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REFERENCES

1. *Offtracking Characteristics of Trucks and Truck Combinations.* Western Highway Institute, San Bruno, Calif., Feb. 1970.
2. M. W. Sayers. "Vehicle Offtracking Models." In *Transportation Research Record 1052*, TRB, National Research Council, Washington, D.C., 1986, pp. 53–62.
3. *Longer Combination Vehicles Operational Test.* California Department of Transportation, Sacramento, March 1984.
4. H. Heald. "Use of the WHI Offtracking Formula." In *Transportation Research Record 1052*, TRB, National Research Council, Washington, D.C., 1986, pp. 45–53.

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Two-Lane Traffic Simulation: A Field Evaluation of Roadsim

JUAN M. MORALES AND JEFFREY F. PANIATI

Roadsim is a traffic simulation model for two-lane rural roads developed in 1980 by FHWA. In the subject study the accuracy of the model was evaluated by comparing its results with observed traffic behavior. The field data were collected on a two-lane rural road in Loudoun County, Virginia. Statistical analyses were performed to compare the measures of effectiveness (MOEs) observed in the field with those obtained from the simulation. The selected MOEs included mean vehicle speed, traffic volume, percent of vehicles following, platoon distribution, and average platoon size. Analysis showed that Roadsim's simulation results compared favorably with those observed in the field. Although this study validates Roadsim under a single geometric and traffic condition, results support its potential usefulness to the transportation engineering community. Further validation under a wide range of traffic and geometric conditions, however, is needed. Researchers are encouraged to use Roadsim to further validate its potential and recommend enhancements.

Traffic simulation, a tool used by traffic engineers in the analysis of roadway capital investment and traffic control management, provides valuable information to decision makers by predicting the likely effects of traffic or geometric changes on a roadway before the changes actually occur. Simulation results may be used to decide whether to proceed with the change, modify it, or abandon it. Simulation may determine the most effective way to spend available funds.

Initially, traffic simulation was directed to the urban scene. Because urban intersection traffic essentially behaves as a multilane queueing system, traffic may be simulated by using techniques developed for operations research. Simulation of freeway ramp traffic required modeling of traffic behavior by using queueing analogies. Freeway simulation studies were the pioneers of traffic simulation as a research tool.

Simulation of rural traffic on two-lane roads developed at a slower pace because the two-lane flow is complicated by platooning and passing decisions and therefore not easily modeled. Also, the low volumes on rural two-lane roads usually do not make simulation cost-effective. In addition, two-lane traffic simulation requires numerous computations, which require

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considerable computer time and memory, particularly for microscopic models. To date, most of the two-lane simulation models are microscopic. These models simulate and trace individual vehicles and are more accurate and realistic than macroscopic models, which simulate traffic using aggregate variables such as traffic volume and average speed.

Simulation models for two-lane roads have evolved over the past two decades. Most of the early attempts contributed little to the study of two-lane flow at a practical level. However, those attempts were stepping stones for other sophisticated simulation models currently available.

The ability of Roadsim, a traffic simulation model for two-lane rural roads that was developed in 1980 for FHWA, to replicate traffic operations observed on an existing two-lane rural road is evaluated. Field data were collected on a two-lane rural road in Loudoun County, Virginia. Statistical analyses performed to compare the measures of effectiveness (MOEs) observed in the field with those obtained from the simulation show that Roadsim's simulation results compare favorably with those observed in the field. Results support its potential usefulness to the transportation engineering community after the model has been further validated under a range of traffic and geometric conditions.

EVOLUTION OF ROADSIM

Roadsim, the latest product of the evolutionary process of two-lane simulation model development, is not a new model with new methodology and logic but rather a reprogrammed version of an earlier model (called TWOWAF) with modified routines and adaptations from other models *(1)*.

TWOWAF, a microscopic traffic simulation model, was developed in 1978 as part of the National Cooperative Highway Research Program (NCHRP) Project 3–19 *(2)*. The model can move individual vehicles in accordance with several parameters specified by the user. The vehicles are advanced through successive 1-sec intervals, and the roadway geometry, traffic control, driver preferences, vehicle type and performance characteristics, and passing opportunities based on the oncoming traffic are taken into account. Spot data, space data, vehicle interaction data, and the overall traffic data are accumulated and processed. Several statistical summaries are reported.

TWOWAF logic was modified to include logic elements from two other simulation models—INTRAS and SOVT *(3)*. INTRAS, a microscopic freeway simulation model developed in 1976 for FHWA, provided the basic car-following logic to TWOWAF. This logic is based on the premise that a vehicle that is following another will always maintain a space headway relative to its lead vehicle that is linearly proportional to its speed. This premise was much simpler than the one used in TWOWAF and thus easier to calibrate. SOVT, a microscopic two-lane simulation model developed in 1980 at North Carolina State University, provided its vehicle generation logic to TWOWAF. This logic emits vehicles onto the simulated roadway at each end. For low volumes, the Schuhl distribution used in SOVT provides a realistic approximation of vehicles generated. However, for high volumes where traffic density approaches queueing, a shifted exponential headway distribution is used.

The new TWOWAF model was reprogrammed according to FHWA specifications, modified with new input and output subroutines, and renamed Roadsim. Detailed documentation was made available as part of TRAF, an integrated system of simulation models *(1)*. This evolutionary process is shown in Figure 1.

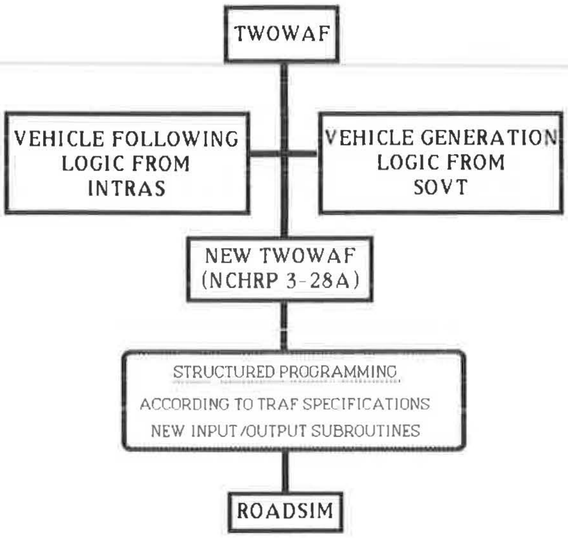

FIGURE 1 Evolution of Roadsim.

