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HOW TRAF-NETSIM WORKS

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ABSTRACT

PAKSARSAWAN, S, MONTGOMERY, FO and CLARK, SD (1992). How TRAF-NETSIM works. *ITS Working Paper* **380**, Institute for Transport Studies, University of Leeds, Leeds.

This paper describes how TRAF-NETSIM works in detail. It is a review of the TRAF-NETSIM micro-simulation model, for use in the research topic "The Development of Queueing Simulation Procedures for Traffic in Bangkok".

TRAF-NETSIM is a computer program for modelling of traffic in urban networks. It is written in the FORTRAN 77 computer language. It uses bit-manipulation mechanisms for "packing" and "unpacking" data and a program overlay structure to reduce the computer memory requirements of the program.

The model is based on a fixed time, and discrete event simulation approach. The periodic scan method is used in the model with a time interval of one second.

In the model, up to 16 different vehicle types with 4 different vehicle categories (car, carpool, bus and truck) can be identified. Also, the driver's behaviour (passive, normal, aggressive), pedestrians' movement, parking and blocking (*eg* a broken-down car) can be simulated. Moreover, it has the capability to simulate the effects of traffic control ranging from a simple stop sign controlled junction to a dynamic/real time control system. The effects of spillbacks can be simulated in detail. The estimation of fuel consumption and vehicle emissions are optional simulations. Car following and lane changing models are incorporated into TRAF-NETSIM. The outputs can be shown in US standard units, Metric units, or both.

Key Words: Microsimulation, traffic, discrete event simulation, urban network, queueing delays, Bangkok, TRAF-NETSIM

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HOW TRAF-NETSIM WORKS

1.BACKGROUND

TRAF-NETSIM (Rathi and Santiago, 1990b) is a microscopic stochastic simulation model which describes the operational performance of vehicles travelling on urban street networks. It was originally developed for the Federal Highway Administration (FHWA) more than 20 years ago and has been continuously enhanced. This version has already been tested and approved by the FHWA. TRAF-NETSIM has been used by over 130 local and state agencies (Chang and Kanaan, 1990), also by many education institutes and private sectors.

Initially, this program was called UTCS-1. Then, the first version of NETSIM was released in 1971 and was updated again in 1973 and 1978. Subsequently, the model was integrated within the TRAF simulation system in early 1980. Finally, it has been called TRAF-NETSIM since that time.

The model is a traffic simulation for driving on the right. To apply to driving on the left, it only requires changes of a left, a left most or a left turn pocket lane to a right, a right most, or a right turn pocket lane, respectively. The description that follows is for driving on the right.

The current TRAF-NETSIM (version 2) modified for this research is the PC version. This version has been distributed in the USA and overseas through traffic software distribution centres such as McTRANS at the University of Florida.

The input data and the output results from running TRAF-NETSIM can be displayed in a graphical format. The graphics package for TRAF-NETSIM is called GTRAF. The results from running TRAF-NETSIM are converted to graphics data files for GTRAF by CONVRT (a conversion program). GTRAF (FHWA, 1989C) can display the input data for review and the output results for analysis in static graphic format, and the output results for review in an animated format. The graphics output is optional, and not a main requirement of this research.

TRAF-NETSIM is written in the FORTRAN 77 computer language. It uses PARAMETER statements to define the dimensions of arrays. Also, it uses bit-manipulation mechanisms for "packing" and "unpacking" data using mod and division functions, and powers of 2 and 10. Moreover, a program overlay structure is used in this model. Both the above techniques have been adopted to reduce the computer memory requirements of the program. The program is compiled by using Microsoft FORTRAN Version 5.0 and is linked by using the PLINK86+ linker which is a special linker software capable of producing complex overlays.

Documentation and comment statements of TRAF-NETSIM are in English.

2.AN OVERVIEW OF TRAF-NETSIM

TRAF-NETSIM is based on a fixed time and discrete event simulation approach, which describes the dynamics of the traffic operations in urban street networks. The periodic scan method is used in this model with a time interval of one second.

In the model (FHWA, 1989b) vehicles can be identified by a category (bus, car, car-pool, truck), a type (up to 16 different vehicle types with different operational and performance characteristics) within each category, and by driver behaviour characteristics (passive, normal, aggressive). Pedestrians, parking and blockers (*eg*, a broken car, and a loading truck) are also considered in TRAF-NETSIM. Flared approaches are allowed in this model. There is, however, no assignment model in TRAF-NETSIM.

The simulated network in TRAF-NETSIM is represented by nodes and links. The nodes and links of the network represent junctions and urban streets, respectively. Concerning the links, one link represents a unidirectional traffic road, *ie* if the urban street is one way, there is only one link, while a two way street is described by two links.

Each network link may have an associated source/sink node which emits/absorbs traffic onto/from that link. These nodes serve to represent traffic at such facilities as garages, parking lots, side streets, alleys, etc.

TRAF-NETSIM has the capability to simulate the effects of traffic control ranging from a simple stop sign controlled junction to a dynamic/real-time control system. The effects of blockers and the blocking back of queues on surface street networks can be simulated in a highly detailed manner.

Acceptable gaps are used for the sign control system. Signal controllers may be either fixed time or actuated. The logic of a dynamic control system is based on the type 170 signal controller. Section 6 (traffic Control) gives more detail on this.

The queue discharge headways and the start up lost time can be classified into 4 distribution types depending on the driver behaviour. This is an option which the user can specify. The defaults of the mean queue discharge headway and the average start up lost time are 2.2 and 2.5 seconds, respectively.

Concerning priority junctions, acceptable gaps in near-side and far-side cross-street traffic are considered for each vehicle before it passes through a stop-line or give-way at a junction. These gaps are extracted from a decile distribution depending on the driver behaviour by a random number.

