Comparison of Performance of TWOPAS and TRARR Models When Simulating Traffic on Two-Lane Highways with Low Design Speeds

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A comparison of the TWOPAS and TRARR models when used to simulate traffic operation on two-way rural highways with low design speed and two lanes is reported on in this paper. It was found that the TWOPAS and TRARR models are generally comparable in their ability to simulate traffic operations on two-lane, two-way highways. However, the TWOPAS simulation results compared better with field data for roads with an 80-km/hr (50-mph) design speed. This was the case for both a level terrain site and a rolling terrain site. The comparison was made in travel time and percentage time delay. Both models require further work before they can be applied without reservation to the many types of situations that might arise on two-lane roads. It is recommended, however, that TWOPAS be adopted for analysis related to capacity and level of service.

Computer simulation models are becoming increasingly important in the analysis of traffic on highways and streets. This is particularly true for two-lane highways where frequent changes in alignment and lack of passing opportunities create complex and frequently changing traffic conditions. These conditions are difficult and expensive to analyze with empirical methods because of the large amount of data required. Simulation models are often used to analyze such situations.

The performance of the TWOPAS and TRARR simulation models is compared. The models are used to simulate traffic operation on two-lane, two-way rural highways with low design speeds. TWOPAS is a microscopic stochastic computer model originally developed and documented at the Midwest Research Institute (*1,2*). It was used to generate the basic data presented in the 1985 *Highway Capacity Manual* for the analysis of the capacity and level of service for rural two-lane highways (*3–5*). The TRARR model was developed by the Australian Road Research Board (*6*). TRARR has become noteworthy not only because of its use in Australia but also because it has been applied for important research in Canada and the United States (*7,8*). Both TWOPAS and TRARR were developed specifically for simulation of traffic operations on two-lane rural highways.

The model comparison was carried out as part of a project undertaken for the California Department of Transportation (Caltrans). The aim of the project was to develop a methodology for the analysis of the capacity and level of service for two-lane highways with design speeds of less than 96 km/hr (60 mph).

The comparison is presented in terms of the features of the models as well as the conformance of the model predictions with field data. In addition, noteworthy experience with the models and information on model modifications made during the course of the project are presented. The comparison is discussed, and a summary of major conclusions and recommendations is presented.

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COMPARISON OF MODEL FEATURES

A major difference between the models, before the modifications made during this project, was that TRARR was operational on an IBM-compatible personal computer (PC) whereas TWOPAS was operational only on a mainframe computer. During the course of the project, TWOPAS was modified to operate on an IBM-compatible PC. Recently it was discovered that FHWA also had modified the model to run on a PC.

TRARR used metric units for both input and output. The field data used as input were, however, in imperial units and the output was also required in imperial units. Because a large number of computer runs were made during the course of the project, the input and output were converted to imperial units.

The remaining major model features considered in the comparison are

1. Basic methodology;
2. Model input;
3. Model output;
4. Documentation, support, and computer requirements; and
5. Ease of use.

Basic Methodology

Both TRARR and TWOPAS are microscopic, stochastic models that can simulate uninterrupted traffic on two-lane, two-way highways with or without auxiliary lanes. Both models operate on a time-scanning basis for updating vehicle movements.

The models are similar in that individual driver behavior and vehicle performance are modeled in detail. Differences in driver behavior with respect to desired speeds are accounted for. Several vehicle types are modeled. Both driver behavior and vehicle performance are restricted by horizontal and vertical alignment as well as other geometric features, such as passing and no-passing zones.

The logic of the models consists essentially of initially placing vehicles on the road and allowing a warm-up time during which the traffic settles into a pattern representative of the prevailing roadway and traffic conditions. Different driver and vehicle types, proportional to the specified flow rates, are generated at each end of the road. A warm-up section precedes the actual test section. The warm-up section allows the traffic to settle into a pattern representative of the field conditions at the entrance to the test section.

Model Input

The models are very similar as far as input is concerned. Both models use data on road geometry, traffic control (passing and no-passing zones), vehicle characteristics (by direction and vehicle type), driver behavior, and entering traffic (by direction and vehicle type). In most cases the data on road geometry, traffic control, and entering traffic are required and default values are provided for the remainder. More details on the possible input items are shown in Figure 1.

Although the input is in principle similar for the two models, there are some notable differences. Vertical and horizontal curves can be directly input into TWOPAS, whereas the vertical alignment has to be directly input into TRARR but the horizontal alignment is input through a road speed index. The road speed index is a function of the curve radius and the 85th percentile of the desired speed. A table of road speed indexes is provided in the manual.

