (default path) at the rate of lateral movement, if it
need not move to the side to give way to a fast vehicle to overtake.

If a vehicle is not able to move under free flow conditions, the vehicle will move to
the right side and overtake the leading slow vehicle using the space available
adjacent to the vehicle in front. This can be called as 'Fly-over taking' condition.
Some times it may so happen that for a vehicle under consideration there may
two vehicles in the front. Then the vehicle on the front right will be identified and
will be taken as the reference vehicle.

If it is not possible to overtake the leading slow vehicle, then the vehicle will follow
the lead vehicle at a reduced speed, till overtaking opportunity is available. This
can be called as 'Following' condition. This is preceded by 'Decelerating' state
and followed by 'Accelerating' state.

So a vehicle can be in any one of these five states at a given point of time. The
logic used for movement of vehicles through the simulated stretch was developed
taking into account the available and required linear and lateral clearances for a
vehicle to continue in a particular state or change to a different state.
Logic

➢ If the frontal headway is greater than or equal to the threshold headway, the vehicle will accelerate/decelerate to its desired speed or continue at its desired speed. (Free Flowing Condition)

➢ If the available frontal headway is less than the threshold headway and the available total lateral clearance is greater than or equal to the required total lateral clearance, the vehicle will initiate overtaking.

➢ If the clearances with respect to the vehicles in the target path are greater than required clearances, then the vehicle continues to overtake. Let the vehicles A & C are in the target path of the subject vehicle (R). The lead gap, gap with respect to the lead vehicle B in the target path and lag gap, gap with respect to the lag vehicle C in the target path will be determined based on the positions and speeds of the vehicles and if they are greater than the required lead and lag gaps then the subject vehicle will move laterally to the target path, as shown in Fig 7.6. The required gaps are determined taking into consideration the type and speed of the vehicles in target path.

➢ If moving to the target path and overtaking is not possible, the vehicle will follow the vehicle in the front. For this purpose, the car-following subroutine is invoked.

---

**Fig 7.6 Lead & Lag Gaps**

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A vehicle in the car-following mode continuously looks for an overtaking opportunity and will initiate the overtaking as and when an opportunity is available.

The various subroutines that are part of the vehicle manoeuvring logic are presented in Fig 7.7 to 7.10.

7.7 OUTPUT MODULE

During the scanning and updating process at the end of each scan interval, each and every vehicle is examined whether it had passed any of the control points. In case it had passed, the information of the vehicle was recorded in a separate file. At the end of simulation, the recorded information were analysed and the required output were obtained. The simulation model output included the stream characteristics viz., the flow, the density and the stream speed and the speeds of individual vehicles.

Provision has been made in the program to obtain the number of overtakings performed and the headways also. It is also possible to define any number of control points, at which the information of the vehicles has to be recorded.

7.7.1 Graphics Output Module

A graphics display module that facilitates the visual observation of vehicles as they move through the simulated system was specially incorporated in the simulation program. The graphics module include various functions for drawing of a blank road image, drawing of windows for display of simulation status, display of the simulation status, generation of vehicle images, putting the vehicle images at proper positions on the screen, etc. Components and working of graphics module are shown in Fig.7.11.
Fig 7.7 Subroutine update_vehicle_data
Fig 7.8 Function MOVE

- cisp = Change in speed
- dsp = Free flow speed
- csp = Speed
- lp = lateral placement
- flp = free lateral placement
- ld = lateral displacement

START

Speed - free flow speed

< 0
Call acceleration
Calculate cisp

Is cisp > dsp - csp
Y
Cisp = dsp - csp

N
N

> 0
Call deceleration
Calculate cisp

Cisp = csp - dsp

Cisp = 0

< 0
Lp - flp

Calculate ld

Id = 0

Calculate ld

Calculate new longitudinal and lateral position

Conflict with any other vehicle

Y
Move straight

N
Return
Fig 7.9 Function move_right_overtake
A realistic display of vehicle movement was achieved by erasing and drawing images of vehicles at the end of each scanning interval. The graphics display provided an opportunity to check for any inconsistencies, such as two vehicles occupying the same position at same time, and to apply suitable corrections. As the vehicles have to be erased and redrawn at the end of each scan period, running of simulation model with graphical display takes lot of computer time. An option has been provided to run the simulation model without the graphics display so that experimental runs can be conducted in less time. Fig 7.12 & 7.13 show screen shots of Graphic Display of simulation model.
Fig 7.11 Components of Graphics Module

Another feature of the model is that the user can interact with the program through key board. The program will check if any key is pressed during each scan interval and if any key is pressed it will call the function 'user_interrupt'. The working of this function is presented in Fig. 7.14.
Fig 7.12 Graphic Display of the Model with Empty Roadway

Fig 7.13 Graphic Display of the Model with Vehicles
START

ch ← key press

N →

Is ch='Q'

Y → Call close_program

N →

Is ch='T'

Y → Pause/Start

N →

Is ch='P'

Y → Call write_output

N →

Is ch='D'

Y → Show Vehicle Images

N →

Is ch='F'

Y → Pan right displayed road stretch by 10 m

N →

Is ch='H'

Y → Pan right displayed road stretch by 100 m

N →

Is ch='R'

Y → Pan left displayed road stretch by 10 m

N →

Is ch='B'

Y → Pan left displayed road stretch by 100 m

N →

Is ch='S'

Y → Display first 200 m of simulation stretch

N → Return

Return

Is ch='E'

Y → Display first 200 m of simulation stretch

N →

Return

Fig 7.14 Function User_Interrupt
One of the features is to display or not to display the images of vehicles. By default, the images will not be displayed and if required key 'D' has to be pressed.

