DEVELOPMENT OF CRITERIA FOR WARRANTS OF PASSING RELIEF LANES ON TWO-LANE TWO-WAY HIGHWAYS

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MUKESH KUMAR JAIN
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DEVELOPMENT OF CRITERIA FOR WARRANTS OF PASSING RELIEF LANES ON TWO-LANE TWO-WAY HIGHWAYS

By

Mukesh Kumar Jain

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ABSTRACT

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There are some serious safety and operational problems with the design of two-lane two-way roads, especially with the rapid increase in the number of trucks on the road. The two-lane road in rolling and hilly topography may not provide sufficient passing zone length between crests of vertical curves. If a large portion of a road consists of no-passing zones, motorists may violate the established passing restriction thereby increasing the probability of an accident. The use of passing lanes can increase the passing opportunities and can alleviate safety and operational problems on two-lane highways in a more cost-effective manner.

Different simulation models used to describe the phenomenon of the passing maneuver on two-lane two-way highways have been reviewed and a simulation model called "TWOPAS" was selected for use in this study. To calibrate this model, headway, speed and traffic

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composition data were collected on two selected two-lane two-way roads in Michigan. The simulation model output values for these variables were compared to the field values at different locations along the simulated roadway. It was found that the " TWOPAS" model can be calibrated to accurately depict different traffic and roadway conditions in Michigan.

The calibrated model was used to study the operational benefit gained by providing passing lanes on two-lane highways. Two parameters, delay and percentage vehicles in platoon were selected to study the operational benefits due to passing lanes. Simulation runs were made to obtain the operational benefits for different combinations of passing lane configurations, alignment of the roadway, percent grades and traffic volumes.

The magnitude of the accident reduction potential of passing lanes were calculated in terms of dollars per year. The total delay benefits (dollars per year) were calculated by using a unit value of time established by AASHTO. The total benefit per year for different truck percentage and roadway conditions were plotted against different ADT values. These values were also used to determine the sensitivity of delay to different parameters. The construction cost for passing lane(s) for different terrain were plotted on the respective graphs. The volume warrants for different traffic and roadway conditions were obtained.

DEDICATED TO:

My Mother and Father, My wife ANJU

My Brothers ARUN and HEMANT, and My sister MADHU

for their love and encouragement

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CHAPTER 1

1.0 INTRODUCTION

There are more than 3 million miles of two-lane rural highways in the United States that comprise about 97 percent of the total rural system and 80 percent of all U.S. roadways. More than two thirds of the two-lane mileage is in mountainous or rolling terrain characterized by steep grades and sharp curves. Geometric design standards vary considerably between sub-systems of the rural system. An estimated 68 percent of rural travel and 30 percent of all travel occur on the rural two-lane system. Many of these roadways experience significant increases in traffic on weekends and during peak vacation periods.

1.1. OBJECTIVES

There are some serious safety and operational problems with the design of two-lane two-way roads, especially with the rapid increase in the number of trucks on the road. The two-lane road in rolling and hilly topography may not provide sufficient passing zone length between crests of vertical curves. Slow moving heavy trucks on two-lane roads create operational problems in terms of reduced level of service, delay and an increase in passing attempts as well as aborted passes and driver frustration. If a large portion of a road consists of no-passing zones, motorists may violate the established passing restriction thereby increasing the probability of an accident. In these situations the use of passing lanes can increase the passing opportunities and can alleviate safety and operational problems.

The passing opportunities on two-lane roads depend not only on the availability of passing sight distance, but also the availability of gaps in the opposing traffic stream. The lack of passing opportunities is increased by high traffic volumes that limit the frequency of adequate gaps in opposing traffic. This phenomenon leads to the formation of traffic platoons as faster vehicles catch up with slower ones and are unable to pass. The percentage of traffic flowing in platoons reflects the extent of delay to drivers caused by inadequate passing opportunities. This complex phenomenon of passing maneuver can be understood by using an appropriate simulation model. This research will analyze accidents and traffic characteristics with and without passing lanes to provide information for determining the possible benefits of passing relief lanes under various traffic conditions. The objectives of the research are:

1. To determine the traffic and roadway geometric characteristics which effect the passing maneuver.
2. To review the procedures, assumptions and other details of models which simulate traffic operation on a two-lane two-way road and select the model best suited to study the behavior of traffic, including the passing maneuver, on two-lane highways.