During the course of the project, TWOPAS was modified to increase the number of horizontal curves that it could accommodate from 9 to 50 and the number of grades from 30 to 100 to accommodate the alignment encountered on roads with low design speeds. The alignment specification limitations for TRARR are different. The road is divided into units of which the lengths have to be specified. The limitation on the number of units is 165, but the model was only successfully executed with 150 units. The grade, road speed index, sight distance, and presence of a barrier line as well as an auxiliary lane have to be specified. It is very awkward to make changes to these data because of the constant length of the road unit.

TWOPAS can accommodate 13 vehicle types: 5 types of trucks and buses, 4 types of recreational vehicles (RVs), and 5 types of automobiles.

Characteristics such as acceleration and speed capabilities can be specified or default values used.

Eighteen vehicle types can be specified for TRARR. Existing files containing default values for vehicle characteristics can be used or changed to reflect local conditions. Default values are specified for nine types of large or heavy trucks, one small truck, one car and caravan, and seven types of cars. Some of the vehicles described appear to be vehicles that are found in Australia but not in the United States. No large RVs of the types found in the United States are described by the default values. However, some of the existing vehicle types could be converted to RVs and designated as such in the output.

Model Output

The standard TWOPAS output is much more extensive than the standard TRARR output. The more extensive output of

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Geometrics
          °Grades
          °Horizontal curves
          °Passing sight distance
          °Passing and climbing lanes
          °Immediate upstream alignment
Traffic Control
          °Passing and no-passing zones
Vehicle Characteristics
          °Vehicle acceleration and speed capabilities
          °Vehicle lengths
Driver Characteristics and Preferences
          °Desired speeds
          °Preferred acceleration levels
          °Limitations on use of vehicle power
          °Passing decisions
          °Behavior in passing and climbing lanes
Entering Traffic
          °Flow rates
          °Vehicle mix
          °Platooning of entering traffic
Simulation Parameters
          °Warm-up time
          °Simulation time
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FIGURE 1 TWOPAS and TRARR input features.

TWOPAS is an advantage when detailed output is desired, but it is time-consuming and cumbersome when only a few output items are desired, because the detailed output cannot be suppressed. Additional output can be obtained from both models by printing program files.

A summary of the basic output for TWOPAS is given in Figure 2. Additional final output at intermediate times as well as data that can be used to calculate fuel consumption are available on program files. The latter feature was removed from the existing PC version.

A summary of the standard output for TRARR is also presented in Figure 2. A display of vehicles moving along the road, passing, and merging can be generated on the computer screen. TRARR does not automatically provide output for vehicle characteristics, road characteristics, and desired speed distributions (as TWOPAS does), but these data can be printed from input files.

It should be noted that the term "overtaking," as used in Figure 2, has different meanings for TWOPAS and TRARR. In TWOPAS it means catching up, whereas in TRARR it means passing.

The output data for both programs generally are classified by direction and by vehicle type and summarized by subgroup, that is, trucks, RVs, and automobiles.

Documentation, Support, and Computer Requirements

Documentation of each model has about the same level of detail. The TRARR documentation, though, contains terms different from the terminology used in the United States, and the precise meaning is not always clear. In view of the fact that use of these models has increased in the recent past and

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TWOPAS

°Reflection of Input Data
°Summary of Specified
     Simulation times
     Flow rates
     Desired speeds
     Vehicle characteristics
°Detail Road Characteristics
°Desired Speeds for Different Vehicle Types
°Actual Measured Desired Speeds
°Average Speeds
°Operating (85th percentile) Speeds
°Speeds for Zero Traffic
°Speeds on Straight and Level Alignment
°Travel Times for Straight and Level Alignment
°Travel Times for Zero Traffic
°Geometric Delay
°Traffic Delay
°Traffic Snapshots
°Flow Rates at Finish Line
°Time Margins (to oncoming vehicle) in Passes and Pass Aborts
°Passes Started and Aborted
°Platoon Leader Vehicle Types at Finish Lines
°Percent of Time Unimpeded
°Headways at Beginning and Finish Lines
°Platoon Sizes at Finish Lines
°Overtakings Classified According to Speed Distributions
°Overtakings Classified According to Initial Acceleration
°Selected Output for User-Selected Stations
°Selected Output for User-Specified Subsections

TRARR

°Simulation Time
°Specified Percent Following
°Input Flow Rates
°Actual Flow Rates
°At Intermediate Positions
     Overtakings commenced
     Spot mean speeds
     Percent following
°Travel Times
°Journey Mean Speeds
°Percent Time Spent Following
°Number and Rate of Overtakings
°Average Desired Speeds
°Unimpeded Speeds (only accounting for road speed indices)
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FIGURE 2 TWOPAS and TRARR output features.

will probably increase in the future, further documentation and increased user-friendly features would be useful.

The TRARR model is supported in the United States by the University of Calgary. It is not clear who is responsible for providing support for the TWOPAS model, but Doug Harwood of the Midwest Research Institute has provided support for this project.

