Indo-Swedish Road Traffic Simulation Model: Generalized Traffic System Simulator

S. P. PALANISWAMY, G. GYNNERSTEDT, and Y. R. PHULL

ABSTRACT

A stochastic discrete-event simulation model system for heterogeneous road traffic, which prevails on the Indian highway network, is presented. The original Swedish Road Traffic Simulation Model system, designed for motorized traffic, has been generalized to cover heterogeneous traffic that includes slow-moving nonmotorized traffic. The model has also been extended for narrow roads and covers roadwidths from 3.75 to 13 m with different shoulder types and alignments in flat, rolling, and hilly terrains. Submodels for the basic desired speed, power-to-mass ratio, overtaking gap acceptance and yielding probability distributions, passing speeds, and fuel consumption rates have been calibrated with extensive field data for subsequent validation of the simulation model. The output of the model has been intended primarily (a) to furnish relevant vehicle operating data for appraisal of individual road projects, (b) to constitute background data for a relevant level of service concept, and (c) ultimately to provide a basis for an appropriate policy on geometric design of rural roads in general. The model has been programmed in SIMULA-67 language using Jackson Structured Programming concepts. The results of validation exercises have been convincing; the model should be useful to decision makers for obtaining reliable data for investment analysis.

There have been various attempts in the past to simulate rural two-lane road traffic and the most successful among them is the model developed at the Swedish National Road and Traffic Research Institute (VTI) (1-4). This is the first discrete-event simulation model with a long history of development and rigorous validation. The objective of the research reported was to adapt, modify, and extend the basic structure of the VTI model to the heterogeneous traffic prevailing on the Indian road network. The modified Swedish Road Traffic Simulation Model (INSWERTS) simulates eight different vehicle types including the slowest moving bullock carts. Roadwidths considered varied from 3.75-m-wide single lane to two lane with auxiliary lanes. Multilane highways have also been treated.

Many submodels such as the basic desired speed (BDS), power-to-mass ratio, gap acceptance probabilities, passing speed, yielding probabilities of vehicles for passing opportunities, and fuel consumption have been calibrated with extensive field data (5). These submodels along with the main simulation model have been validated for traffic on flat, rolling, and hilly terrains for different road categories. Measures used for the validation are travel time, spot speed, time headway, and number of overtakings over road stretches of about 5 km.

INDIAN HIGHWAY TRAFFIC SYSTEM

Bidirectional single-lane roads (3.5 m wide) with soft shoulders constitute the largest percentage of the rural road network in India. Traffic on these roads is subjected to significant delay due to high levels of overtaking and passing impedance. The second largest road type is known as intermediate-lane road, which is 5.5 m wide and has fewer impedances than single-lane roads. Two-lane roads (7 m wide) constitute a small percentage and traffic on these roads also experiences significant delay due to the behavior of heterogeneous traffic.

Traffic is composed of a spectrum of vehicle types that share the available road space. Vehicles differ considerably in their physical size, motive power, and control and guidance as well as performance capabilities. Passenger cars, buses, and trucks operate at higher speeds, and animal-drawn vehicles (ADVs) move at speeds of about 5 km/hr. A large number of motorcycles and scooters also operate on these roads. The interaction among these vehicles takes place in complex ways that result in congestion even under low to medium flows due to frequent bottlenecks caused by slow-moving vehicles.

Traffic Behavior on Indian Roads

On two-lane roads, vehicles in opposing streams do not interact when they pass. However, passing impedance increases as the roadwidth decreases and, in the extreme, passing vehicles are forced to stop because there is room for movement of vehicles in only one direction. Especially on narrower roads vehicles normally operate in the middle of the roadway. Drivers of slower vehicles do not yield when faster ones catch up from behind resulting in delays to the latter.

Narrow roads present a formidable impediment to the catching-up vehicles because they have to follow slower ones that have to reduce their speeds and then move partly onto the shoulder to enable the faster ones to overtake. Often slower vehicles do not yield when a faster one catches up. A queued vehicle is normally allowed to overtake after a period, which is rather random. However, if the shoulder ahead is in good condition, the probability of the slower vehicle yielding is higher. Other roadway parameters affecting this yielding probability are the roadwidth and geometric details (6).

On wider two-lane roads, slower vehicles do not move to the shoulder to enable faster ones to get by because there are overtaking opportunities for the latter (7). However, on narrow roads, the operating rules are such that slow-moving vehicles are virtually forced to use the shoulder, which results in reduced operating speed. Thus, on narrow roads, the shoulders play a significant role in determining overtaking and passing speeds.

This discussion establishes that the decision maker in overtaking situations on narrow roads is the leader not the follower, which complicates the decision logic of drivers on these roads. In addition, there are no flying or accelerative overtakings on narrow roads. The overtaking sequence is akin to that in the inner lane of multilane unidirectional traffic (6).

SIMULATION MODEL

The model has been programmed in SIMULA-67 language using Jackson Structured Programming (JSP) concepts that permit lucid organization of vehicle flow logic (8-10). The entities considered in the modified Indo-Swedish model are the roads, the vehicles, and the drivers. The following sections contain a brief explanation of how the VTI model has been successfully adapted and modified for Indian traffic.