TRAF-NETSIM considers the gradient for each link. It allows for a gradient between -9% and +9% for simulation traffic links in the network.

The total simulation time duration in TRAF-NETSIM can be divided into 19 time periods. This is to accommodate the changing conditions of traffic in the network over time, *eg* traffic volumes, turning movement percentages, and lane channelizations. Each time period can be further subdivided into a sequence of time intervals. In general, the time interval duration is set to the most common signal cycle length in the study network. The duration of each time period must, however, be an integer multiple of the time interval duration.

For each vehicle entering into the network, the vehicle and driver behaviour are generated randomly based on a Monte Carlo technique (Ying Wong, 1990). Monte Carlo simulation (Neelamkavil, 1987) is performed by using an approximate stochastic simulation model of a deterministic system.

A car following model and a lane changing model are incorporated into TRAF-NETSIM. The vehicles enter the network through entry links and source nodes, and are moved whilst responding to traffic control devices, pedestrian activity, transit operations, the performance of neighbouring vehicles and other conditions which influence driver behaviour.

The output results from running TRAF-NETSIM (FHWA, 1989b) include a variety of measures of effectiveness (MOE), *eg* blocking back of queues, delays, speed, turning movements, and volumes. Also, the estimation of fuel consumption and emissions can be obtained from this output.

The output can be divided into three types: each link of the network, groups of links and the whole network (over the user-specified time periods).

The maximum sizes of arrays to describe the network that may be simulated by TRAF-NETSIM are as follows (unit in brackets):

Number of Actuated Controllers	18	(controller)
Number of Buses	256	(vehicle)
Number of Bus Routes	25	(route)
Number of Bus Stops	99	(bus stop)
Number of Detectors in a Link	10	(detector)
Number of Links	150	(link)
Number of Long Term Events	60	(event)
Number of Nodes	75	(node)
Number of Sensors in the Network	200	(sensor)
Number of Vehicles at any second (in the Network)	1500	(vehicle)

TRAF-NETSIM (Santiago and Rathi, 1989) allows the user to test and analyse in detail the operation effects of: bus and truck traffic, channelisation, detectorisation, geometrics, one-way versus two-way operation, parking activities, pedestrian actions, signalization, and traffic management for special events in special periods.

Even though TRAF-NETSIM (Rathi and Santiago, 1990c) has been developed over several years and is one of the most suitable tools for analysis of traffic, it still has many limitations both in terms of its logic and capabilities, *eg* traffic circles (roundabouts), an intersection logic and weaving and merging manoeuvres.

One of these limitations has been refined for this research, *ie* the junction logic. The details are shown in Chapters 3 and 4 of Paksarsawan (1992).

3.THE TRAFFIC GENERATION

In general, there are two basic approaches in simulation: Continuous and Discrete System (Neelamkavil, 1987). The former applies where variables (attributes of the system elements or entities) represent smooth changes, *eg* water flow. The latter applies where changes in variables take place instantaneously in discrete steps, *eg* number of customers in a bank.

TRAF-NETSIM is based on a fixed time and discrete event simulation approach. It simulates traffic flow on urban street networks by representing the movement of individual driver vehicle combinations. It uses a stochastic process, with random sampling from discrete and continuous distributions to represent the real life behaviour.

The generation of movement-specific emission headways for the "emission", or "generation" of vehicles entering the network in TRAF-NETSIM uses the values specified for entry volumes and turning percentages on entry links. Vehicles are regularly introduced into the network by turning movements at the stop line of an entry link (at these emission headways). An identification number, a vehicle type and a category are assigned to each vehicle.

A new vehicle is placed at the stop line of the entry link on one of the lanes available for that turning movement. The vehicle will leave the entry link and enter into the network, when the traffic control at the entry link and the traffic conditions on the receiving link permit it. The entry links have no lengths or queues.

If the vehicle is due for emission from the entry link, and the lane for that turning movement has a vehicle already waiting for emission, the new vehicle will be delayed until that lane is available. Vehicle emissions are continually scheduled at the turning movement specific headways.

Vehicles are emitted from the mid-link source stations in a similar pattern. Buses are emitted at the stop line of the entry link at the route-specific headways and traverse the network along the given routes.

When each vehicle, other than a bus, enters the network, vehicle and driver behaviour are created randomly. Then, its turning movement from the previous link to the new link is randomly assigned while satisfying the user's specification, and the percentage (volume) of link specific turning movements. Also, the driver behavioural and operational decisions, for example, a gap acceptance, a free-flow speed, a queue discharge headway and an amber phase response, are also randomly generated.

To account for the above, the model employs Monte Carlo procedures. There are three steps for generating the pseudo random behaviour in TRAF-NETSIM.

The first step consists of generating a random number. Then, a uniform deviate (U) is generated from this random number. The generation of a random observation from the probability distribution is the final step.

The model uses an initial random number seed as the basis for all stochastic decisions in the simulation process. The generation random number in TRAF-NETSIM is based on a linear recursive procedure (Rathi and Santiago, 1990a). A multiplicative congruence technique which is a special case of linear congruential generators (Neelamkavil, 1987) is used in this model. A sequence of random numbers are generated by always calculating the new one from the previous one.

The recursive relation (FHWA, 1989a, Neelamkavil, 1987, and Rathi and Santiago, 1990a) is as follows:

$$X_{n+1} \quad = \quad \text{mod}[(a \times X_n + \text{mod}(X_n, k) \times k), m] \qquad \text{(B1)}$$

where a, m, and k are positive integers. This procedure generates random number between k+1 and m-1. From this random number, a uniform deviate (U) between 0 and 99 is produced by dividing X_{n+1} by the integer "p". Then the uniform deviate (U) is used to create a random number observation from the decile uniform probability distributions which are used in TRAF-NETSIM.