Both models are coded in FORTRAN. Both TRARR and TWOPAS were run on an IBM PS/2 386-55SX computer with 640K of RAM memory. The run time depends on the simulation time, length of road, and volume of vehicles. TWOPAS usually takes longer to execute because it is a larger program.

Ease of Use

Neither model is easy to use if one is unfamiliar with the background and underlying theory. Initially TRARR was easier to use because no programming bugs were discovered, whereas some debugging of TWOPAS had to be carried out. However, as the project progressed, it was found that TWOPAS was easier to use, particularly because changes to the geometric alignment could be made more readily.

COMPARISON WITH FIELD DATA

Study Sites and Data Collection

The two study sites are both in northwestern California in Caltrans District 1. District 1 provided the guidance for this project and also helped with the site selection and data collection.

The following criteria were established for the site selection:

1. Design speed of 80 km/hr (50 mph). Caltrans actually uses the average highway speed (AHS), which is the weighted average of the design speed within a highway section. On nonengineered roads the average highway speed is estimated.
2. Length greater than 1609 m (2 mi). This criterion was established to meet the minimum length specification for general terrain segments as defined in the *Highway Capacity Manual* (HCM) (*5*).
3. Good vantage points should be available for observation.
4. As-built drawings must be available beyond the limits of the test section.
5. Traffic volumes should vary significantly throughout the day, with some high-volume time periods.
6. The section should not include locations of major turning movements.
7. There should be no passing lanes or four-lane sections within 1609 m (2 mi).
8. Horizontal and vertical geometry should be fairly consistent throughout the test section.

The original intent was to have one site that met the requirements for mountainous terrain and a second that met the requirements for rolling terrain, as defined in the HCM. Most of the roads were designed and constructed many years ago, so it was impossible to find as-built drawings for many of the available sites. It was not possible to obtain a mountainous site in this district that met the length requirement, although the region has several mountainous areas. A level terrain site was therefore substituted for the mountainous terrain site. The principal characteristics of the two sites are given in the following:

- MEN101 (on US-101 in Mendocino County, PM 96.42 to PM 98.52)
  1. Rolling terrain
  2. Length = 2851 m (9,355 ft)
  3. 100 percent no-passing zones
  4. Traffic flow data
     a. Direction 1
        (1) Flow rate = 451 vph
        (2) 4.0 percent trucks
        (3) 4.7 percent RVs
     b. Direction 2
        (1) Flow rate = 369 vph
        (2) 5.2 percent trucks
        (3) 5.4 percent RVs
- LAK20 (on State Route 20 in Lake County, PM 19.22 to PM 23.03)
  1. Level Terrain
  2. Length = 6,118 m (20,072 ft)
  3. 94 percent no-passing zones
  4. Traffic Flow Data:
     a. Direction 1
        (1) Flow rate = 210 vph
        (2) 11.9 percent trucks
        (3) 1.9 percent RVs
     b. Direction 2
        (1) Flow rate = 272 vph
        (2) 10.6 percent trucks
        (3) 4.3 percent RVs

The data were collected by placing video cameras at each end of the section and one at approximately the midpoint. The videotapes were subsequently analyzed to obtain the following information:

1. Fifteen-minute flow rates at the beginning of the section, by vehicle type.
2. Average travel time through the section.
3. Percentage of vehicles in platoons at each measurement station. A vehicle was considered to be in a platoon if it was within 5 sec of a leading vehicle. This definition conforms to the definition of the field measurement of percentage time delay, according to the HCM (*5*).

Model Calibration and Validation

For present purposes, the term "model calibration" defines the phase of the comparison with field data in which changes are made to model input, which would not normally be varied, and to the model itself to obtain the best correspondence with field data at a site or sites. During the validation phase, the intent is to determine whether the model is transportable, that is, whether the model can simulate traffic operations at another site or sites without essential modification to the model or input data that would not normally be varied. No changes to the model itself are made, and only input data directly related to the characteristics of the sites are changed. Major structural modifications to the models were outside the scope of the project.

Both models were calibrated against data obtained at the MEN101 site and validated against data obtained at the LAK20 site. The measures used to test the performance of the models were

1. Travel time over the test section for each direction.
2. Percentage time delay as measured by the model. This is the percentage of time that each vehicle is impeded by another vehicle while traveling over the test section. This is the definition of percentage time delay used in the HCM (*5*).
3. Percentage time delay as measured in the field. This is the percentage of vehicles within 5 sec of a leading vehicle, measured at a point on the highway. This is the surrogate measure recommended in the HCM for representing percentage time delay.

Model Calibration Input

Some of the input data required were not available and had to be estimated. Care was taken to determine either that the models were not sensitive to possible errors in the estimates or that the data were representative of the conditions in the field.