MOES GENERATED BY ROADSIM

Roadsim is structured in a link-node format, which requires the simulated roadway to be divided into segments called links. Links are interconnected at points called nodes. It is through the links that the roadway geometrics are specified to the model.

In addition to overall statistics, some of the MOEs generated by Roadsim are reported as link-specific or link- and direction-specific. Link-specific MOEs are generated for each direction of travel. MOEs and their units reported in the cumulative output of Roadsim are given in Table 1.

DATA COLLECTION AND METHODOLOGY

Site

A 4.6-mi (7.4-km) section of US-15 in Loudoun County near Leesburg, Virginia, was chosen as the site for the data collection on the basis of the following geometric and operational factors:

- Significant truck volume,
- Rolling terrain,
- Minimal roadside activities,
- No major intersections,
- Standard roadway features (e.g., signing, shoulder width, sight distance),

TABLE 1 MOEs OF EFFECTIVENESS GENERATED BY ROADSIM

Measure	Units
Link specific and direction specific by vehicle category (automobile, recreational vehicle, truck)	
Travel	Vehicle-miles Vehicle-trips
Travel time (ideal, zero traffic, and actual)	Seconds/vehicle
Standard deviation of travel time	Seconds
Delay (geometric, traffic, and total)	Seconds/vehicle
Standard deviation of delay	Seconds
Mean speed, standard deviation of speed, speed extremes	Miles/hour
Passes attempted, completed, and aborted	Number per mile per hour
Link specific	
Distribution of headways	Number in each range, percent of total, cumulative percent
Distribution of speeds	Number in each range, percent of total, cumulative percent
Distribution of platoon sizes	Number in each range, percent of total, cumulative percent

Note: 1 mi = 1.6 km.

- Adequate two-way volume to cause significant platooning and passing opportunities, and
- Attainable free-flow speed of 55 mph (89 km/hr) or faster.

Road geometry data, obtained from construction plans supplied by the Virginia Department of Highways and Transportation (VDHT), included horizontal and vertical alignment (Figure 2). Passing zones and link lengths were measured in the field by using a calibrated fifth wheel. Information on sight distance was computed manually with the following formula:

Maximum passing sight distance = length of passing zone + 1,500 ft (1)

Volume and other traffic characteristics were measured in the field. Route 15 carries a significant truck volume because its weight limits are higher than those of adjacent roadways. Observed traffic volume during most of the daylight hours was between 300 and 400 vehicles/hr (in both directions) with 25 percent trucks. These characteristics were desirable for the study because low volumes create frequent passing opportunities and the high percentage of trucks creates platoons.

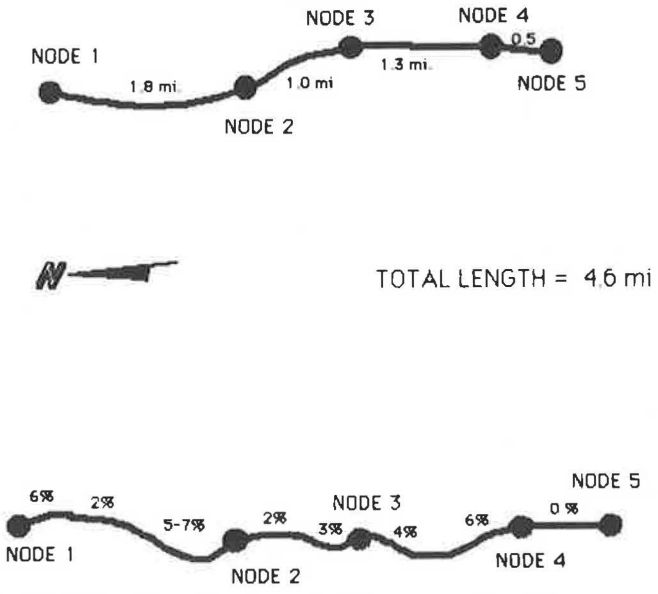

FIGURE 2 Geometric characteristics: ***top*****, horizontal alignment;** ***bottom*****, vertical alignment.**

Procedure

Two-way traffic was observed on the selected roadway section, which was divided into four links based on the geometric similarities of the roadway within each link. Data were collected at each node (called stations) using color videotape recording equipment. The recording procedure was chosen for the following reasons:

- Data reliability was high,
- Staff requirements were low (one person per node),
- Manual data logging in the field was not required,
- Vehicles could be tracked without the recording of license plate numbers,
- Data could be easily verified and corrected,
- A permanent record of the data was available for future studies, and
- Equipment cost was low.

Each node required a color videotape recorder, a camera, a power supply, a digital stopwatch, and a tripod. The average setup rental was $100 per day.

Both equipment and attendants were stationed in an unobtrusive location off the roadway. All cameras were positioned at the same angle to obtain similar views of each vehicle and facilitate vehicle tracking from node to node.

Data were collected for three 2-hr periods over 2 days. The video recorders were run in real time for the duration of each period. Digital watches were used to synchronize the cameras. Each camera attendant audibly recorded the time on the recorder every 15 min to provide a time reference during data reduction.

DATA REDUCTION

The videotaped traffic data were manually coded onto data forms. This task required approximately 48 person-hr to reduce each of the three 2-hr data collection periods for all five nodes.

The data obtained from the videotapes were arrival time (to the nearest second), vehicle type (atuomobile, recreational vehicle, single-unit truck, or combination truck), and vehicle description for tracking purposes (e.g., color, make, model).