In the current version of TRAF-NETSIM, the values of a, k, m, and p are defined as follows:

a = an arbitrarily selected odd number 1, 3, 7, or 9
k = 10,000
m = 100,000,000
p = 1,000,000.

The initial value of the random number seed (X_o) is a user input or default value. This value is an odd number (except one ending in 5) of up to 8 digits.

There are two types of random number seeds used in TRAF-NETSIM. One is an identical traffic stream random number seed (a base seed of each vehicle). The other is a general random number seed (a common seed).

The former is used to generate the traffic stream for a given simulation run, such as the decisions of the routing pattern of each vehicle and the characteristics of each driver/vehicle combination.

The latter is used for all time-dependent stochastic decision processes, *eg* accepting available gaps for turns, determining location and duration of lane blockages.

The advantages (Rathi and Santiago, 1990a, and Rathi, 1992) of using only one random seed for all stochastic process are as follows. (i) The output results from running TRAF-NETSIM are more amenable to sophisticated statistical analysis techniques such as variance reduction. (ii) It is much simpler to implement and more user friendly. (iii) Also, it is more efficient in terms of disk space utilization and volume input/output data.

4.ENTERING THE VEHICLES INTO THE NETWORK

Vehicles enter into the network at a uniform rate proportional to the input volume. For example, if the input volume is 3600 vehicles per hour, then the number of vehicles entering is 1 per second. Each vehicle is assigned to a lane depending on its movement. This means that a left/right turn movement vehicle is assigned to the left/right most lane. A straight through movement vehicle is assigned to the lane which has the most unoccupied space.

When vehicles enter the lanes, each vehicle travels in a lane by a logical downstream path. If a vehicle is a leader, an acceleration rate is applied to the vehicle until it achieves a free flow speed. The following vehicles accelerate to reach the free flow speeds while keeping a safe stopping distance between each other using the car following model, which is described below (Section 14).

The logic for cars, car-pools, buses, and trucks is the same, but with different accelerations, decelerations, speeds, vehicle lengths, headways, gap acceptances, and driver behaviours.

5.THE TURNING MOVEMENT CONDITION

In general, the turning movement percentages specified are applied to all vehicles entering a new link regardless of their previous paths. The user can, however, specify discharge turn percentages which are conditional on their direction of entry into the link. This means that the user can specify the percentages of vehicles turning left, right, diagonal and straight through at node j from left turn, right turn, diagonal or straight though movement vehicles which enter link (i, j) at node i.

This logic reduces the chance of entering a link on an inappropriate lane for the downstream turning movement.

The turning decisions in TRAF-NETSIM are made stochastically. If the conditional turn probabilities (discharge turn percentages) are not specified, then only the specified (absolute) turning percentages are used. Otherwise, both are used.

6.TRAFFIC CONTROL

The traffic control in TRAF-NETSIM can be divided into two groups: a sign control, and a signal control.

The sign control group is a Stop or a Yield (Give Way) sign. The signal control group may be either fixed-time, multi-dial (where fixed-time plans may be changed as a result of time-of-day variations in traffic flows), or actuated.

There are two algorithms which have been implemented to evaluate the minimum disruption of traffic when the fixed-time signal patterns are changed from one timing plan to the next. The user can select one of these algorithms: immediate [commonly called "crash change" in the UK (Bell, 1983, and Bell, Gault and Taylor, 1983)] or stage.

The first is based on an "immediate" transition to the new signal timing plan. In this technique, the signal dwells on Main Street Green until the new offset is obtained. The latter is a "stage" approach. This transition proceeds over the course of 2 or 3 cycles by adjusting the signal-splits and the offsets until the new value of the signal timing plan are achieved. The user can specify either 2 or 3 signal cycle periods in the model.

Note however that more sophisticated vehicle responsive traffic control systems such SCOOT (Split, Cycle, and Offset Optimisation Technique) (Hunt et al, 1981) or MOVA (Microprocessor Optimised Vehicle Actuation) (Vincent, Pierce, and Webb, 1990) cannot be modelled by TRAF-NETSIM.

Traffic actuated signal control in TRAF-NETSIM is based on the recommendation of the National Electrical Manufactures Association (NEMA) or the type 170 signal controller.

The logic behind the traffic-actuated signal is, however, mainly based on the type 170 signal controller. There are some modifications in traffic-actuated signal. Firstly, the type 170 controller can be operated as the NEMA-type controller. Secondly, this model allows for up to 6 detector ports per phase. Also, it allows the controllers to be co-ordinated with other controllers in the system. Moreover, pedestrian calls to all 8 phases are allowed in TRAF-NETSIM. In the current application, up to 18 actuated controlled nodes can be accommodated in a single network. For each node, up to 10 reference links may be specified. The maximum number of sensors allowed in the network is 200. Also, the number of detectors on each link may be up to 10.

For the actuated traffic signal, the signals can change depending upon traffic demand. TRAF-NETSIM knows the time and position of each vehicle (by calculation), and the location of detectors (user input). Also, the model knows when and where a call is placed. Thus, it can change the traffic signals according to the current traffic situations. For example, (i) If an arrival headway is greater than the maximum gap (user input), the signal will "gap out" (the traffic signal will change to a next stage). (ii) If the traffic demand exceeds the maximum green (user input), the signal will "max out" (the traffic signal will change to a next stage). (iii) If there is no call, the signal will skip the stage (USA uses "phase" instead of "stage").

There are two groups of detectors defined in TRAF-NETSIM. Each detector has its own characteristics. There are three detectors for each group.