The geometric data available for the MEN101 site extended not far beyond the limits of the test section. Experience with the models, particularly with TWOPAS, indicated that fairly long warm-up sections are required to produce realistic results. Warm-up sections of 1072 and 1622 m (3,520 and 5,322 ft) were used, with a warm-up time of 15 min. The test simulation time was 1 hr.

Passing sight distances were unavailable for the sites. It was assumed that the passing sight distance recommended by AASHTO (*9*) was available. Passing is not allowed at the MEN101 site. Experimentation with the models indicated that the results were not sensitive to the choice of different passing sight distances.

The input requirements for vehicle characteristics had to be treated differently for the two models. As mentioned before, four types of trucks and buses, four types of RVs, and five types of automobiles can be specified for the TWOPAS model. Both vehicle characteristics and proportions of the different vehicle types can be specified. Through communication with Doug Harwood of the Midwest Research Institute, it was established that the subgroups of trucks, RVs, and automobiles represent the performance of these subgroups of vehicles but that the default values for the specific vehicle characteristics do not describe specific vehicle types found on the road. For the truck subgroup, for instance, the collective individual vehicle types in the truck group, as specified through the default characteristics, represent the performance of the total truck population on the road.

The calibration of TWOPAS was carried out using the default values for the vehicle characteristics and also the default values for the distribution of each vehicle type within the subgroup. These default values are identical to those used in the simulation experiment underlying the data used in the HCM to conduct level of service analysis (*3*). Field data were used to determine the proportions of trucks, RVs, and automobiles.

After the calibration was completed, another simulation was carried out using another vehicle type distribution. Vehicle types were identified that most closely resembled the default values for vehicle characteristics. Subsequently the observed traffic was classified according to these vehicle types. No significant deviation from the results obtained previously was observed.

The calibration of TRARR was carried out similarly with vehicle characteristics. In the case of TRARR, 18 vehicle types and their proportions of the traffic stream can be specified. The calibration was first carried out using the TRARR default values for vehicle characteristics and their proportions within the subgroups of trucks and automobiles. RVs were classified as trucks. As in the case of TWOPAS, a simulation was also carried out using the proportions of vehicle types observed in the field.

The observed vehicles were classified according to the default vehicle characteristics. This was difficult to accomplish, because some of the vehicles described in the program documentation are particular to Australia. For instance, the Australian vehicle types do not explicitly provide for the RVs found in the United States. The results obtained using this distribution were, however, better than those based on the default distribution. Consequently, the distribution based on the field data was used for the calibration and validation of TRARR.

It was found that the percentage time delay predicted by the model was very sensitive to the percentage of entering vehicles that are in platoons. In many cases, the predicted percentage time delay was almost the same as the percentage of entering vehicles in platoons. As a consequence, the percentage of vehicles in platoons, as measured in the field at the beginning of the test sections, was specified as entering the warm-up sections.

The mean of the desired speeds of the drivers was determined by simulating the traffic and finding the desired speed that led to the best results for the travel time distribution. In the case of the TWOPAS model, an adjustment was also made to the model itself. The limiting desired speed in horizontal curves was increased by 6.4 m/sec (21 ft/sec). A mean desired speed of 81.6 km/hr (51 mph) combined with a standard deviation of 8 km/hr (5 mph) yielded the best results for TWOPAS. The results discussed in the following section are based on a mean desired speed of 96 km/hr (60 mph) and a standard deviation of 8 km/hr (5 mph) for TRARR.

Default values were assumed for the remainder of the variables.

Model Calibration Results

The results of the model calibration are presented in Figures 3 through 6. From Figures 3 and 4 it can be seen that the TWOPAS output for travel time corresponds well with the field data for both Directions 1 and 2. Figures 3 and 4 also indicate that the TRARR output for Direction 2 corresponded well with the field data but that there is a large difference in