3. To calibrate the selected model for Michigan traffic conditions and define the distribution of desired speed of Michigan drivers in the Michigan roadway environment.
4. To develop information on travel time saving due to a passing lane for different traffic composition and roadway geometry and driver characteristics.
5. To obtain and analyse accident data for all two-lane two-way Michigan highways and for those sections having passing lanes to obtain the potential benefit in terms of fewer accidents.
6. To evaluate passing relief lanes on the basis of benefit-cost analyses for different combination of traffic composition and geometrics.

The method of upgrading a two-lane rural highway is more often one of making selective improvements at spot locations to increase the frequency of passing zones rather than complete reconstruction. This is caused either by fund limitations or because future traffic volume will not be sufficiently large to warrant extensive reconstruction. The use of passing lanes can increase the passing opportunities and can alleviate safety and operational problems on two-lane highways in a more cost-effective manner.

Different simulation models used to describe the phenomenon of the passing maneuver on two-lane two-way highways have been reviewed and a simulation model called "TWOPAS" was selected for use in this study. To calibrate this model, headway, speed and traffic composition data were collected on two selected two-lane two-way roads in Michigan. The simulation model output values for these variables were compared to the field values at different locations along the simulated roadway. It was found that the " TWOPAS" model can be calibrated to accurately depict different traffic and roadway conditions in Michigan.

The accident rate (per million vehicle miles) was calculated for sections of highway in Michigan where passing relief lanes exist. These rates were compared with the accident rates on all other sections of rural two-lane roads in Michigan to estimate the magnitude of the accident reduction potential of passing lanes.

Once calibrated, the selected simulation model was run with a wide variety of input values to obtain the average delay. These values were used to determine the sensitivity of delay to different parameters. The cost of motorist delay and accidents were used to develop warrants for passing relief lane construction.

CHAPTER 2

2.0 LITERATURE REVIEW

The successful execution of a passing maneuver depends on a complex interrelationship among the driver, vehicle and environment in which the passing maneuver takes place. Many aspects of the passing maneuver have been thoroughly investigated during previous research. These elements will be reviewed in some detail. Finally, safety and operational problems on two lane roads with passing relief lanes will be reviewed.

2.1. PASSING MANEUVER

2.1.1. DRIVER CHARACTERISTICS

The passing maneuver is one of the most complex maneuvers a driver is required to perform. Performing a safe passing maneuver necessitates correct judgement of many variables. This judgement becomes more difficult with increased speed. Considerable research has been conducted to obtain an understanding of passing maneuvers. Several studies evaluated the driver's ability to estimate variables such as: available sight distance, closure speed between a passing vehicle, measured in distance or time under impedence conditions (either by an approaching vehicle or by available sight distance) and other judgement aspects of the passing maneuver [1,2,3,4,5].

The research conducted by Gorden and Mast, published in 1968[6] was concerned with the ability of drivers to judge the distance required to overtake and pass. The conclusions of this study are that drivers are unable to estimate overtaking and passing distance accurately when the car ahead is travelling at a high speed; and that drivers predict their overtaking performance better in their own cars than in an unfamiliar car. The authors analysed the passing maneuver and compared their data to those of Maston and Forbes [7], Prisk [8], and Crawford [9], authors of previous studies on overtaking and passing maneuvers.

Performance results of Maston and Forbes, Prisk and Crawford are presented in Figure 1, for comparison. The performance curve indicates that as speed increases, passing distance also increases, but at an increasing rate. Although none of these researchers was concerned with passing zone length, the best fit curves clearly indicate the inadequacy of the Manual of Uniform Traffic Control Devices (MUTCD) recommended minimum length of 400-ft (122-m) for a passing zone.

Another research project was conducted by the Franklin Research Laboratories for the Bureau of Public Roads regarding driver judgement and the decision process for overtaking. Farber and Silver [10,11,12] defined the requirements for the overtaking and passing maneuvers. The major findings of the driver judgement and decision making studies were that drivers judged distance accurately in passing situations, but their ability to estimate the time variable and time required to complete the pass is rather poor. Without supplemental information they could not discriminate between oncoming car speeds of 30 mph and 60 mph.