Although the roadway section selected contained no major intersections, there were several residential driveways and two minor intersections. Eight percent of the observed vehicles did not travel the entire roadway (entry at Node 1 and exit at Node 5) and so were not included in the data analysis. Data, entered into an electronic spreadsheet for compilation, could be corrected and updated. After the data were input, they were checked for errors against the videotapes.

Vehicle data were stored separately for each direction of travel. Vehicles were numbered sequentially on the basis of their arrival order at the entry node. The difference between a vehicle's arrival times at the individual nodes determined its travel time for each link. Speeds were obtained by dividing the length of each link by the travel time. Headway was defined as the difference between the arrival time of a vehicle and the arrival time of the next vehicle.

To complement the spreadsheet, programs were developed to compute platoon sizes and the number of completed passes. Platoon sizes were computed after it had been determined whether a vehicle was a leader or a follower. By definition, a vehicle was said to be following another if its bumper-to-bumper headway was 6 sec or less. This is the same headway used by Roadsim for this purpose. Each platoon consisted of a leader and its followers, if any.

The number of completed passes was determined by comparing the arrival sequence at individual nodes with the sequence at the previous node. Separate data were obtained from the spreadsheet for the four vehicle types for comparison with Roadsim. The data included mean speed, headway, travel time, and number of completed passes. Some data had to be discarded after careful examination; for instance, artificial delays were created because of extremely slow vehicles (tractors) in the traffic stream, and the simulation is unable to represent this. Of the 6 hr of traffic data collected, two segments (one 30-min and one 60-min) were used in the comparative analysis.

Comparison of the two selected periods showed their traffic flow characteristics to be different. Therefore, they were compared separately with the simulation results. The factors considered were variations in traffic volume, vehicle mix, directional split, and platooning because these data have to be input into the model.

The reduced data included statistics for the overall roadway length as well as for individual links and vehicle types. These data, along with the spreadsheet templates (LOTUS 1-2-3, which is IBM compatible) and other programs (IBM BASIC) generated for this study, are available to other researchers through the authors.

THE SIMULATION PROCEDURE

Once the field data were reduced, Roadsim was coded and executed to obtain data for comparison.

Coding Roadsim

To replicate field conditions and simplify coding the model, the following assumptions were made:

- All vehicles fell into one of four possible vehicle types: type 1—automobiles, vans, pickup trucks; type 2—recreational vehicles, horse trailers, tow trucks; type 3—single-unit trucks, school buses, sanitation trucks; or type 4—combination trucks.
- Field maximum passing sight distance, required in the input stream, was determined by adding the length of the passing zones to 1,500 ft (457 m) (VDHT standard minimum), as previously explained.

Several default values contained in the model that were judged adequate and compatible with the field data were used to simplify coding. The data required to run the model and the default values used in this study are given in Table 2.

Coding the required input was tedious because interactive data input procedures were not available. The model is coded by entering data into specific fields of 80-column cards from a mainframe computer terminal. This required constant reference to the User's Guide *(1)* and several runs to correct misplaced data entries. The User's Guide, however, contains a complete error message section that proved to be very useful in completing this task.

Adjusting Roadsim

To simulate the observed field conditions, the model's control input had to be adjusted initially. These adjustments are not to be confused with model calibration, which refers to the fine tuning of empirical coefficients in the actual computer code. The adjustments were made to the control data and not to the Roadsim code. Because of the random nature of traffic behavior, these adjustments were necessary to ensure that the collected field data could be directly compared with the simulation data. Other adjustments made because of the input and output formats of the model are discussed in the following sections.

Model Links Versus Field Links

Because the Roadsim input format allows the user to specify only one horizontal curve, two vertical curves, and three no-passing zones per link, it was necessary to divide the four field links into seven smaller model links.

TABLE 2 REQUIRED DATA AND VALUES USED

Variable	Comment or Value
Free-flow speed	Variable (see text)
Standard deviation	9 percent of free-flow speed
Forward sight distance	1,500 ft
No-passing regions	Variable (three per link maximum)
Link length	Variable (9,999-ft maximum)
Passing sight distance	Variable (three regions per link maximum)
Horizontal curve data	Variable (one curve per link maximum)
Length	
Radius	
Superelevation	
Vertical curve data	Variable (two curves per link maximum)
Length	
Grade	
Vehicle type data	Variable (16 types maximum)
Automobiles	
Length	17 ft[a]
Maximum acceleration	5.5 mph/sec[a]
Maximum speed	75 mph[a]
Maximum entry speed	75 mph[a]
Volume	Variable (vph/direction)
Recreational vehicles	
Length	25 ft[a]
Maximum acceleration	5.9 mph/sec[a]
Maximum speed	65 mph[a]
Maximum entry speed	65 mph[a]
Volume	Variable (vph/direction)
Single-unit trucks	
Length	30 ft
Weight/horsepower (power factor)	72 lb/horsepower
Weight/frontal area (mass to frontal area factor)	158 lb/ft[a]
Elevation factor	1.0
Drag factor	0.96
Maximum entry speed	65 mph
Volume	Variable (vph/direction)
Combination trucks	
Length	65 ft
Weight/horsepower (power factor)	266 lb/horsepower
Weight/frontal area (mass to frontal area factor)	620 lb/ft[a]
Elevation factor	1.0
Drag factor	0.96
Maximum entry speed	65 mph
Maximum acceleration using partial horsepower	81 percent
Maximum 0-grade speed using partial horsepower	90 percent[a]
Pass suppressing influence upstream of curve to right	10 sec[a]
Bias to add to trucks' desired speeds	–1.5 ft/sec[a]
Bias to add to recreation vehicles' desired speeds	–2.2 ft/sec[a]

Note: 1 ft = 0.305 m; 1 lb/horsepower = 0.608 kg/kw; 1 mph/sec = 1.01 km/sec; 1 mph = 1.6 km/hr; 1 lb/ft^2 = 4.88 kg/m^2.