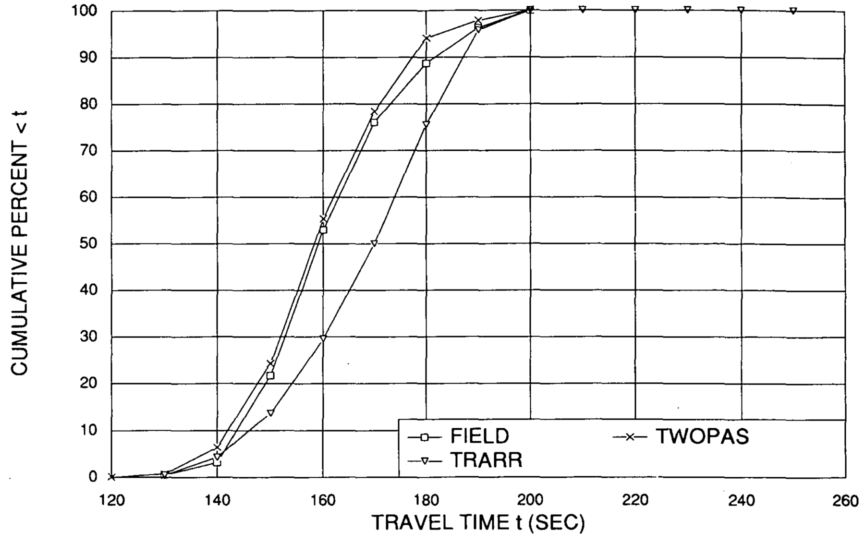

FIGURE 3 Calibration of travel time on MEN101, Direction 1.

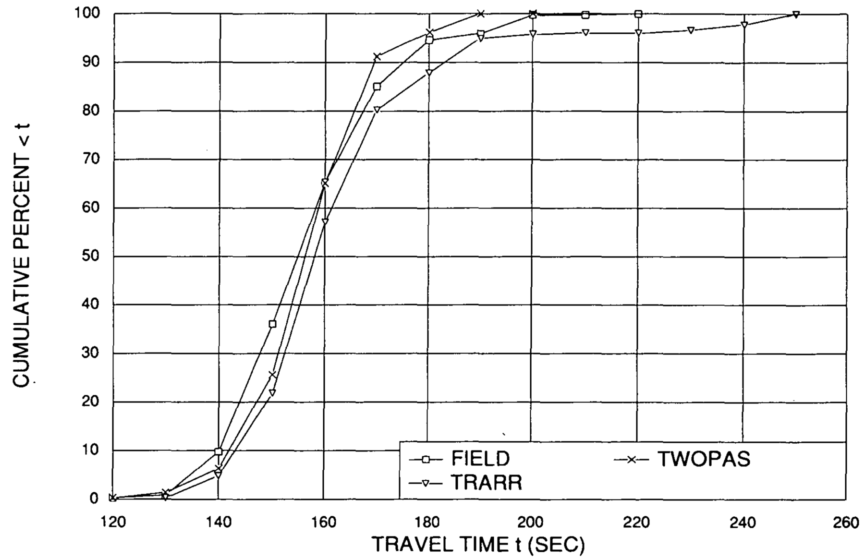

FIGURE 4 Calibration of percentage time delay on MEN101, Direction 1.

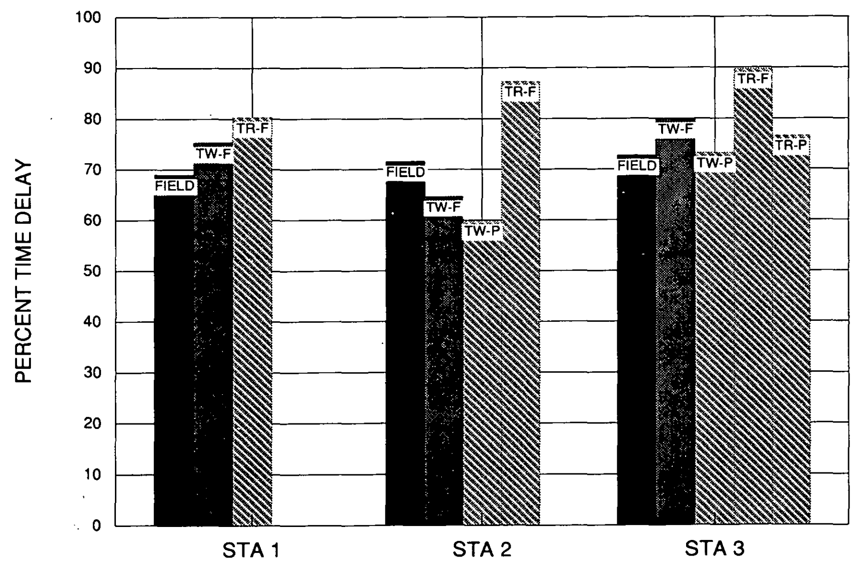

FIGURE 5 Calibration of travel time on MEN101, Direction 2.