Roads

Road sections with varying width, roughness, curves, grades, and speed limits can be simulated. The road is represented by homogeneous blocks with the same geometry and traffic regulations. Sight distance along the road stretch, presence of good shoulders as well as auxiliary lanes, overtaking restrictions, and presence of overtaking and no-overtaking zones are also included. Each block is associated with a median speed about which vehicle speeds are distributed.

Vehicle Types

The significant factors contributing to the performance of traffic are the physical size and power-to-mass ratio distributions of vehicles. Each vehicle type has been identified within this framework:

- Passenger cars, pickups, and jeeps;
- Trucks and buses [heavy motor vehicles (HMVs)];
- Farm tractors and ADVs; and
- Motorcycles and scooters.

These four vehicle groups constitute the majority of traffic on Indian roads. In addition, bicycles, pedaled cycle rickshaws, and other slower vehicles also form part of the traffic, but their effect on traffic flow has been taken as noise on the system and calibrations of submodels have been adjusted for this noise.

Basic Desired Speed and Passing Speed Distribution

The notion of basic desired speed (BDS) distribution is pivotal to the modeling of a traffic system. On ideal roadways drivers are assumed to travel at a speed restricted only by the characteristics of their vehicles; this distribution is the BDS. BDS is the starting point for modeling speed reductions caused by roadwidth and alignment. Figure 1 shows the BDS distribution for passenger cars, trucks and buses, and two wheelers.

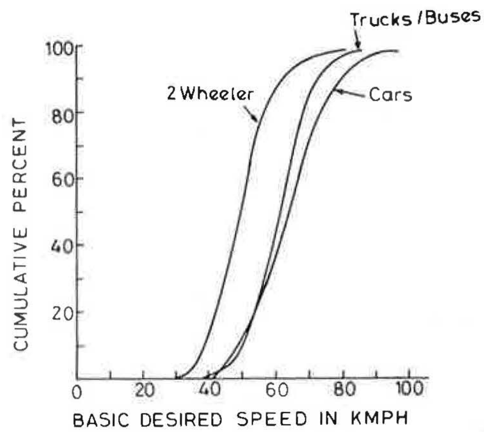

FIGURE 1 Basic desired speed distribution.

Submodels Describing the Effect of Roadwidth, Curvature, and Speed Limit on BDS

The effects of roadwidth, curvature, and speed limit on BDS have been considered in a recursive model form. The effect of roadwidth is modeled first. Then individual curves that cannot be taken at the speed limit are modeled. Grade has been taken into account in the simulation model by using the force equation.

For roads that have straight horizontal alignment and are 12 m or more wide, there is a BDS distribution with a given median speed (V_o). For roads that have straight horizontal alignment but are less than 12 m wide, V_o is reduced to V_1 where V_1 is a function of roadwidth. At this stage, V_1 is reduced by accounting for the horizontal alignment. Thus a new median speed (V_2), which is a function of roadwidth and its curvature, is obtained. Curves with a mean radius of 1000 m or less are considered. The new median speed (V_2) is adjusted for the speed limit to V_3. After the median speed V_3 has been calculated a resulting new speed distribution is calculated. This is accomplished by moving the BDS from the median value V_o to the new median V_3 and at the same time rotating it about V_3 so that the dispersion of the distribution decreases.

A transformation measure (Q-value) is used to indicate how far the BDS must be rotated about V_3. The Q-value, which is a function of the median speeds V_o, V_1, V_2, and V_3, is expressed as

$$V_o^Q - V_3^Q = V_{oi}^Q - V_{3i}^Q$$

where V_{oi} and V_{3i} are the speeds at an arbitrary percentile in the respective distributions. The distributions are thus shifted parallel to each other in the space V^Q as shown in Figure 2. For $Q = 1$ the relation implies a purely parallel shift of the two distributions and no rotation about the median value V_3. For $Q < 1$ the desired distribution is rotated counterclockwise about V_3. This rotation results in smaller variation between different percentiles compared with the BDS distribution. These rotations imply that a vehicle with a higher BDS reduces its speed more than those with a lower speed when influenced by speed-reducing factors. Furthermore, the smaller the value of Q, the larger will be the rotation (8). Individual road factors have their own speed reduction measure (q_i).

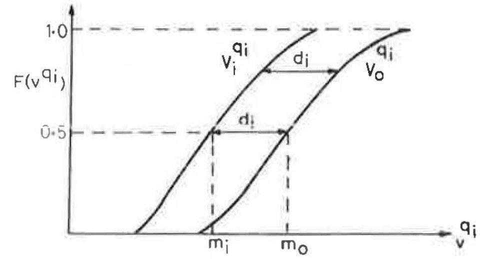

FIGURE 2 Effect of roadway factors on basic desired speed.