[a] Default value applied by the model.

Buffer (Dummy) Links

The Roadsim output does not generate speed, headway, or platoon distribution data for exit links because of the breakdown of the car-following logic when vehicles are leaving the simulated road. To obtain the distribution data for these links (for each direction of travel), a buffer link was added to both ends of the simulated roadway section. Each link was 750 ft (229 m) long, had no horizontal or vertical curvature, and no passing was allowed. This was the shortest possible length that would not affect upstream conditions.

Free-Flow Speed

Free-flow speed is the mean speed at which unimpeded passenger cars (platoon leaders) travel. Roadsim requires a free-flow speed to be specified for the entire roadway or by individual link. An overall free-flow speed was obtained from the field data by averaging the speed of all the platoon leaders.Using this speed in the model's input resulted in mean speeds that were significantly lower than those observed in the field. It was decided to adjust the free-flow speed inputs of individual links to "force" the model mean speeds to be comparable with the observed mean speeds. Therefore, mean speed was a controlled variable. The 30-min data were used to determine this adjustment. The same adjustment was then used in the 60-min data. The average bias per link ranged between 2 and 8 mph (3.2 and 12.9 km/hr). An increase of 5 mph (8 km/hr) in the overall free-flow speed appeared to give similar Roadsim and field results for the mean speed of the overall roadway section.

Traffic Volume

To compare the selected MOEs, a similar number of field vehicle trips and simulation vehicle trips was necessary. Directional hourly volumes for each of the four vehicle types are required input for the model. These volumes are used by Roadsim as an approximation to generate vehicle trips. The actual number of vehicle trips might differ from the input volumes because vehicles that had not traveled the entire roadway when simulation stopped are excluded from the vehicle trip tally and because of the randomness of the vehicle generation logic. To compensate for these, the input volumes were adjusted by trial and error on several Roadsim runs until the number of vehicle trips was similar to the number of trips observed in the field. Therefore, traffic volume was the second controlled variable.

Having the same mean speeds and the same traffic volumes constrains the modeled speed distributions to approximate those observed in the field.

Roadsim Execution

Although the simulation runs would have the same volumes and mean speeds, certain variations were expected because of the randomness of the model's logic. These variations may be observed by changing the "random number seeds" of each run for the initial selection of various parameters, such as headway distributions and driver aggressiveness.

To account for these variations, 10 runs were executed by using different random number seeds. An analysis of variance indicated that 10 mean speeds were not statistically different. Therefore, the results of the 10 runs were aggregated into a single data set for comparison with the field data.

Data Reduction

In most instances, the output generated by Roadsim was in a format that was not directly compatible with the field data. Data manipulation was necessary to convert the simulation data to a comparable format. This inconvenience was a direct result of having to break down the field links into smaller model links and Roadsim's inability to aggregate individual link data into longer links. Enhancing the model to overcome these limiting factors is desirable because restricting the number of horizontal and vertical curves per link results in short links. The user typically is interested in MOEs over long sections of roadway, which might require a large number of links.

Data were manually taken from the Roadsim outputs and manipulated by using the spreadsheet. After all the simulation data had been reduced to the same format as the field data, a statistical comparison was possible.

STATISTICAL COMPARISON

Once the field data and the simulation data had been reduced to similar formats, the MOEs of interest could be compared and analyzed statistically. Because the simulation volume and the mean speed were controlled by varying the input volumes and the free-flow speed entry, an inferential statistical analysis was not appropriate. Instead, the primary MOEs of interest were percent of trucks, percent of vehicles following, cumulative platoon distributions, average platoon size, and the number of completed passes. The collected field data and the simulation data are summarized in Tables 3 and 4.

Traffic Volume

Once traffic volumes had been adjusted to obtain a similar number of vehicle trips, no difference was apparent.

Mean Speed

The mean speed of all vehicles was an adjusted variable. To verify that the model was reasonably adjusted, a t-test at a 95 percent confidence interval was performed. As expected, no statistical difference between the field and Roadsim overall mean speeds was found.

Percent of Trucks

To verify the accuracy of the vehicle generation logic, the percentage of trucks observed in the field was compared with the Roadsim percentage of trucks. No difference was apparent.

Cumulative Platoon Distributions

The cumulative platoon distributions, a good indicator of the level of service of a given roadway, were considered the most important MOE. On two-lane roads, platooning has been proposed as a better method of quantifying level of service than the operating-speed method currently used in the *Highway Capacity Manual (4, 5)*. Platooning characteristics can account for the effect of road geometry and traffic conditions on traffic performance.

The platoon distributions were statistically analyzed by using the Kolmogorov-Smirnov test, which is useful in comparing cumulative distributions that may not be normally distributed. The overall comparison of the field and simulation distributions was found to have no significant difference at a 95

TABLE 3 SUMMARY OF THE 30-MIN DATA

MOE's	Field data		Roadsim data	
	Northbound	Southbound	Northbound	Southbound
Volume (vehicles/hour)	150	152	143[1]	138[1]
Mean speed (mi/h)	54.8	55.4	54.5[1]	55.6[1]
Percent trucks	24	24	22	25
Percent following	44.5	38.5	44.5	38.7
Average platoon size	1.80	1.62	1.83	1.75
Completed passes	2	13	5	12

[1] After adjustment.

percent confidence interval. These cumulative distributions are presented in Figures 3–6.

Percent of Vehicles Following

The percent of vehicles following (vehicles impeded by the vehicle immediately in front) is another MOE that can be derived from the platoon distributions. The results obtained from this MOE for the overall section compared favorably.

Average Platoon Size

This comparison provided another measure of Roadsim's ability to replicate the vehicle grouping that occurred in the field. Comparison of the overall section results indicated a negligible difference between field observations and those obtained through simulation.