The first group is the extension and count detectors (also known as calling). They also place "calls" to a references stage whenever the signal is red, and then there is an actuation. They thus place "calls" on a stage whether it is active or inactive.

When the stage is green, the extension detectors provide for a vehicle extension of the service green for each actuation (up to the maximum extension or maximum green).

If the traffic model needs traffic volume for initial computation, the count detectors will provide these counts. The count detectors record traffic volume during the amber and red intervals.

The second group is an extension-only detector and type III detectors.

The extension-only detector does not provide counts. It places "calls" when the stage is active.

The type III detector is a special type of the calling detector. It maintains the phase call after the signal indication has changed to green as long as the demand is continuous. The type III detector time starts when the traffic signal indication turns green and finishes when there is no demand or when the user specified limit time has finished. Then, it is disconnected from the active phase until the traffic signal indication changes back to red. Next, it operates as a standard call detector. It can be applied, for example, if the sluggish start-up of the heavy trucks will impede the following traffic.

There are three pedestrian actuation modes defined in this model. The first mode is based on the stochastic arrivals of pedestrians, *ie* they take place at random times according to a Poisson process. The Poisson distribution is a discrete probability distribution (Neelamkavil 1987). The second is based on deterministic arrivals (with constant headways) of pedestrians. The last actuation mode is based on the periods of constant pedestrian demand, *ie* as if the pedestrian push button were continuously depressed.

The constant pedestrian demand periods may be combined with either the stochastic or deterministic pedestrian arrivals. The constant demand will be modelled during the times specified. The stochastic and deterministic demand will be modelled at other times.

7.THE LOGIC IDEAS FOR VEHICLES UNDER TRAFFIC CONTROL

When vehicles approach traffic signals, one of the following actions will take place.

If a traffic signal is red, a deceleration rate of 1 foot/second^2 is applied to a vehicle until its speed has reduced by 10%. Then, a deceleration rate of 7 feet/second^2 is applied to a vehicle until it stops.

When the traffic signal changes from red to green, the first vehicle in the queue will incur a start up lost time. Then, an acceleration rate will be applied to it until it reaches the free flow speed. The second and third vehicle in the queue will have start up lost times which are equal to the mean headways plus 0.5, and 0.2 seconds, respectively. The subsequent vehicles will leave the stop line at rates which are equal to the mean headways. Next, acceleration rates will be applied to the vehicles for their free flow speeds.

If the traffic signal turns to green, the vehicle will proceed without stopping.

If a signal turns to amber, and the position of a vehicle is at a distance closer than the stopping distance from the stop line, the vehicle will proceed without stopping. If the position of a vehicle is at a distance greater than the stopping distance from the stop line, the vehicle will stop behind the stop line. The stopping distance is the safety distance that the vehicle can be stopped without accident. This depends on its speed, acceleration and deceleration. Each vehicle has different values.

There is an amber phase response which is applied only to the lead vehicle in a lane. It should have no queues at the instant of the signal changing to amber. The deceleration which is required for the vehicle to stop is readily calculated from the current position and speed of the vehicle. Then, the required deceleration will be compared with the acceptable deceleration. The acceptable deceleration is obtained from a decile statistical distribution in TRAF-NETSIM (user specified or default values). If the required deceleration is more than the acceptable deceleration, the vehicle will continue moving through the junction. If not, the vehicle will stop according to the rule for a red signal.

Whether or not a left turning vehicle jumps across the junction before the opposite traffic starts is determined by using the probability of jumping. The default value is 38%. The left turn jumper is only the first vehicle in a queue when the traffic signal changes to green.

Also, a left turning vehicle (driving on the right), which is in conflict with the opposing traffic, will wait for an acceptable gap before making the turn during the green period. This value is from a decile distribution which depends upon the driver characteristics.

When the traffic signal changes from green to amber, a left turning vehicle which is waiting at the stop line can make a turn by using a (lagger) turn probability of a left turn. The defaults for this probability are 0.97, 0.77, or 0.37 for 2, 4, or 5 seconds after the start of the amber period, respectively.

When a vehicle approaches a stop sign a deceleration rate of 1 foot/second^2 is applied to a vehicle until its speed has reduced by 10%. Then, a deceleration rate of 7 feet/second^2 is applied to a vehicle until it stops. A stopped vehicle will not move through the stop line to enter into a new link, if an acceptable gap for the near or far side of the cross street is not available. This depends on their turning movements. If a gap is available, then, an acceleration rate will be applied to it until it reaches the free flow speed.

When a vehicle approaches a yield (give way) sign, the model will check the near and far side cross street for available gaps. If a gap is available, the vehicle will proceed without stopping. If not, it will stop. Then, the logic of the stop sign will be applied to it.

A moving vehicle unimpeded by other vehicles must slow down when it approaches a junction. If it is negotiating a turning movement, speed defaults of 13 and 22 feet/second are used for all right and left turns in this model, respectively. These speeds, however, can be specified by the user.

If a vehicle is a right-turn-on-red vehicle (RTOR), it requires an acceptable lag in the traffic stream on the outside lane of the near-side cross-street for completing RTOR. This value is in a decile distribution which depends on the driver behaviour.

8.THE SATURATED CONDITION AND THE JUNCTION OVERFLOW

If the receiving lanes are full, a discharged vehicle at the stop line may wait at the stop line or join one of the queues. If it is a right or left turning vehicle, it will always join a queue and block the junction. If it is a straight through vehicle, a probability of a vehicle joining (or causing) spillback will be applied. The default values of the probability are 1.00, 0.81, 0.69, and 0.40 for the first, second, third and fourth straight through vehicle, respectively. Also, the probability for the fifth and subsequent straight though vehicles is the same as the fourth vehicle.