Model for Speed Sequence on Grades and Acceleration Sections

Consider the free-body diagram of forces acting on a vehicle on an upgrade:

$$m\ (dv/dt) = F - F_L - F_r - mg \sin i$$

where m is mass of the vehicle, v is speed, i is slope, and t is time. The tractive force at the wheel is

$$F = P/V$$

where P is the power of the vehicle in Watts measured at the wheels. The air resistance is

$$F_L = C_L\ Av2$$

where C_L is the air resistance coefficient in kilograms per cubic meter and A is the frontal exposed area in square meters. The rolling resistance is

$$F_r = m \cos i\ (C_{r1} + C_{r2} \cdot v) \approx m\ (C_{r1} + C_{r2} \cdot V)$$

where C_{r1} and C_{r2} are rolling resistance coefficients. Force due to gravity is mg sin i $\approx$ mgi. These expressions are substituted in the force equation and the following is obtained:

$$(dv/dt) = (p/v) - [(C_2A/m)\ v^2] - (C_{r1} + C_{r2} \cdot v) - gi$$

where p = P/m is the power-to-mass ratio of the vehicle. Each vehicle is allotted a p-value, which is the maximum power-to-mass ratio that the driver desires to or can use. Figure 3 shows the p-distribution for different vehicle types obtained from the field studies. Each time a vehicle passes a block limit, its ability to maintain its desired speed

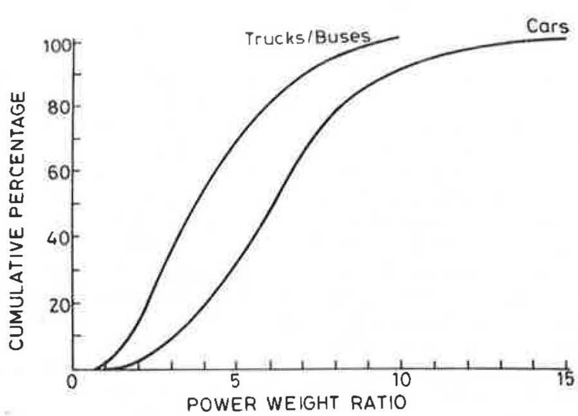

FIGURE 3 Power-to-weight ratio distribution.

(V_{3i}) is tested. If a < 0 or if the vehicle's current speed is lower than V_{3i}, the speed is calculated by solving the force equation numerically. In this way a free-running speed profile along the road is created. This procedure is used only for fast traffic. Animal-drawn vehicles and farm tractors move at constant speeds that are independent of roadwidth, curves, and gradient.

Speed Reduction for Heavy Vehicles Traveling Downhill

For faster vehicles traveling downhill, the additional gravitation force results in higher acceleration ability and hence such vehicles could attain the desired block speed (V_{3i}) quite rapidly. However, observations of vehicles on hills indicate that they descend in lower gears and thus maintain a lower rate of acceleration in reaching V_{3i}. For this reason the p-value available to them is not fully used. This is more pronounced in the case of heavy vehicles. To account for this downhill travel behavior, adjustment has been made to reduce V_{3i} (7). The block speed reduction for heavy vehicles on grades with slope $\leq$ -1 percent has been empirically determined to be 4.24 m/sec for $p \leq 3.3$, 11.39 - 2.166p for $3.3 < p < 5.25$, and 0 for $p \geq 5.25$.

Model for Vehicle Interactions

The modeling of vehicle behavior that constitutes the core of the simulation model considers critically different kinds of vehicle interactions and develops concepts necessary for a dynamic sequence of vehicle movement. A free-moving vehicle interacts with the road and its speed is conditioned by roadwidth, curves, hills, speed limits, and other road conditions. However, as traffic flow increases, interactions among vehicles are to be considered as well. For example, when a faster vehicle catches up with a slower vehicle the interaction is viewed in terms of the catching-up vehicle that reduces its speed and prepares to follow if the slower one decides not to yield space by moving to the hard shoulder. On narrow roads, when two vehicles traveling in opposing streams meet, both vehicles reduce their speed to a level at which they can pass each other. As the flow increases, a multiplicity of events occurs; such events require specific decisions that are discussed elsewhere (8). Most of these events are common to vehicles traveling on narrow as well as wider roads. On narrow roads there are more stringent rules to be considered for event prediction. As roadwidth increases, narrow lane traffic behavior can be logically extended to wider two-lane roads as well as to four-lane divided highways. These are discussed later.

Traffic Interactions on Narrow Roads

For narrow roads a distinctive behavioral logic has been developed to reflect the peculiar conditions prevailing on the Indian road network. This is one of the major achievements of the research reported in this paper.

Overtaking Decisions

Consider what happens when two vehicles with different desired speeds travel in the same direction. The road stretch is assumed to be free of any oncoming vehicle. Let e_i be the faster vehicle and e_j the slower one in front. Eventually e_i catches up with e_j. The decision situation for e_i is whether to continue to travel at the same speed. The point at which this decision has to be made is similar to that at which the decision about flying overtaking is made in the case of two-lane roads except that e_j is the decision maker. Vehicle e_i could continue to travel at its own desired speed if e_j decides to move partly to the shoulder; otherwise e_i becomes constrained. Observations in the field can be used to assess the yielding probability distribution of the slower vehicle, which is a function of roadway and vehicle parameters. The Monte Carlo method is used to decide whether e_j will yield space so that e_i can travel unimpeded (6).