Completed Passes

The comparison between the field data and the simulation data of the number of completed passes should be studied carefully. Passing is a traffic measure that reflects the degree of constraint on drivers. Passing opportunities are a function of the opposing traffic and the available sight distance. The lack of passing opportunities translates into an increase in traffic platooning and a decrease in operating speeds and therefore a reduced level of service.

When the number of completed passes is compared, it

TABLE 4 SUMMARY OF THE 60-MIN DATA

MOE's	Field data		Roadsim data	
	Northbound	Southbound	Northbound	Southbound
Volume (vehicles/hour)	138	130	143[1]	136[1]
Mean speed (mi/h)	54.2	54.6	54.7[1]	54.8[1]
Percent trucks	23	25	21	26
Percent following	42.5	41.7	42.0	41.2
Average platoon size	1.74	1.72	1.74	1.71
Completed passes	10	19	10	26

[1] After adjustment.

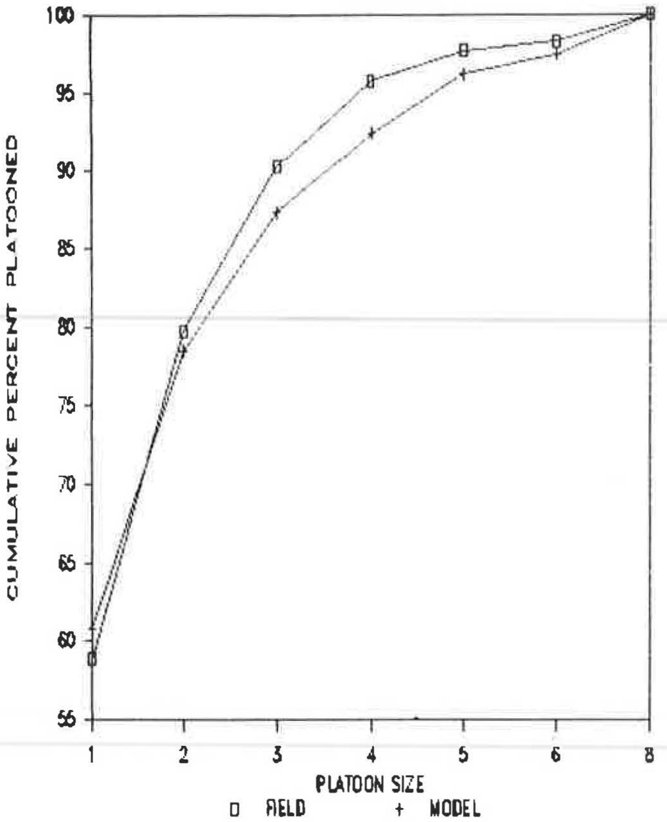

FIGURE 3 Platoon distribution: northbound overall, 30-min data.

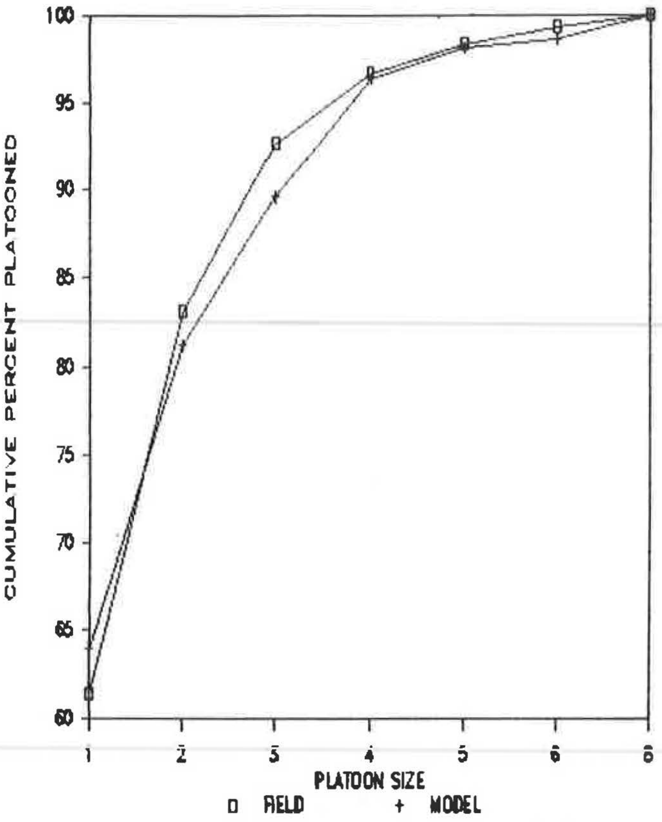

FIGURE 5 Platoon distribution: northbound overall, 60-min data.

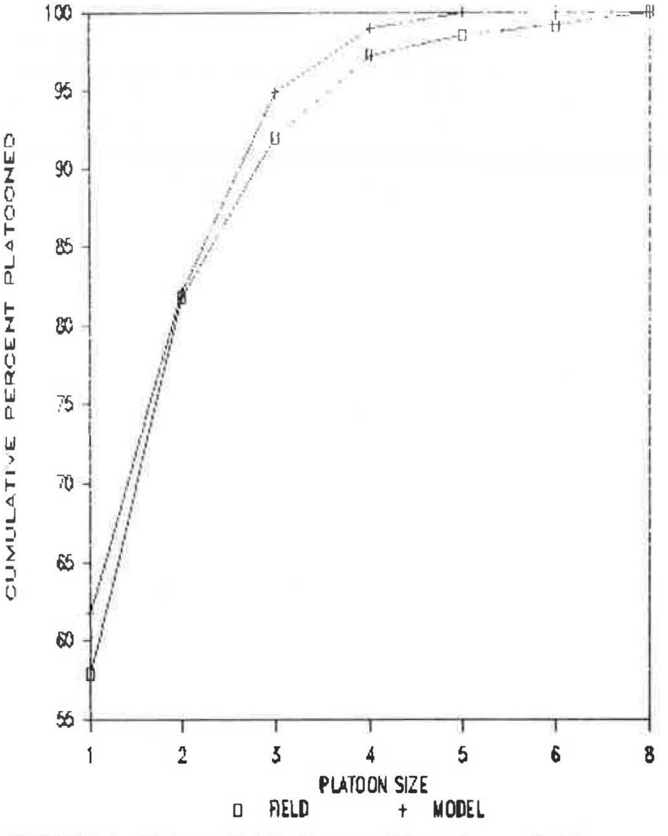

FIGURE 4 Platoon distribution: southbound overall, 30-min data.