Another feature is to pan the view of the simulated stretch either forward or backward. By default the section at the beginning of the simulated stretch will be displayed. The view can be moved forward by 100 m by pressing the key 'H'. This feature enables to follow a selected vehicle as it moves through the simulated stretch.

7.8 DETERMINATION OF WARM-UP ZONE LENGTH

In the warm-up zone approach, it is assumed that the traffic would reach a state of equilibrium by the time the vehicles reach the entry to the observation stretch. Hence, the system will begin to give true results only after the traffic stream achieves spatial and temporal stability. To arrive at the length of the warm-up zone and the time-taken for the system to stabilise, the following experiments were conducted on the model.

Experiments were conducted with 2 km as the length of simulation stretch and a simulation time of 60 minutes for various volume levels. The headways were recorded at every 0.100 km sections. Headways at successive sections were compared using the percent frequency distribution diagrams prepared. The frequency diagrams of headways for the volumes 500, 1500 and 2500 vph are presented in Fig.7.15, 7.16 & 7.17 respectively. The headways were also compared by calculating the sum of normalised squared deviations of percent frequencies of headways at successive sections, which are given in Table 7.1. It was observed from these frequency distribution diagrams and the values of sum
Fig. 7. 15 Percentage Frequency Distribution of Headway – 500 vph
Fig. 7. 16 Percentage Frequency Distribution of Headway – 1500 vph
Fig. 7. 17 Percentage Frequency Distribution of Headway – 2500 vph
of normalised squared deviations that flow stabilises at 500 m from the entry point of the simulated stretch. Hence, the warm-up zone length was taken as 500 m and observations for the stream characteristics were taken over 500 – 1500 m stretch. The time required to traverse 1500 m length is approximately 3 minutes, hence, the warm up time was selected as 5 minutes.

### Table 7.1 Sum of Normalised Squared Deviations

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<tr>
<th>Section at, m</th>
<th>500</th>
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<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>4000</th>
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<td>0.34</td>
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</table>

### 7.9 VALIDATION OF THE MODEL

Validation is the process of checking the reality of the model in representing the system under study. The three broad types of validity generally applied to traffic flow models are the predictive, the structural and the elemental validity.

Predictive validity means that the model is capable of predicting outcomes with an acceptable degree of accuracy, i.e. there should be statistical concordance between predicted and real values. Structural validity means that the model structure is a valid representation of the traffic flow process. The ability of the model to predict outcomes with reasonable accuracy is generally taken as
evidence of structural validity. Elemental validity applies to specific elements or components of the model. It is particularly relevant to the theoretical aspects of a model's formulation, or to simplifying assumptions made. Elemental validity helps furthering the state-of-art at the theoretical level. In simulation modelling, elemental validity and predictive validity are the two main things with which the developer has to be concerned.

In the present work, the elemental validation was done by comparing the outcomes of the component models with corresponding field values. The field data collected for development of various component models was split into two parts, one part for calibration of the model and the other part for validation. In many cases, it was found that the model values were in close agreement with actual values.

The vehicle movement logic was validated making use of the display of the simulated vehicles provided by the graphics output module. In the absence of such a device, the modeller will be unaware of the unwanted things, like, more than one vehicle occupying the same position, vehicles coming very close to each other, etc., taking place in the simulated system. With the help of graphics display, it was possible to observe each and every vehicle as it passed through the study section for any inconsistencies. Many hours of time were spent in front of the monitor watching the display and modifications were made to the model as and when found necessary.

Predictive validation was carried out in two stages. Firstly, it was checked whether the model is reproducing the general trends observed in real life situation. For instance, it is generally accepted that the average stream speed
reduces with increase in vehicular volume or density. For this purpose, the model was run by varying the input volume from 100 vph to 5000 vph for cars only stream. The model outputs in the form of speed-density, speed-flow and flow-density plots were prepared and are given in Fig. 7.18. It could be observed that the model could reproduce the general trend as expected in reality.

The model was also validated by comparing the model outputs with the corresponding field data collected at two locations in Calicut city. The model outputs and the field values are presented in Table 7.2. It could be observed that the predicted values are not much different from actual values. The literature survey has revealed that there are no clear guidelines in regard to the allowable percentage error. Hence, the model was considered to be reasonably good in replicating the field conditions and hence accepted for further experimentation.

<table>
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<th>S.No.</th>
<th>Simulated Volume</th>
<th>Simulated Speed</th>
<th>Observed Volume</th>
<th>Observed Speed</th>
<th>Percentage difference in Speed</th>
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Fig 7.18 Speed – Density - Flow Plots
7.10 CONCLUSIONS

Development of the neural integrated simulation model by integrating the models for various components has been described in this chapter. The simulation model developed in 'C' can simulate the unidirectional traffic flow with options to vary the traffic flow composition, width of road, length of simulated stretch. The model gives steam speed, desired speed of stream, average flow rate, average density, percentage composition, headways, etc as the output. The model provides an visual display of the vehicles as they move through the simulated stretch and this feature was found to be very helpful in observing the working of the simulation model for any inconsistencies. The simulation model was validated by comparing the simulation outputs with values from field observation. The model thus developed is intended to be used for conducting experiments with the aim of understanding the behaviour of mixed traffic and the details of the experiments and analysis of results are presented in the coming chapter.