Vehicles which block the junction will have an effect on the cross street traffic stream. Vehicles which are waiting at the stop line will have no effect on the cross traffic stream, but they will incur delays.

9.THE SIMULATION OF BUSES

TRAF-NETSIM allows for 25 bus routes and 99 bus stops within the traffic network. The bus stops can be classified into 6 types. Each type represents a different dwell time.

Each bus stop can also be divided into three groups: a protected bus stop, an unprotected bus stop, and a bus stop pocket. When a bus, while servicing passengers, does not block vehicles in a moving traffic stream, it is a "protected" bus stop. On the other hand, if a bus blocks the right-most moving lane, it is identified as an "unprotected" bus stop. The "bus stop pocket" is a protected bus stop which is located at the downstream end of a link (within 20 feet from the downstream stop line). Also, this bus stop can be used as a pocket lane by right-turning vehicles, when it is not occupied by a bus.

The simulation logic for buses has been modified to reflect intrinsic differences in the processing and to represent the real life operations for each bus stop type. These include;

i)the blocking back of queues at the upstream end of a bus stop when the bus stop is full,
ii)the bus movement within the bus stop before and after the dwell, and
iii)the movement of buses in a bus stop when the first bus leaves the bus stop after servicing passengers.

As an illustration of case (i), if a bus blocks the lane when it is serving passengers (the unprotected bus stop), the vehicle which is following the bus will wait behind the bus. Also, this vehicle will change a lane if an acceptable gap in the adjacent lane is available. For case (ii), if the bus stop capacity (the number of buses that can be served at the same time) is full, an arriving bus will wait (in the right most lane) for an available space before entering into the bus stop. Finally for case (iii), a bus which is coming out of a protected bus stop will wait for an acceptable gap before merging into the travel lane.

10.THE SIMULATION OF PEDESTRIANS

If the traffic is in conflict with pedestrians, delays will be incurred. The amount of delay depends on pedestrian volumes and an elapsed time after the beginning of the green period. This logic is applied to TRAF-NETSIM.

There are two groups of conflicts: a weak and a strong interaction. The duration of vehicular delay, in seconds, generated by each type of conflict is defined by a statistical decile distribution.

The demarcation between the weak and the strong interaction is expressed in terms of the elapsed time after the start of the green period. At the beginning of the green period, the strong interaction will be applied. For the rest of the green period, the weak interaction will be in effect. There are three default values for the duration of the strong pedestrian interaction, *ie* 0, 10, and 25 seconds when the pedestrian flows are light, moderate and heavy, respectively.

The light, moderate, or heavy pedestrian flows are 100-250, 250-500, or above 500 pedestrians per hour, respectively.

When pedestrian flows are heavy, a strong interaction delay is equal to double its usual values as defined by a statistical decile distribution.

11.THE LANE CLOSURE

There are three types of the lane closure: a short term event, a long term event and a parking activity (on street parking). This lane closure is a temporary event/activity.

If an average lane closure period is less than or equal to 60 seconds, it is a short term event. When an average lane closure period is more than 60 seconds, it is a long term event. The short term event may be illegal parking or the standing/stopping vehicle. The long term event may be illegal parking or a vehicle break down.

The simulation logic permits only one short or long term event on a link at any time period. This means that if there are two concurrent events, only one blockage will be modelled on the link.

The same link and lane may have different short and long term events in different periods. If two or more events take place in the same lane with overlapping durations, the longer duration will be assumed. The obstruction positions along the link for the short and long term events are determined stochastically by using a uniform distribution ranging from the tail of the queue at the downstream node to 40 feet from the upstream node.

Short term events and on street parking can occur only in lane 1 (*ie* the curb lane). Long term events can be specified in any lane, except a pocket lane.

An average duration of the parking activity should not exceed 100 seconds. The on street parking position along the link is determined stochastically by using a uniform distribution within the parking zone.

The parking zone cannot extend into a turn pocket, a bus stop or within 40 feet from the upstream junction. Also, a minimum length of a parking zone is 20 feet.

Links with parking activities and events may have up to 3 lanes blocked during one period. This will only take place when an event is located in a non-curb lane, or when the parking manoeuvres are occurring on both the right and left curb lanes at the same time.

The main differences between the parking activities and the events are as follows.

i)The events take place only at the specified intervals, *ie* only during the first time period (user specified).
ii)The parking activities (frequency and parking duration) and parking zone sizes (length, location and presence) can vary from one time period to the next.
iii)The events can occur on links with or without curb parking permitted anywhere along the curb, but not in the pocket lanes or the bus stops.
iv)The parking activities can only be modelled somewhere within the specified parking zones.

The user can specify any combination of events and/or parking activities or none of these for any link. This means that a link can have (i) no events and no parkers, (ii) events but no parkers, (iii) parkers but no events, or (iv) both events and parkers.

12.THE ESTIMATION OF THE FUEL CONSUMPTION AND THE VEHICLE EMISSION

TRAF-NETSIM can optionally simulate the fuel consumption and emission rates of HC, CO, and NO_x for each type of acceleration, speed, and vehicle type (*ie* bus, car, and truck). It requires fuel consumption and emission rates which should be specified as a function of acceleration/deceleration and speed for each vehicle type.

Speeds vary from 0 through to 70 feet/second, and accelerations vary from -9 through to +9 feet/second^2. The interval of speed and deceleration is 1 foot/second and 1 foot/second^2, respectively. Thus, each consumption or emission rate table is of size 71 × 19 (speed × acceleration).

13.THE LANE CHANGING MODEL

If a vehicle joins a queue and there are one or more adjacent lanes available, the vehicle will attempt to improve its position and switch over to the adjacent lane which offers the smaller queue. An acceptable gap should, however, be available in the target lane. The default value is 3.1 seconds.