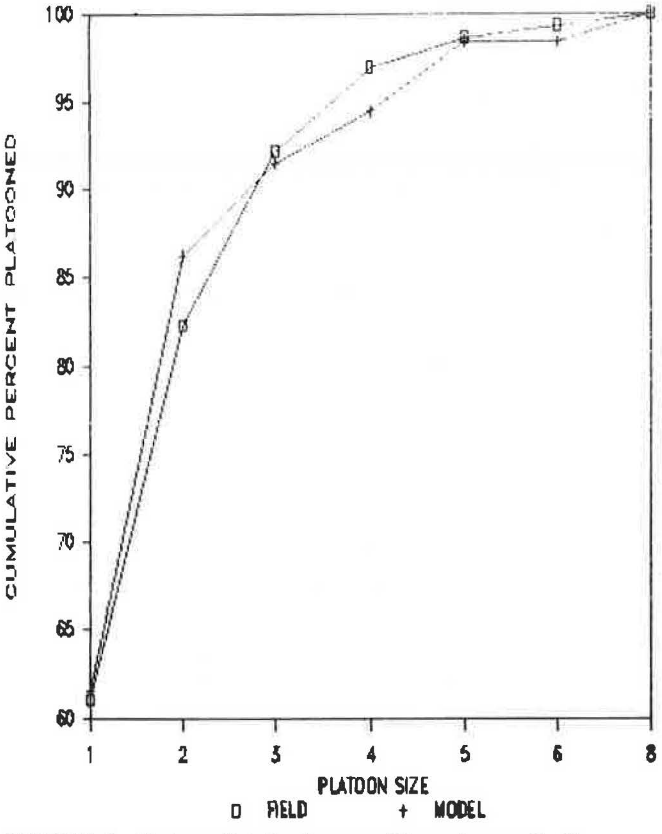

FIGURE 6 Platoon distribution: southbound overall, 60-min data.

should be remembered that there are several factors that influence the decision to pass (for example, driver's aggressiveness and gap acceptance). These factors, although considered in the simulation, cannot be replicated without collection of data for long periods of time. The short data periods being compared in this study were judged insufficient to reach a definite conclusion on the validity of Roadsim's passing logic. Ideally, passes should be compared per unit of time (such as passes per hour), for which longer data periods are desirable. However, the number of completed passes simulated by Roadsim for the available data periods appeared to compare adequately with the field data for the overall roadway section.

SENSITIVITY ANALYSIS

In addition to testing the ability of the Roadsim model to stimulate field conditions, the sensitivity of the model was examined by varying several input parameters to study what effect the parameters have on the mean vehicle speed. The effect on other MOEs was not examined. The parameters studied were the horizontal alignment, the vertical alignment, and a combination of the two. This sensitivity analysis indicated which ranges of the studied parameters significantly affect the mean vehicle speed in Roadsim.

Horizontal and vertical alignments were selected because they are the limiting factors when a roadway section is divided into smaller simulation links. Excluding insignificant geometric features makes possible the use of longer links and simplifies coding the model.

A simple scenario, independent of the field data collection site, was chosen to test these parameters. The following analysis has not been compared with any field data and was undertaken to study the sensitivity within the model.

Horizontal Alignment

Ten simulation runs were executed in which the radius of a curve joining two tangents was varied. The following parameters were held constant during these runs:

- Length of tangents [3,400 ft (1036 m) each];
- Delta of the curve (40 degrees);
- No vertical curvature (0 percent grade);
- Passing allowed on tangents, no passing on curve;
- Free-flow speed [60 mph (97 km/hr)];
- Volume (300 vph, 50–50 directional split); and
- Vehicle mix (20 percent trucks, 0 percent recreational vehicles).

The radius of curvature was varied from 500 ft (152 m) to 3,000 ft (914 m) in increments of 500 ft (152 m). The length of the curve was compared and the superelevation rates were obtained from AASHTO Green Book *(6)*.

Roadsim's results indicated that the effect of curves with a radius greater than 1,500 ft (457 m) was negligible for both automobiles and trucks. This suggests that horizontal curves with radii larger than 1,500 ft (457 m) will not affect the mean vehicle speeds in Roadsim (Figures 7 and 8).

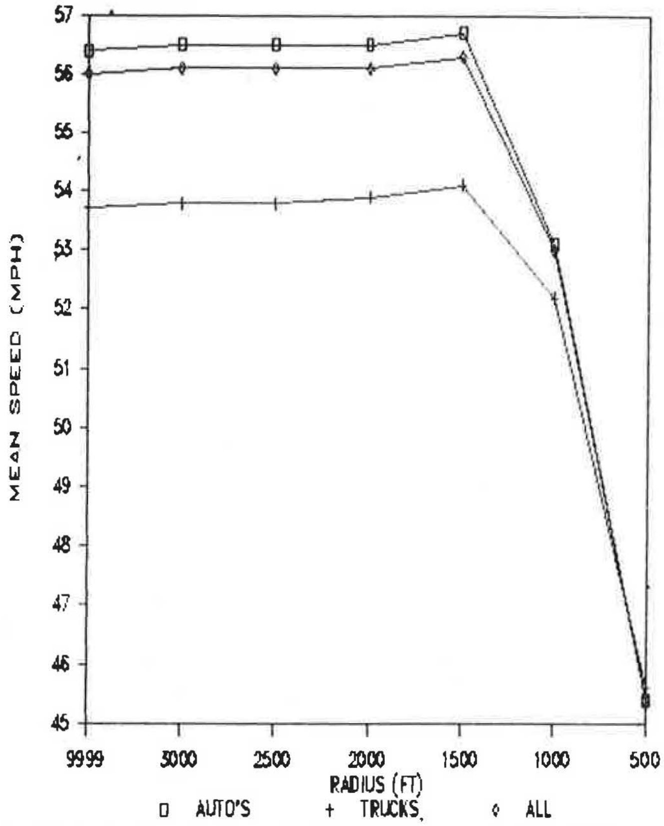

FIGURE 7 Sensitivity analysis: horizontal alignment, right.