When e_j does not yield, e_i must decelerate and follow e_j until e_j does yield. If the shoulder ahead is equivalent to an extra lane, e_j will yield with a specified probability and change to the shoulder to travel with a speed consistent with shoulder conditions. Other sections at which e_j could yield are where there is adequate shoulder (beginning at a block border) and the maximum sight point. This overtaking opportunity is accepted if the obstructing vehicle (e_j) yields way by moving to the hard shoulder or climbing lane and if the trailing vehicle (e_i) has sufficient ability to overtake. Three different conditions must be fulfilled for an obstructing vehicle to yield for overtaking:

1. There must be a hard shoulder or extra lane at least a certain number of meters in front, and this model constant is set at 200 m;
2. Surrounding traffic must be such that space is available; and
3. A stochastic function for yielding must be true.

The trailing vehicle is considered to be able to overtake the lead vehicle if the driver estimates the distance available for overtaking to be $\leq$ x m. Vehicle e_j returns to its normal lane when e_i has overtaken it and space is available. The importance of alignment (in terms of the frequency with which maximum sight distance is provided), shoulder type and condition, and their effect on traffic flow on narrow roads are captured in this decision submodel (6).

Meeting and Passing Decision Process

Consider the trajectories of two vehicles that meet and pass each other. Let e_1 be the vehicle traveling in direction 1 and e_2 the vehicle traveling in direction 2. Let v_1 be the speed of e_1 and v_2 the speed of e_2. Scanning the road ahead the driver of each vehicle identifies the oncoming vehicle. Both e_1 and e_2 are required to decelerate and pass each other at their desired passing speeds. Let the passing speeds of these vehicles be v_1' and v_2'. Both vehicles then decelerate at acceptable rates to reach their passing speeds. The decision point at which e_1 initiates its deceleration need not be the same as that of e_2. For instance a bullock cart never reduces its speed when passing. Deceleration distances (D_1 and D_2) are determined and are known as passing head lengths for e_1 and e_2, respectively. It is now possible to identify the start of deceleration decision points for e_1 and e_2. When coordinates of their current positions in space and time are given, the corresponding coordinates at which their passing head lengths overlap can be determined. This point of overlap is defined as the meeting point. Therefore, meeting point is the decision point for vehicles to start deceleration. There are three phases in a passing sequence. First, a vehicle decelerates to its desired passing speed. Second, the passing vehicle travels at a constant speed during the passing mode. Finally, the vehicle accelerates to attain its desired operating speed. This sequence involving deceleration, lower speeds during passing, and then acceleration results in higher levels of acceleration noise and considerable delay to vehicles. In addition, they are exposed to severe conflict situations that lead to high accident rates on these roads.

Meeting and Passing Involving Platoons

A more complex passing situation involving a two vehicle platoon and an oncoming vehicle can be modeled now. Let e_{11} and e_{12} be the platoon leader and constrained vehicle traveling in one direction and e_2 the vehicle traveling in the other direction. To start with, assume that e_{12} is not constrained and that e_{11} and e_2 are separated by a large gap. Eventually e_{12} catches up with e_{11}. At this time, it has also been assumed that e_{11} and e_2 are close to their meeting point. In this situation, it is important to know how the decisions are made by e_{11}. There are two possibilities: In the first case e_{11} allows e_{12} to overtake and then passes e_2. In the second case e_{11} passes e_2 and then allows e_{12} to overtake while it is still on the shoulder lane.

In the first case the speed of e_{11} depends on the shoulder condition as well as the speed of the overtaking vehicle and e_{12} will have to decelerate to pass e_2 immediately after overtaking e_{11}. In the second case e_{12} follows e_{11} and both move to the shoulder and then pass e_2. When e_{11} and e_{12} have passed e_2, e_{11} allows e_{12} to overtake by accelerating (see Figure 4). The second case has been chosen for use in the simulation logic so that account is taken of the preferential structure of drivers; namely, that priority is given to passing and only then are other events considered. This is more often true of fast-moving vehicles except motorcycles.

The procedure involving the prediction of event times during passing is unique to this model. It must be emphasized that when the meeting of vehicles in opposing streams is imminent, this meeting event is given top priority in obtaining vehicle trajectories (6).

Application of Overtaking and Passing Behavior on Indian Roads

Passing is a totally unavoidable event on narrow Indian roads. Overtaking can be avoided or deferred. Therefore, it is passing that is given top priority in obtaining vehicle trajectories on narrow roads, even if overtaking is imminent. The behavior of the platoon leader is not irrational in that it is he who is in the best position to judge passing safety in light of the absence of forward visibility to the following vehicle.

It has been shown that overtaking and passing are highly interrelated on narrow roads. The degree to which this interaction is reduced is not dependent on road designation but on effective pavement width. Due to the ubiquity of narrow vehicles on Indian roads, even in the case of two-lane roads effective roadwidth is often diminished to the extent that narrow road behavior is required. However, the number of events will be extremely large if passings have to be taken into account. On wider two-lane roads, if it can be assumed that the medial friction due to passing is negligible, relevant events could be modeled appropriately as discussed next.