To improve its position, the vehicle's position should be improved by at least two average vehicle lengths. The vehicle in a queue can also seek to move into an adjacent lane in order to improve its position in the link/lane by using this logic.

A vehicle may change lane if it can gain access to a lane that might be required for its downstream turning movement.

When a vehicle is in a lane which is specially channelised for the turn movement and is approaching a turn pocket lane, the vehicle may or may not enter the turn pocket lane. This depends upon the traffic situation in this period.

When a vehicle is moving from the upstream to the downstream node, it will react to a lane obstruction. The lane obstructions can be a bus loading/unloading, a lane closure (*eg* a broken car), or a parking manoeuvre.

When a lead vehicle is moving towards the obstruction, it will start to look for a lane changing opportunity at a distance "D" from the obstruction (FHWA, 1986, and Ying Wong 1990), where:

D	=	$\mathrm{MAX}(40, V^2/2A)$	(feet)	(B2)
V	=	approaching speed	(feet/second),	
A	=	deceleration rate	(5 feet/second^2), and	
MAX	=	value of the largest argument		

If a vehicle comes within 5 feet of the obstruction and an acceptable gap in the adjacent lanes is not enough, it will stop behind the obstruction. Then, it will try to find an opportunity to change lane. If possible, it will switch to a new lane. If not, it will queue until the obstruction is cleared.

When a lead vehicle is moving, a following vehicle will follow the leader, unaware of the obstruction. A car following method is, however, applied in this case.

As soon as the lead vehicle stops, and the distance between the lead and the following vehicle is less than $V^2/2A$, the following vehicle will try to change lane. This requires an acceptable gap enough for a lane switching.

When the following vehicle is within VT+4 feet from the stopped leader (where T is the reaction time in seconds), the following vehicle will decelerate behind the lead vehicle. Then, the following vehicle will look for an acceptable gap for lane changing. If the gap is available, it will change lane. If not, it will join the queue.

When a vehicle attempts to change lane, the logic will examine the adjacent lanes of the vehicle from right to left (FHWA, 1986). This means that first the model considers the lane to the right of the current lane as the potential target lane.

The logic will examine a left adjacent lane, when (i) a target lane does not exist, (ii) the target lane is to the right of the lane changer, but the lane changer prefers to change lane to the left, (iii) a target lane is to the left of the lane changer, or (iv) the target lane is a channelised lane.

Lane changing is permitted, when the target lane is empty. When the target lane is not empty, the logic attempts to identify the lead and the following vehicles in the target lane. Three cases are then considered. These are (i) only a lead vehicle in the target lane is identified, (ii) only a following vehicle in the target lane is identified, and (iii) both a lead and a following vehicle in the target lane are identified.

With the first case, a lane changing to the target lane will not be allowed if (i) the lead vehicle is the blocker (*eg* a broken-down car and a loading truck), (ii) the rear bumper of the lead vehicle has the same longitudinal position as the front bumper of the lane changer, or (iii) the lead vehicle belongs to the queue which is formed behind a blocker.

A gap between the following vehicle and a lane changer is considered in the second case. If the gap between the rear bumper of the lane changer and the front bumper of the following vehicle exceeds an acceptable gap, the lane changer can change to the target lane. If not, it cannot switch lane.

The third case is the combination of the first and second cases. The lane changer can change to a target lane, if both the requirements of case 1 and case 2, as above, are satisfied. If not, a lane change is not permitted.

A vehicle that changes lane to avoid an obstruction, can switch back to its preferred lane. The preferred lane for a left turning vehicle is a left turn pocket lane or a left most turn lane when the left turn pocket lane is not available. This idea is similar for the preferred right turn lane. The preferred straight through lane is any lane where the straight through movement is permitted, including turning movement lane.

If a vehicle changes lane from one preferred lane to another preferred lane (in case there is more than one preferred lane), it may or may not switch back to its original lane. The occurrence of the event is determined using a random number based on the field data. When the program generates a random number between 1 and 10, the vehicle will change back to its previous lane when the random number is greater than 5. The reason is that more than 50% of observed vehicles, that were driving past the downstream node and bypassed the lane blockage, returned to their original lane (FHWA, 1986).

The vehicles which have switched lanes to bypass a lane blockage, may attempt to return to their preferred lanes downstream of the blockage. There are four criteria that have to be checked before using the lane changing logic as described above. If these criteria are successful, the lane changing logics can be applied for lane switching. If not, the vehicle cannot change lane.

These criteria are:

i)for a vehicle with an assigned turning movement (left or right) at the downstream junction, the vehicle will not try to change lane if the current lane is the same as its preferred lane;
ii)the target lane must exist;
iii)there is no blockage ahead of the vehicle on the target lane and;
iv)for the vehicle with an assigned straight through movement at the downstream junction, the vehicle will not attempt to change lane if its current lane is a candidate lane. A candidate lane is a lane which the assigned turning manoeuvre is admissible, *eg* a straight through candidate lane is any straight through lane.

When a vehicle is approaching a new link, this logic will be applied to it. The criteria of this logic are that (i) when the lane blockage is located less than 100 feet from the upstream node, the logic then assigns vehicles which are approaching on the blocked lane to the other adjacent lanes; (ii) when the blocked lane is, however, the only lane from which the vehicles can execute an assigned downstream turning movement, the vehicles will be assigned to the block lane, even if they may overtake the blockage.

14.THE CAR FOLLOWING MODEL

There are two types of vehicle in the car following model. One is a lead vehicle, the other is a following vehicle.