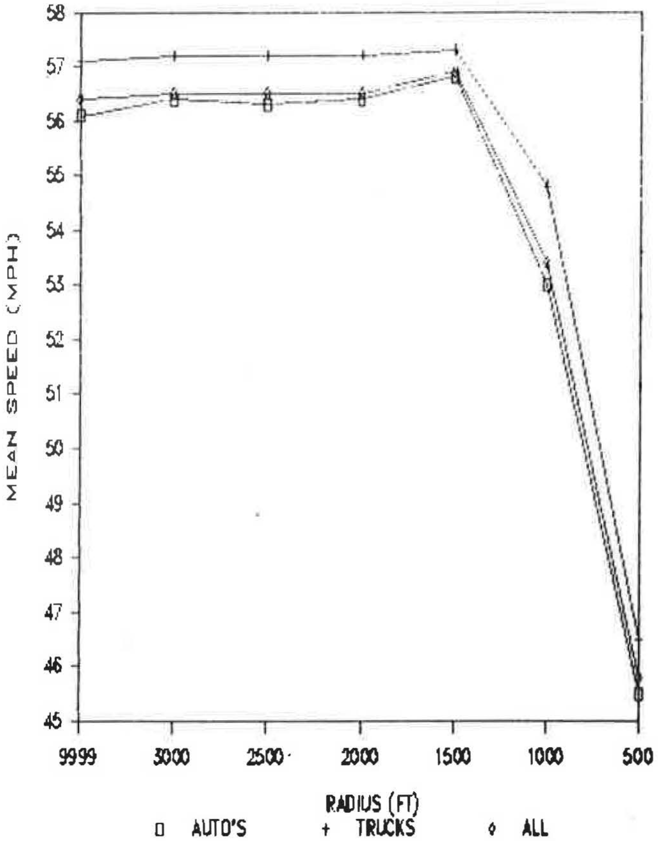

FIGURE 8 Sensitivity analysis: horizontal alignment, left.

Vertical Alignment

Vertical alignment was studied to examine the effect of both the length and magnitude of positive grades. Forty runs were made to study the various combinations. The same parameters just listed remained constant, with the addition of the horizontal curvature (tangent).

The typical truck used had a 266-lb/net-horsepower-ratio (162-kg/kw) power factor and 620-lb/ft^2 (3.03-Mg/m^2) mass-to-frontal area factor.

Results suggested that mean speeds are not significantly affected by grades of 2 percent or less in Roadsim for both automobiles and trucks. At grades of 3 percent and above, the reduction in speed is significant primarily because of the substantial reduction in truck speed on uphill grades. The relatively high percentage (20 percent) of trucks used had a major effect on the overall speeds (Figures 9–11).

Combined Horizontal and Vertical Alignment

Next the combined effect of horizontal and vertical alignment was studied. Having found that grades over 3 percent and curves with a radius of less than 1,500 (457 m) substantially reduced speeds, it was decided not to consider values beyond these thresholds. The worst case of the remaining combinations was selected—a horizontal curve with a 1,500-ft (457-m) radius combined with an uphill grade of 2 percent. Results

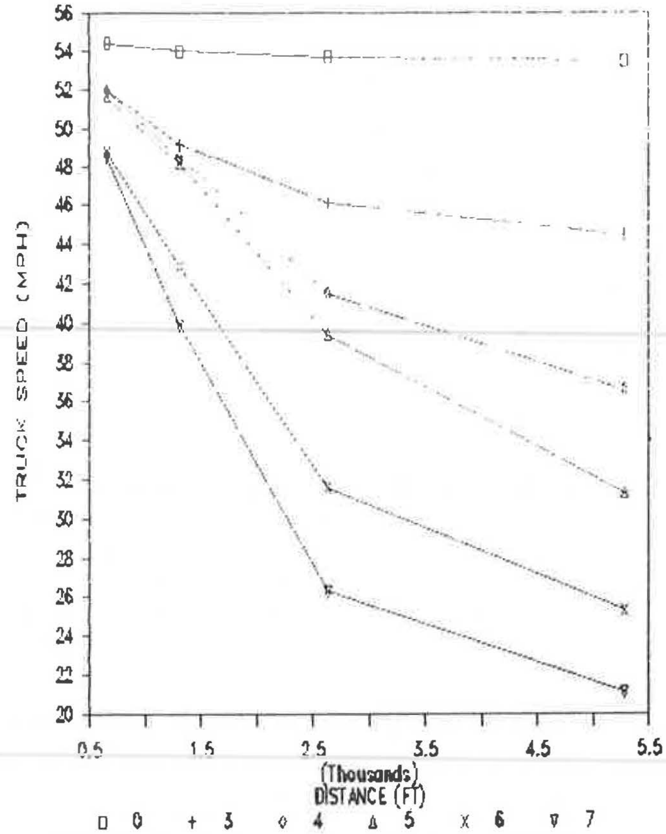

FIGURE 10 Sensitivity analysis: vertical alignment, trucks.