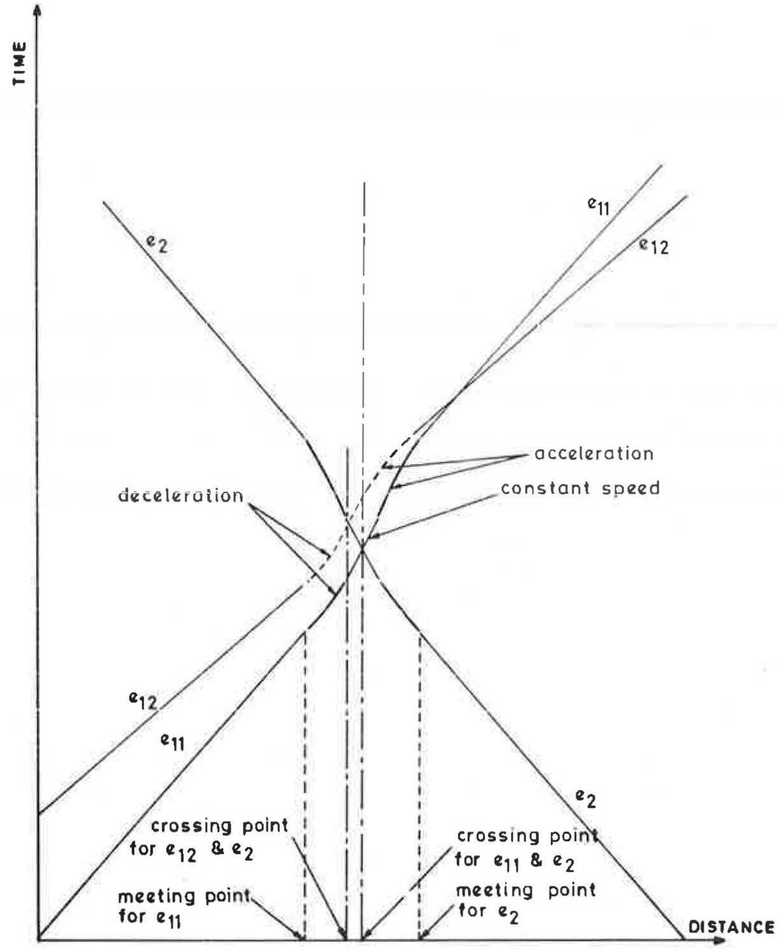

FIGURE 4 Two vehicles with same speed and one with slower speed in passing situation.

Traffic Interactions on Wider Two-Lane Roads

On wider roads overtakings and passings are considered in detail. In considering overtaking situations the VTI model has been adjusted for the reduced impedances of narrow vehicles and ADVs. Gap acceptance functions obtained from the field studies on flat terrain have been adjusted for hilly terrain conditions. Detailed accounts of various events on two-lane roads have been documented elsewhere (6-8). Only the salient modifications proposed for Indian traffic are given here.

Gap Acceptance Function and Modification for Hilly Roads

Overtaking gap acceptance functions have been developed for 32 different situations using test vehicles fitted with video and radar speedmeter instrumentation identical to that used by the Australian Road Research Board (11). They are applicable for roads in flat and rolling terrain. The general form of the functions is expressed as

$$P(x) = \begin{cases} 0 & \text{if } x \le S_1 \text{ m} \\ (x - S_1)/(S_2 - S_1) & \text{if } S_1 < x < S_2 \text{ m} \\ 1 & \text{if } x \ge S_2 \text{ m} \end{cases}$$

where x is the sight distance and S_1 and S_2 are the calibration constants for each of the 32 overtaking situations (7). On hilly roads, vehicles travel slower and therefore distance required for overtaking is smaller. Thus, the probability of a given gap being accepted is higher on hilly roads. The values obtained for S_1 and S_2 on level roads have been modified as follows:

$$S_1^* = S_1\ (\bar{V}_{hill}/\bar{V}_{level})\ n$$

and

$$S_2^* = S_1^* + (S_2 - S_1)\ (\bar{V}_{hill}/\bar{V}_{level})$$

where S_1^* is the minimum gap for overtaking on hilly roads, S_2^* is the distance with highest probability, and $\bar{V}_{hill}$ and $\bar{V}_{level}$ are the mean free speeds of vehicles on hilly and level roads, respectively; n is a calibration constant that is equal to unity in this case.

Modifications for ADV and Narrow Vehicles for Interaction Decisions

In the VTI model decisions regarding overtaking and following are made when a vehicle is close to another vehicle in the same track. This logic holds as long as wider vehicles, which occupy the full lane, are considered but needs modifications to adjust for the interactions involving narrow vehicles such as motorcycles. For example, two motorcycles may be found traveling beside each other in the same lane at their free speeds. Thus, in decisions involving interactions, distinction should be made in terms of whether a vehicle interacts with a vehicle immediately in front or behind. If vehicles in the immediate vicinity do not interact, the vehicle with which interaction is likely should be identified. The modified model calculates a reference to the interacting vehicle in front of (or behind) the vehicle in question. If the vehicle so identified is not likely to interact, the next vehicle in the lane is tested for interaction and the procedure is repeated until an interacting vehicle is found (if one exists). When the interacting vehicle has been identified, all decisions are made with reference to this vehicle only (7).