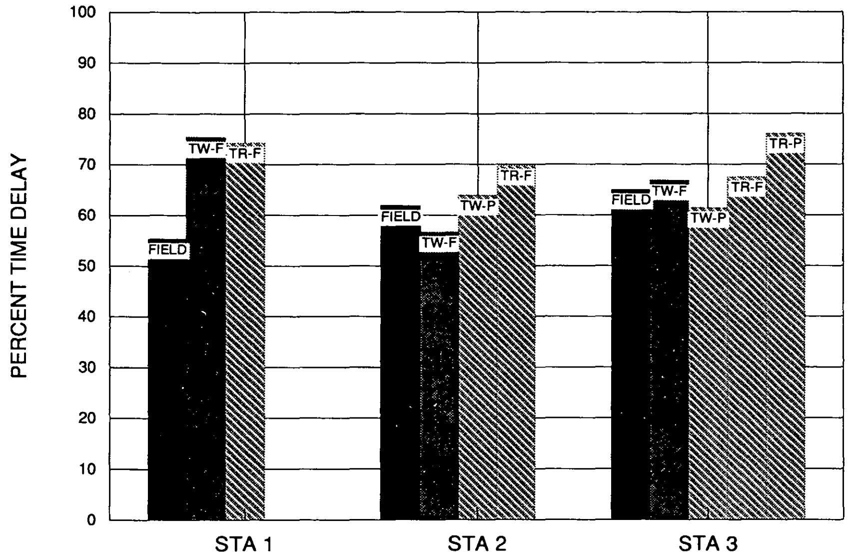

FIGURE 6 Calibration of percentage time delay on MEN101, Direction 2.

Direction 1. These were the best results that could be obtained, given the input data variations discussed in the previous section. Travel time was used as the primary measure for the calibration.

A comparison between the percentage time delay measured in the field (shown as FIELD) and the output from the models is presented in Figures 5 and 6 for the two directions. The model predictions for the percentage time delay, measured over space, are shown as TW-P and as TR-P for TWOPAS and TRARR, respectively. The point measurements are shown as TW-F and TR-F. STA 1 refers to the entrance to the test section, STA 2 to an intermediate point approximately halfway between the beginning and end of the test section, and STA 3 to the end of the test section. TRARR lacks the capability to produce a measurement for the "program definition" at an intermediate point.

Additional output was created to measure the percentage of vehicles in a platoon at a point with the models. The times at which vehicles passed a station were recorded with the aid of the models. Using a separate computer program, a determination was made whether a vehicle was within 5 sec of a leading vehicle.

From the comparison between the field data and the model results for percentage time delay, it can be seen that TRARR generally overestimated the percentage time delay. In some cases TWOPAS underestimated the percentage time delay, whereas in others it produced an overestimation, but generally it produced a closer estimate than TRARR. It is also noteworthy that the percentage time delay measured over space corresponded more closely with the field measurements than the model prediction of percentage time delay measured at a point. This is the reverse of what may be expected.

Model Validation Input

In the case of the LAK20 site, warm-up sections of 1074 and 1465 m (3,522 and 4,806 ft) were used, again with a warm-up time of 15 min. As with the calibration, the simulation time was 1 hr.

It was again assumed that the passing sight distance recommended by AASHTO was available. It was thought that because passing is permitted over 6 percent of the length of the road, the results could have been sensitive to the available passing sight distance. Experimentation with different passing sight distances indicated that the results were not very sensitive to this factor.

Default values were assumed for vehicle characteristics as well as for the distribution of vehicle types within the subgroups of trucks, RVs, and automobiles for TWOPAS. For TRARR, the same procedure was used to specify the vehicle type distribution as was described for the calibration.

Desired speeds were kept at the same values as used in the calibration. Default values were used for the remainder of the variables.

Model Validation Results

The results of the model validation are shown in Figures 7 through 10. TWOPAS estimates of travel time corresponded well with the field data, whereas the TRARR estimates differed substantially in both the mean and the profile of the travel time distribution. These results are presented in Figures 7 and 8.

Experimentation with the mean and standard deviation of the desired speed distribution was undertaken to obtain better results for TRARR. Some improvement was obtained by specifying what could be considered an unreasonably high mean desired speed of 112 km/hr (70 mph). This could indicate that structural changes to the model, recalibration of coefficients internal to the model, or reevaluation of other default values should be considered. Because the TWOPAS model yielded satisfactory results, these possible changes were not considered.

The comparisons of model predictions of the percentage time delay and the field measurements exhibited essentially the same patterns found during the calibration stage. The TWOPAS predictions again were better than the TRARR predictions. The space measurement of TWOPAS compared