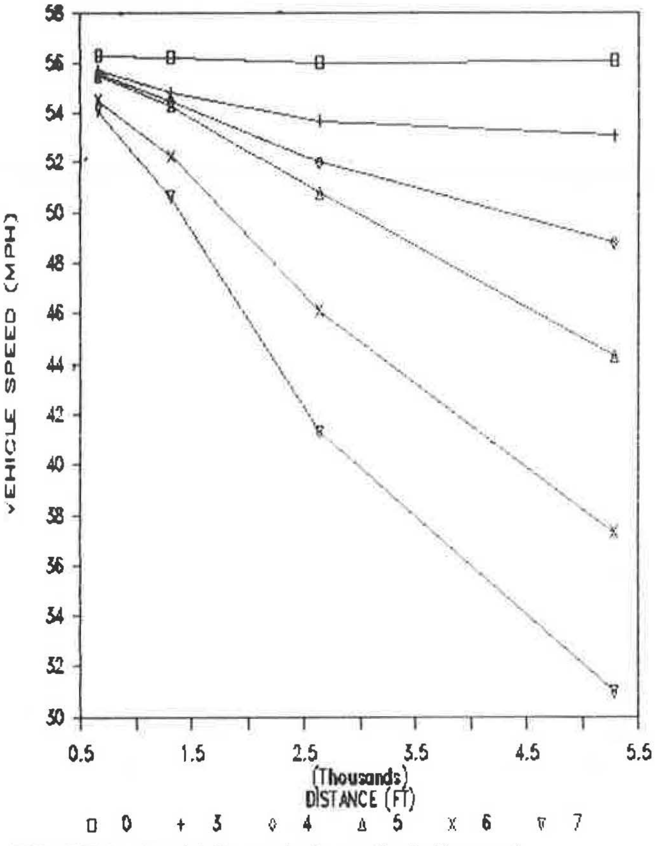

FIGURE 9 Sensitivity analysis: vertical alignment, automobiles.

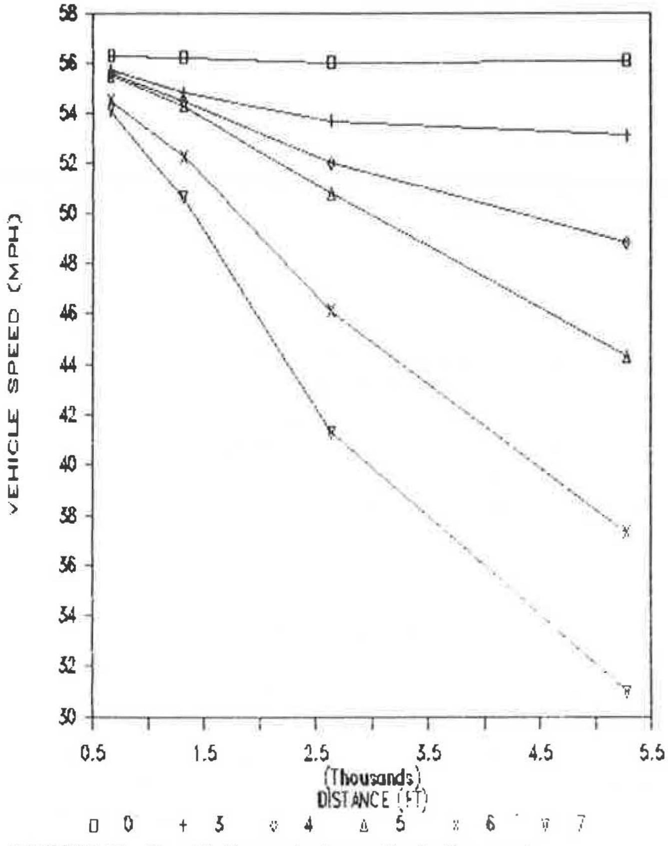

FIGURE 11 Sensitivity analysis: vertical alignment, automobiles and trucks.

showed no apparent difference between the mean speeds on a level, tangent section and the worst-case section.

CONCLUSIONS

On the basis of this comparative evaluation of Roadsim under specific geometric and traffic conditions and the performed sensitivity analysis presented in this paper, the following conclusions may be drawn:

- Roadsim appears to work satisfactorily under the geometric and traffic conditions studied.
- The free-flow speed input appears to be biased. After this input has been adjusted upward, most MOEs compared well with the collected field data for the overall section of road. This bias should be further studied and calibrated.
- Horizontal curves with radii greater than 1,500 ft (457 m) do not appear to significantly affect the overall mean speed of the traffic stream.
- Vertical curves with positive grades of 2 percent or less do not appear to significantly affect the overall mean speed of the traffic stream.
- In its current form, Roadsim can evaluate changes in passing zones, changes in alignment, the effect of volume increases, and the effect of variations in traffic composition.

FUTURE EVALUATIONS AND ENHANCEMENTS

The study described here predicts an optimistic future for Roadsim; however, its full acceptance as a totally valid model is premature. Additional similar studies are necessary to verify the model's performance under a range of traffic and geometric conditions. For example, the performance of Roadsim must be examined in comparison with different real-world traffic bidirectional volumes such as 500, 750, 1,000, and 1,500 vehicles per hour for various terrains (flat, rolling, and mountainous). Further examinations of the free-flow speed input also are needed.

If Roadsim consistently yields results similar to those obtained in the field, the model could be made available for widespread use. However, if it is found that changes and improvements not mentioned in this paper are needed, they could be made when programming upgrades for passing lanes, climbing lanes, and rural intersections are added.

To further assess the functional ability of Roadsim, FHWA would like to receive research reports, results, and recommendations from other users. All comments should be directed to

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REFERENCES

1. *TRAF User's Guide.* Report FHWA–IP–82–18. FHWA, U.S. Department of Transportation, June 1983.
2. A. D. St. John and D. R. Kobett. *NCHRP Report 185: Grade Effects on Traffic Flow Stability and Capacity.* TRB, National Research Council, Washington, D.C., 1978.
3. *Final Report, NCHRP Project 3–28.* TRB, National Research Council, Washington, D.C., 1983.
4. C. J. Hoban. Toward a Review of the Concept of Level of Service for Two-Lane Rural Roads (Technical Note 1). *Australian Road Research,* Sept. 1983.
5. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
6. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1984.

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