The car following model is applied in TRAF-NETSIM when only the distance between a lead and a subject vehicle has effect on the subject vehicle.

If there is no lead vehicle or the separation distance between a lead vehicle and a subject vehicle has no effect on the subject vehicle, the subject vehicle can move at the unimpeded speed. The unimpeded speed varies over time because of acceleration/deceleration, traffic signal, etc. TRAF-NETSIM models this variation in discrete time step.

The acceleration obtained from the car following relation is compared with
i)the acceleration received from the difference between free flow speed and current speed, and
ii)the panic deceleration before applying it to the subject vehicle.

When the acceleration obtained from the above criteria is, however, equal to or more than 3 feet/second^2, the minimum value between (i) this acceleration and (ii) the acceleration obtained from the acceleration-speed relationship for each vehicle type and characteristic on each link, is applied to the subject vehicle.

Next, the subject vehicle speed and the distance travelled by the subject vehicle during the time step are calculated at the end of time step. Then, these values are applied to the subject vehicle for the next time step.

The details of the above are described below:

Firstly, there are two criteria for investigating the effects of the separation distance between a lead vehicle and a subject vehicle. (i) One is that the minimum separation distance should be equal to the combined distances of the distance calculated (i.a) from the current speed of the subject vehicle and (i.b) from the lead vehicle speed at the end of the time step, plus 4 feet (for a safety distance). (ii) The other is that the distance calculated from the lead vehicle's speed at the end of the time step should be more than the distance calculated from the current speed of the subject vehicle plus 4 feet (for a safety distance).

If both of these criteria are successful, the acceleration of the subject vehicle (A_{ss1}) will be selected from the maximum value of (i) the acceleration/deceleration obtained from the difference between current and free flow speed of the subject vehicle at the time step, or (ii) -4 feet/second^2 (the minimum acceptable deceleration).

If either one or both of these criteria are not successful, then the car following model will be considered.

The details of the car following model are as follows:

A_{ss2}	=	$MAX[MIN(A_{s1}, V_{sf} - V_{sc}), -12]$	(B3)
A_{s1}	=	$RACC + SIGN\ (0.5, RACC)$	(B4)
RACC	=	$MAX((RF1 \times RF2)/RDEN, -12.0)$ if $RDEN \neq 0$	(B5)
		$= 0$ if $RDEN = 0$	(B6)
RDEN	=	$(RF2 \times RF2) + (RF1 \times K5)$	(B7)
RF1	=	$(K1 \times [D_{fr} - (K3 \times V_{sc})]) - (V_{sc}^2 - V_{le}^2)$	(B8)
RF2	=	$K2 + (K4 \times V_{sc})$	(B9)

where:

A_{ss2} =the acceleration of the subject vehicle during this time step obtained from (i) the computed acceleration by the car following model or the difference between free flow speed and current speed, or (ii) a panic deceleration,
A_{s1} = the acceleration of the subject vehicle calculated by the car following model,
D_{fr} =the distance between the rear bumper of the lead vehicle and the front bumper of the following vehicle,

DELT = 1 [step-size],
K1 = 20 [maximum deceleration × 2],
K2 = 30 [maximum deceleration × (2+DELT) × DELT],
K3 = 2 [DELT+1],
K4 = 2 [DELT × 2],
K5 = 1 [DELT × DELT],
RACC = the acceleration computed by the car following relation,
RDEN = the denominator of the car following acceleration relation,
RF1, RF2 = the factors used in computing the vehicle acceleration,
V_{le} = the lead vehicle speed at the end of the time step,
V_{sf} = the free flow speed of the subject vehicle,
V_{sc} = the current speed of the subject vehicle,
-12 =the maximum deceleration of the subjective vehicle allowed for a safety stop (a panic stop),
MAX = the value of the largest argument,
MIN = the value of the smallest argument, and
SIGN =the sign of the second argument (which should not be zero) applied to the absolute value of the first argument, *eg* SIGN (4.5,-2.2) is - 4.5 .

Thirdly, if the calculated acceleration (A_{ss1} or A_{ss2}) is less than 3 feet/second^2, the subject vehicle will move by this acceleration.

If not, the model will calculate the maximum possible acceleration (A_{ss3}) based on the current and desired speed on this link, and vehicle performance characteristics.

This means that the maximum possible acceleration (A_{ss3}) will be obtained from (i) the maximum attainable speed based on link and vehicle characteristics (*ie* the minimum value between the free flow speed value of the subject vehicle and the maximum speed of the subject vehicle at zero acceleration), and (ii) the maximum acceleration of the subject vehicle at zero speed.

To achieve the maximum possible acceleration (A_{ss3}) use is made of an approximate linear relationship between the speed and acceleration. The relationship is shown below (Figure B.1). Also, the value of the maximum possible acceleration (A_{ss3}) is always at least 1 foot/second^2.

Then, the minimum value between the acceleration calculated (i) from A_{ss1} or A_{ss2} (depending on the traffic situation at that time step), or (ii) from the maximum possible acceleration (A_{ss3}) will be selected for use in the model.

Finally, the model will calculate the speed and the travelled distance of the subject vehicle at the end of this time step. The maximum allowable speed is 127 feet/second. Also, the minimum travelled distance is zero.

In the case where there is a lead vehicle, and the lead vehicle is also moving, the subject vehicle must move. This means that in this case the minimum speed of the subject vehicle will be equal to 1 foot/second.

The calculation of the travelled distance can be divided into two groups, the travelled distance of the lead and the following vehicles.

The former is obtained from the values of the current speed of the subject (lead) vehicle plus half of the acceleration of the subject (lead) vehicle during this time step.