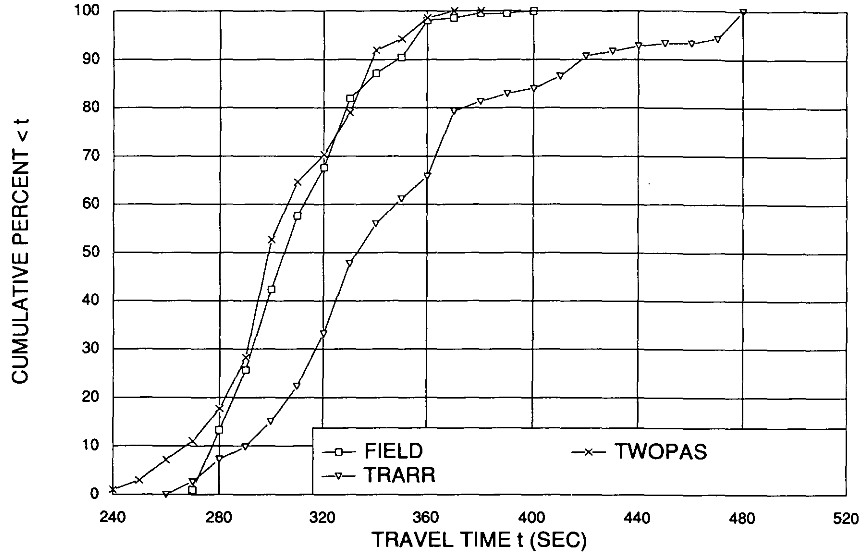

FIGURE 7 Validation of travel time on LAK20, Direction 1.

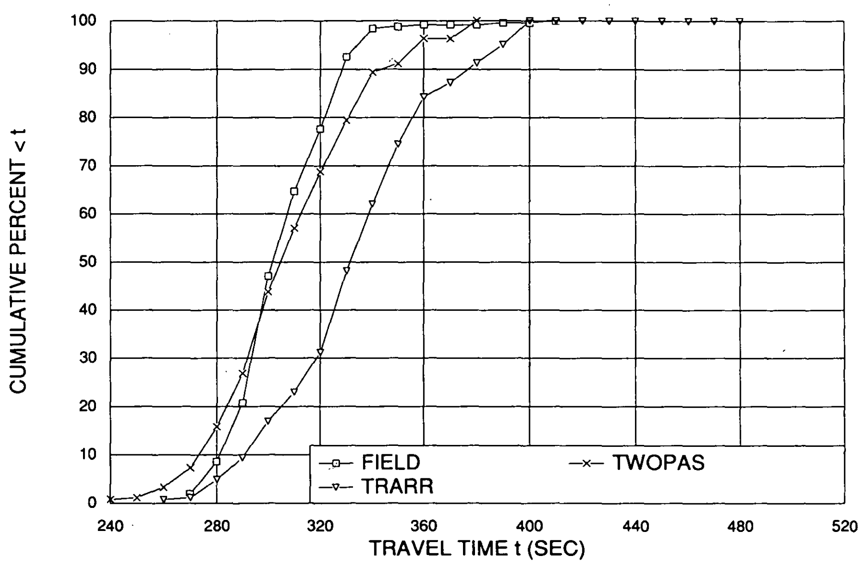

FIGURE 8 Validation of travel time on LAK20, Direction 2.

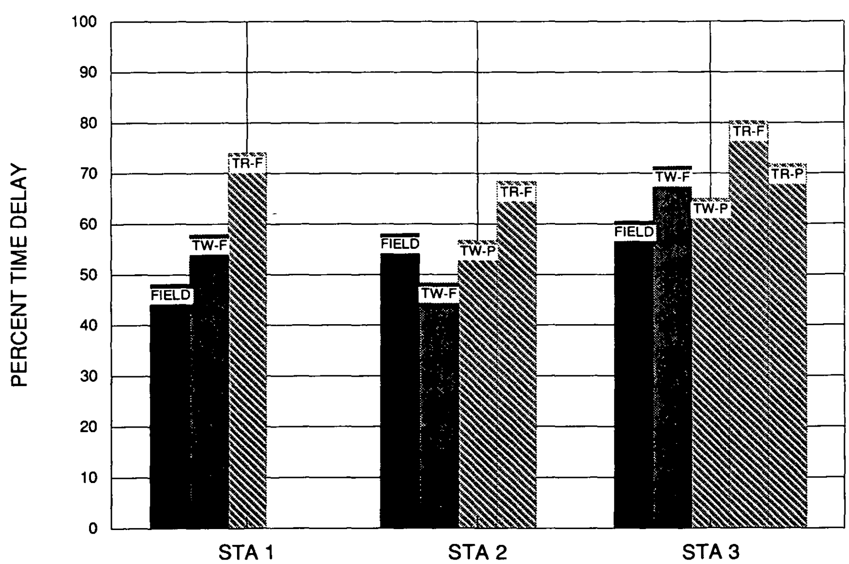

FIGURE 9 Validation of percentage time delay on LAK20, Direction 1.