Extension of the Model to Four-Lane Divided Highways

In the previous sections traffic on narrow roads and wider two-lane roads was discussed. A logical extension of these models to the case of four-lane divided highway has been achieved by invoking the auxiliary lane concept embedded for overtaking situations on two-lane roads and especially in the case of narrow roads if passing is eliminated (6,7). In unidirectional flow situations the logic used for vehicle movement in the opposing lane and traffic from that direction are omitted while vehicles in a normal lane yield and allow catching-up vehicles to overtake as in the former category of roads. The yielding probabilities are obtained from field studies. The highest probability of a slower vehicle yielding by moving to the outer lane has been set to one with all other conditions having been met. This way, the proposed extension is much simpler than the complex multilane traffic process.

Input Data to the Model

Two types of data are used in the validation of the model. The first consists of data structure describing the road alignment and traffic regulations. The road is described for each direction as a series of homogeneous blocks and the data required are (a) space coordinate for the beginning of each block, (b) carriageway width, (c) hard shoulder width, (d) speed limit, (e) slope, (f) curvature, and (g) roughness. In addition, space coordinates for each sight section and the sight distance available at this section are also required. Codes are used for stretches having overtaking restrictions and hard shoulders or climbing lanes. The second data type consists of data on traffic to be simulated over the defined road stretch. They are, for each vehicle, (a) identity number, (b) vehicle type, (c) basic desired speed, (d) p-value, (e) direction of travel, (f) coordinates for entry and exit from the road, and (g) time and spot speed at entry to the road stretch. Individual vehicle data are collected for both directions of traffic at three points along the road: at the ends and midway. Because vehicles have to be associated with their basic desired speed, an inverse transformation is made on the Q-model on the basis of their entry speed. The p-value for each vehicle is obtained from the known distributions for each vehicle type.

Output Data from the Simulation Model

The resulting events from a traffic simulation are obtained in chronological order for statistical analysis of time headway, travel speed, spot speed, number of overtakings, and so forth. Twenty types of situations have been defined that are stored in the form of an event file. There are a number of post-processing programs to analyze the event file to obtain histograms of travel speeds, time headways, and spot speeds. For any stretch of road, a table of overtakings (by type of overtaken and overtaking vehicle) is obtained along with the percentage of free, constrained, and overtaking vehicles.

VALIDATION OF SIMULATION MODEL SYSTEM AND DISCUSSION OF RESULTS

In the validation exercise comparisons were made between the observed and the simulated distributions of travel speeds, spot speeds, time headways, and overtakings. In addition, the validation test considered the difference between observed and simulated means and standard deviations in order to quantify just how "good" or "bad" the comparisons were. The road stretches used in this test are classified according to topography and Indian road designation. Table 1 gives the sampling framework used. Further validation is in progress for those cells in the matrix that were not included in this study.

Comparison of Observed and Simulated Travel Speeds

Travel speed distribution for the heavy motor vehicles on the single-lane, intermediate-lane, two-lane, and four-lane divided highways are shown in Figure 5. The figure indicates consistently good fit between the observed and the simulated travel speeds. For example, on the single- and intermediate-lane roads for a number of simulations the mean percentage differences between the two distributions are 0.635 and 1.917, respectively, indicating an extraordinary fit (6). For certain simulation runs the observed and the simulated mean values were almost the same, confirming the capability of the model. Also, it can be seen from this figure that the effect of roadwidth is captured in the model system in a rather convincing manner. Similar results have been obtained for the spot speed distributions of vehicles, which further reinforces the validity of the model (6,7).

In addition, Figures 6-8 show the plot of observed versus simulated mean travel speeds for all

TABLE 1 Sample Distribution of Roads and Flows Used in Calibration and Validation

	Designation			
Terrain	Single-Lane Road	Intermediate-Lane Road	Two-Lane Road	Four-Lane Road
Flat	Five stretches with negligible gradient and curves (9 flows)	Two stretches with negligible gradient and curves (3 flows)	One stretch (5 flows)	One stretch (3 flows)
Rolling			One stretch (3 flows)	
Hilly	One stretch (3 flows)		One stretch (2 flows)	

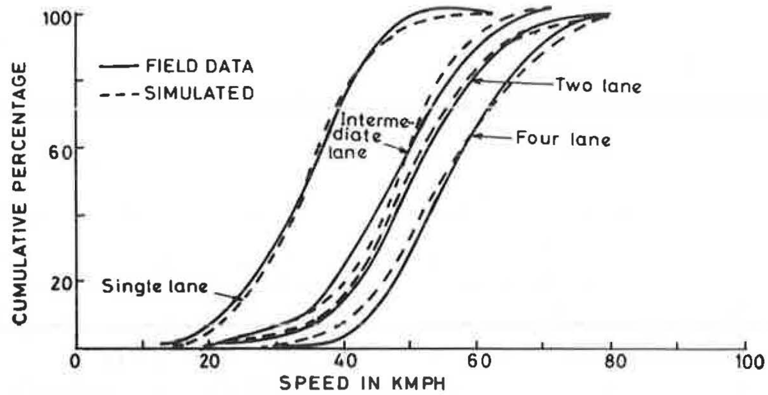

FIGURE 5 Travel speed in km/hr for heavy motor vehicles.