The latter is derived from the relation below (FHWA, 1989a):

$$D_{s1} = MAX(V_{sc} + A_{ss}/2\ ,\ 0) \tag{B10}$$

$$D_{s2} = MAX[MIN\{D_{s1},\ D_{fr} - ABS(MIN(V_{le},\ V_{sc} + A_{ss}) \times 7/10)\},0] \tag{B11}$$

where:

A_{ss} =the acceleration of the subject vehicle during this time step (A_{ss1},A_{ss2}, or A_{ss3}; depending on the traffic situation at that time step),
D_{fr} =the distance between the rear bumper of the lead vehicle and the front bumper of the following vehicle,
D_{s1} =the distance travelled by the subject vehicle during the time step when there is no lead vehicle,
D_{s2} =the distance travelled by the subject vehicle during the time step when there is a lead vehicle,
V_{le} =the lead vehicle speed at the end of the time step,
V_{sc} =the current speed of the subject vehicle,
7/10 = minimum headway at end of time step (seconds),
ABS = the absolute (positive) value of an argument,
MAX = the value of the largest argument, and
MIN = the value of the smallest argument.

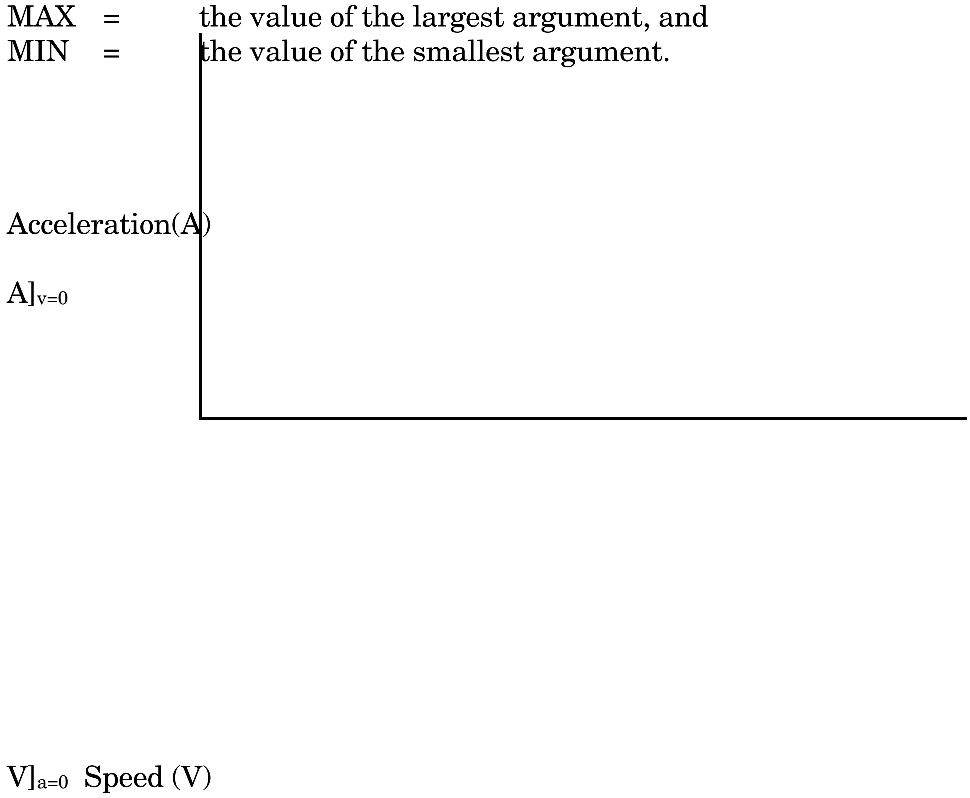

Figure B.1Illustration of an approximate linear relationship between speed and acceleration (FHWA, 1989b, pp. 124).

15.THE SIMULATION OF THE LINK AGGREGATION

This simulation is optional. It is only used for the purposes of investigating significant Measures of Effectiveness (MOE) for a particular set of links in more detail. The link aggregation can be any one of 4 configurations as shown below.

i)The Linear Section:

$N_1 N_2 N_3$ N_8

(ii) The Converging Section:

$N_1 N_3 N_4$ N_8

N_2

(iii) The Diverging Section:

N_7

$N_1 N_2 N_3 N_6$

N_8

(iv) The Converging and Diverging Section:

N_1 N_7

$N_3 N_6$

N_2 N_8

The linear section requires a minimum of 3 nodes. The converging or diverging section requires a minimum of 4 nodes. The converging and diverging sections must have at least 5 nodes.

16.THE OUTPUT RESULTS FROM RUNNING TRAF-NETSIM

The output statistics in TRAF-NETSIM can provide a wide rang of Measures of Effectiveness (MOE) on a link specific basis and aggregated over the whole network. Also, separate statistics are provided for bus transit operations, if they are stratified by route.

MOE can be divided into two groups: a cumulative and an intermediate output. The former is the output which provides data accumulated from the end of the initialization until the end of the simulation period. The latter is the output which provides data describing the current status of the traffic environment, *ie* a snapshot of current conditions (user specified).

The MOE generated by TRAF-NETSIM can be divided into 6 groups: link, bus stop, bus route, turn movements (optional output), link aggregation/section specific information (optional output), and link (optional output) specific measures. The first to the fifth MOE are cumulative outputs. The sixth MOE is the intermediate output.

The intermediate output from running TRAF-NETSIM can be provided at specified frequencies from up to 3 periods of the simulation run. The specified frequencies are not related to the time interval durations.

All table outputs of MOE can be shown either in US standard units, Metric units, or both. This is specified by the user.

The selection of the output options and the frequency of the output generation must depend on the judgement of the user. In general, the output should be limited to what is required. The reason is that the more output takes place, the more computer expense is incurred.

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