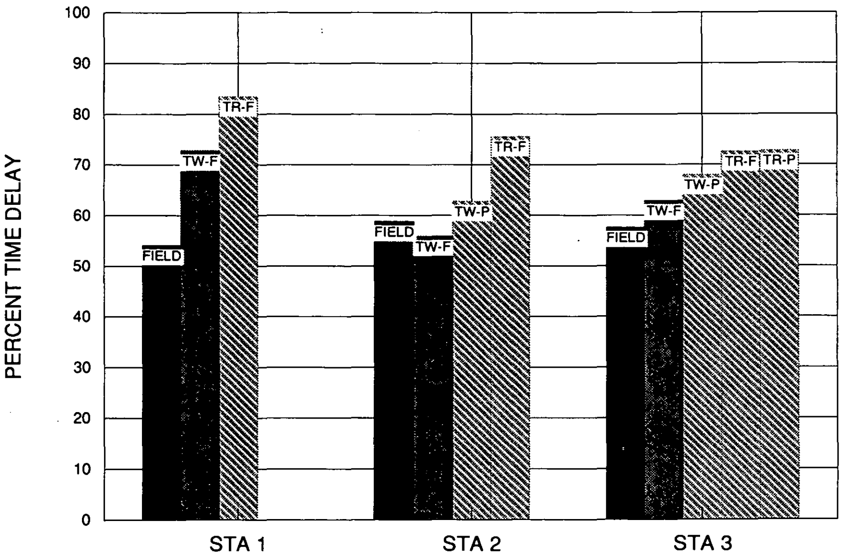

FIGURE 10 Validation of percentage time delay on LAK20, Direction 2.

better with the field point measurement than did the model prediction of the point measurement. It is noteworthy that the TWOPAS space measurement is generally remarkably close to the field point measurement.

DISCUSSION OF RESULTS

As was stated earlier, simulation models appear to be the only affordable way to analyze extensive and complex situations on two-lane roads. Much experience is needed in this area, and it would be useful to continue the development of simulation models and related theories on several fronts. The funding level for work in this area has, however, been very low compared with, for example, research in the area of freeway operations. As a result, there has been some discussion about selecting one two-lane road simulation model to be developed further for application in the United States, to make the best use of available resources.

The results of the comparison of the two models for two-lane highways with low design speeds indicate that TWOPAS performed better. Nevertheless, it may be premature to select TWOPAS for all future work, since clearly both models require further development before they can be applied without reservation to the many different situations that arise in two-lane road operations.

It is useful, however, to provide some perspective on a possible choice of model on the basis of the experience gained in this project. The strong arguments for TRARR revolved around the fact that it alone operated on a PC. That argument is no longer valid. A disadvantage of the TRARR model is that some of the parameters, and particularly the driver and vehicle characteristics, are Australian, whereas the TWOPAS model was created in the United States. It is notable that the TWOPAS vehicle characteristics also may warrant reexamination, as the current default values for vehicle characteristics do not represent specific vehicle types found on the road.

Notwithstanding the fact that it may be premature to commit to one model for use in the United States, there is one very strong argument for making a tentative commitment to the TWOPAS model at this stage. TWOPAS has been used to generate the basic values used in the HCM (*5*) for level of service and capacity analysis, and it is essential that further work in this area be consistent with past work unless the values in the HCM are to be discarded. This appears unlikely in the near future and it does not appear, from the results presented in this paper, that TRARR offers any significant advantage over TWOPAS in this area. It is therefore recommended that TWOPAS be adopted for work related to analysis of capacity and level of service in the areas of two-lane highways. Caution should be exercised in applying the model for this purpose, because its accuracy is questionable in predicting percentage time delay, which is the primary measure used in the HCM (*5*) for capacity and level of service analysis.

SUMMARY OF MAJOR CONCLUSIONS AND RECOMMENDATIONS

1. The TWOPAS and TRARR models are generally comparable in their capability to simulate traffic operations on a two-lane, two-way highway.
2. The application of the TRARR model to highways with low design speeds was carried out with minimal problems, whereas the TWOPAS model had to be debugged on several occasions. It should be noted that the TWOPAS model was converted from a mainframe-based model to run on a PC.
3. TWOPAS simulation results compared better with field data for 80-km/hr (50-mph) design speed roads. This was the case for both a level terrain site and a rolling terrain site. The comparison was made in terms of travel time and percentage time delay.
4. Both models require further work before they can be applied without reservation to the many situations that might arise on two-lane roads and to many possible user require-

ments. Both models should be made more user-friendly. Other major improvements needed for TRARR include improvements in the way it handles horizontal curves, conversion of vehicle types to U.S. types, verification of driver characteristics to ensure conformity with U.S. drivers, and calibration of the factors that influence speeds and percentage time delay. The TWOPAS default values for vehicle characteristics should be modified to represent actual vehicles within the subgroups of trucks, RVs, and automobiles. Although TWOPAS performed better than TRARR in the simulation of vehicle speeds and percentage time delay, further calibration and validation of the model would be beneficial.

5. TWOPAS should be tentatively adopted for analysis in the United States related to capacity and level of service in the short term. After further development of the models, this decision may be reevaluated.

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