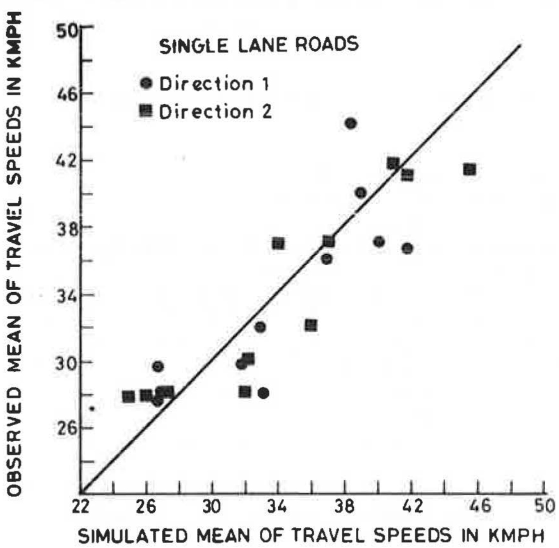

FIGURE 6 Simulated versus observed mean of travel speeds for heavy motor vehicles.

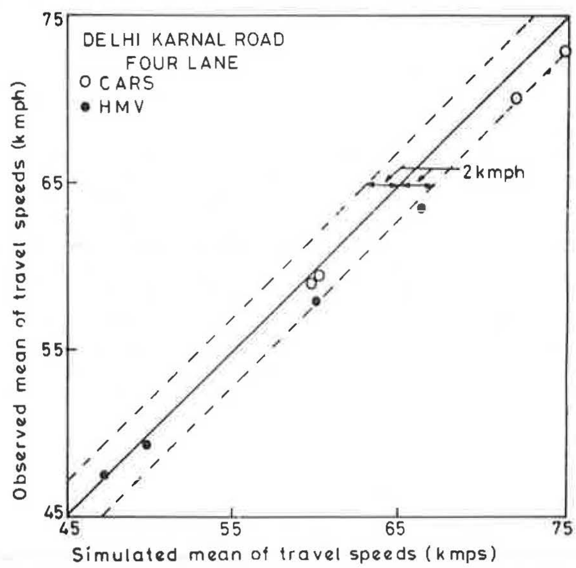

FIGURE 8 Simulated versus observed mean of travel speeds on four-lane road.

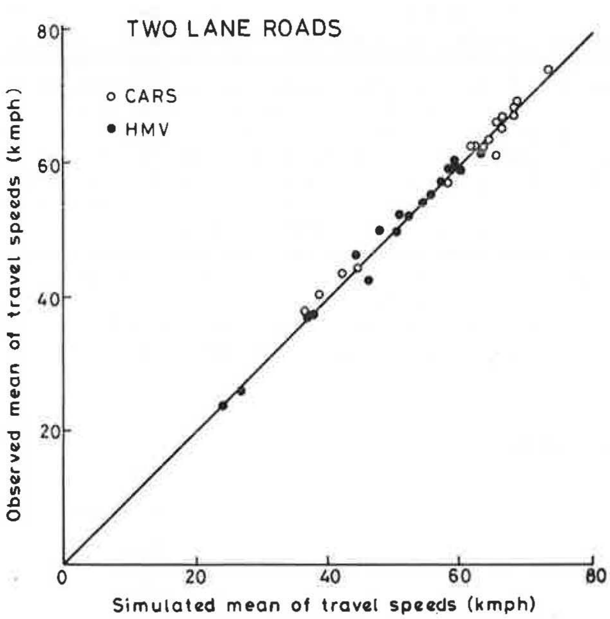

FIGURE 7 Simulated versus observed travel speeds on two-lane roads.

the simulations performed on narrow roads as well as for other, wider roads. This, too, indicates the predictive power of the model.

Comparison of Time Headways at Exits

The mean time headway for a flow of traffic is given by the inverse of the rate of flow. Because the rate of flow for each simulation run was specified from the data, the mean simulated time headway was constrained to be approximately equal to the mean observed time headway for each run. Figure 9 shows the observed versus simulated time headways at exit for the single-lane road. Because the traffic flow was low to medium on all sites, the time headway distributions were all exponential indicating random arrival process at any given point on the road and especially at the exits that have been replicated by the simulation model in close agreement with observed values.

Comparison of Observed and Simulated Overtakings

One of the stringent validation measures in traffic simulation concerns the number of overtakings by

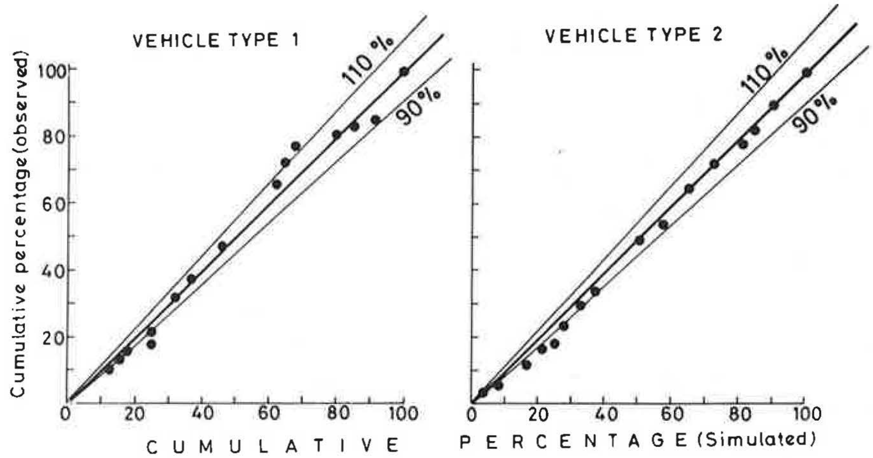

FIGURE 9 Headway distribution of vehicles at exit: G. T. Road, Kanpur, single-lane with bad brick shoulders (Direction 1).

different combinations of vehicle types. Figure 10 shows the observed and simulated overtakings for the two-lane road stretches simulated. The results for other roads are of similar accuracy (6,7). The number of overtakings increases as the roadwidth increases attaining the maximum in the case of divided multilane highways. The results also provide a measure of restraint a given road has on the free movement of the vehicles. The comparison of overtakings was made feasible by the carefully designed data collection procedure as well as by modeling the overtaking decision processes.

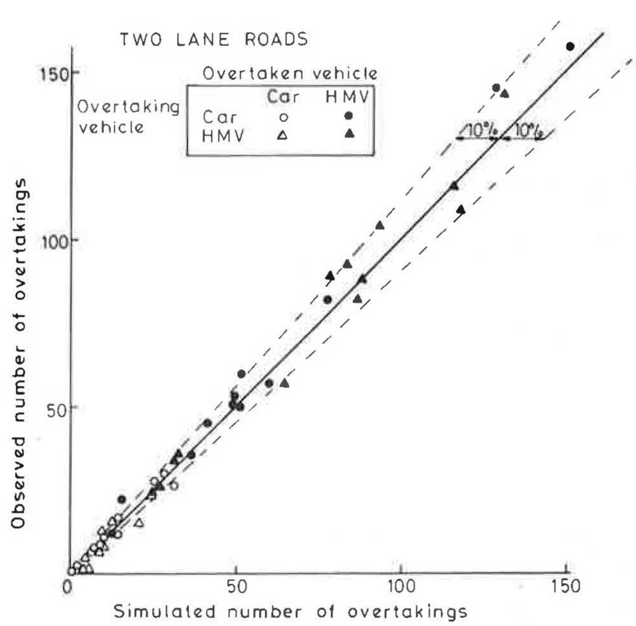

FIGURE 10 Simulated versus observed number of overtakings on two-lane roads.

SUMMARY AND CONCLUSIONS

Indian road conditions are unique in a number of ways and have provided fertile ground for research on quality of traffic flow and resulting highway capacity. Until now, highway capacities and level of service were measured effectively only under the relatively homogeneous vehicle flow conditions found in many Western countries. There, driver behavior is contingent on specific road classification (two lane, four lane divided, and so forth) where specific maneuver patterns are required and better understood by all road users. Heterogeneity in the traffic stream changes the basic premises of Western traffic flow models. On Indian roads, size, width, speed, and operational characteristics vary greatly from one vehicle to another. Individual interactions with other vehicles demand a unique decision-making process. Rigid rules of movement and segregation of vehicles by speed, classification, or direction do not exist on the majority of Indian roads. Therefore, it is the shear width of roads that determines the range of possible driver behavior and hence interaction among vehicles. The breakthrough of the adjusted Swedish model is that it allows analysts to calculate the impact of roadwidth on a myriad of episodic road encounters and the resulting travel time and highway capacity. Combined with the existing knowledge, based on conditions in Western countries, the model for heterogeneous traffic now completes coverage for all rural traffic and road conditions. This model can truly be called a generalized model for vehicle behavior under heterogeneous traffic conditions.

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Reduced-Delay Optimization and Other Enhancements in the PASSER II-84 Program

EDMOND CHIN-PING CHANG, CARROLL J. MESSER, and BLAIR G. MARSDEN

ABSTRACT

The development of a research study conducted by the Texas Transportation Institute entitled "Reduced-Delay Optimization and Other Enhancements to PASSER II-80" is summarized. The research was sponsored by the Texas State Department of Highways and Public Transportation (SDHPT) in cooperation with the FHWA, U.S. Department of Transportation. The brief 6-month research effort was directed toward several topic areas including development of a reduced-delay optimization procedure that could fine tune the offsets of traffic signals to reduce total arterial system delay and maximize arterial progression, development of methods that can better estimate vehicular delay in a nearly saturated traffic system, and development of methods to estimate fuel consumption for arterial traffic movements in an urban network. Significant enhancements have been made to the popular PASSER II program. This study also demonstrated the practical combination of the maximum bandwidth procedure and the minimum delay algorithm to effectively maximize progression and reduce delay, stops, and fuel consumption in optimizing arterial traffic signal operations. An enhanced version of the PASSER II-80 program, PASSER II-84, was programmed on Texas SDHPT's computer system. Program documentation and revised data-coding instructions were also prepared.