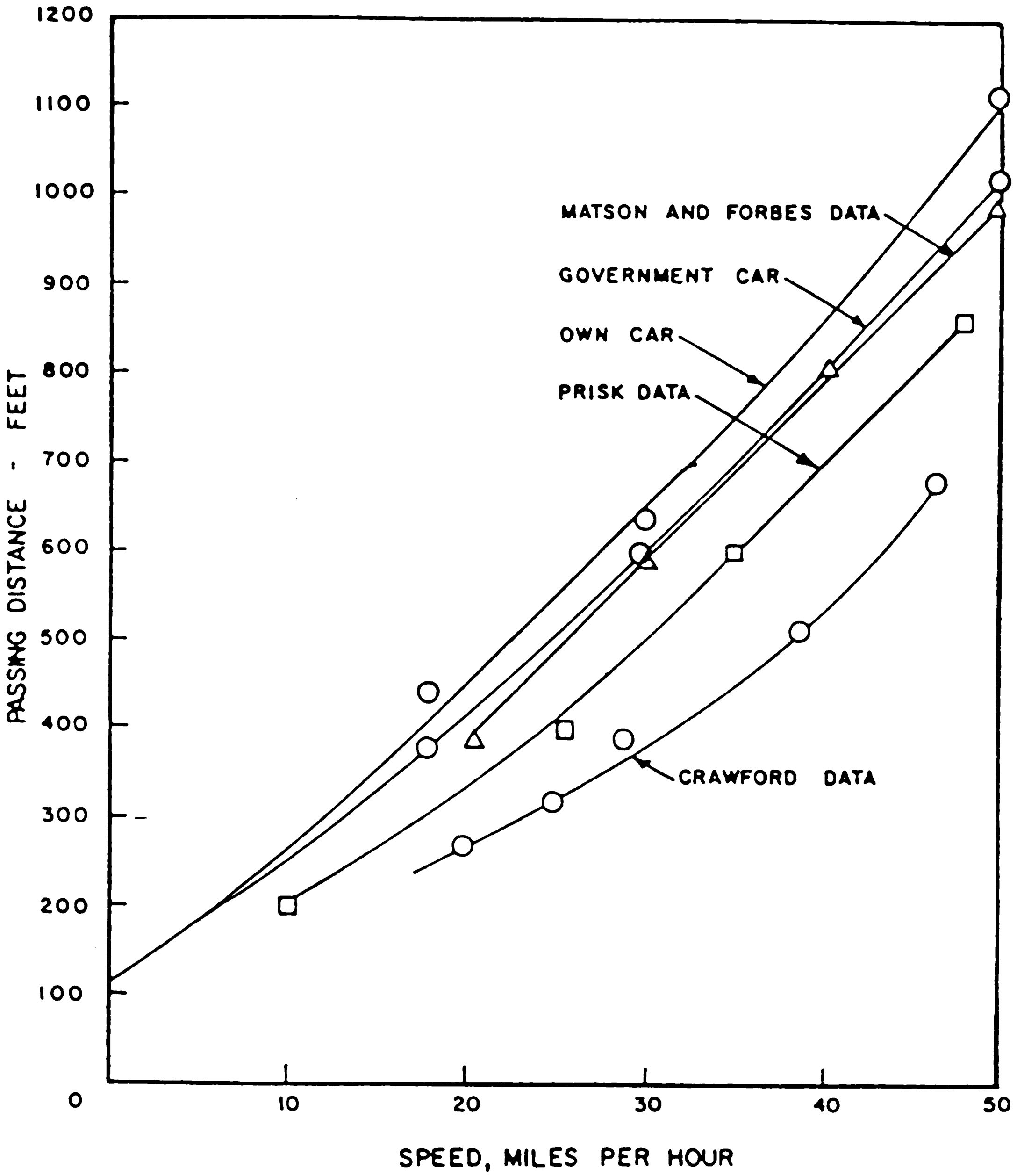
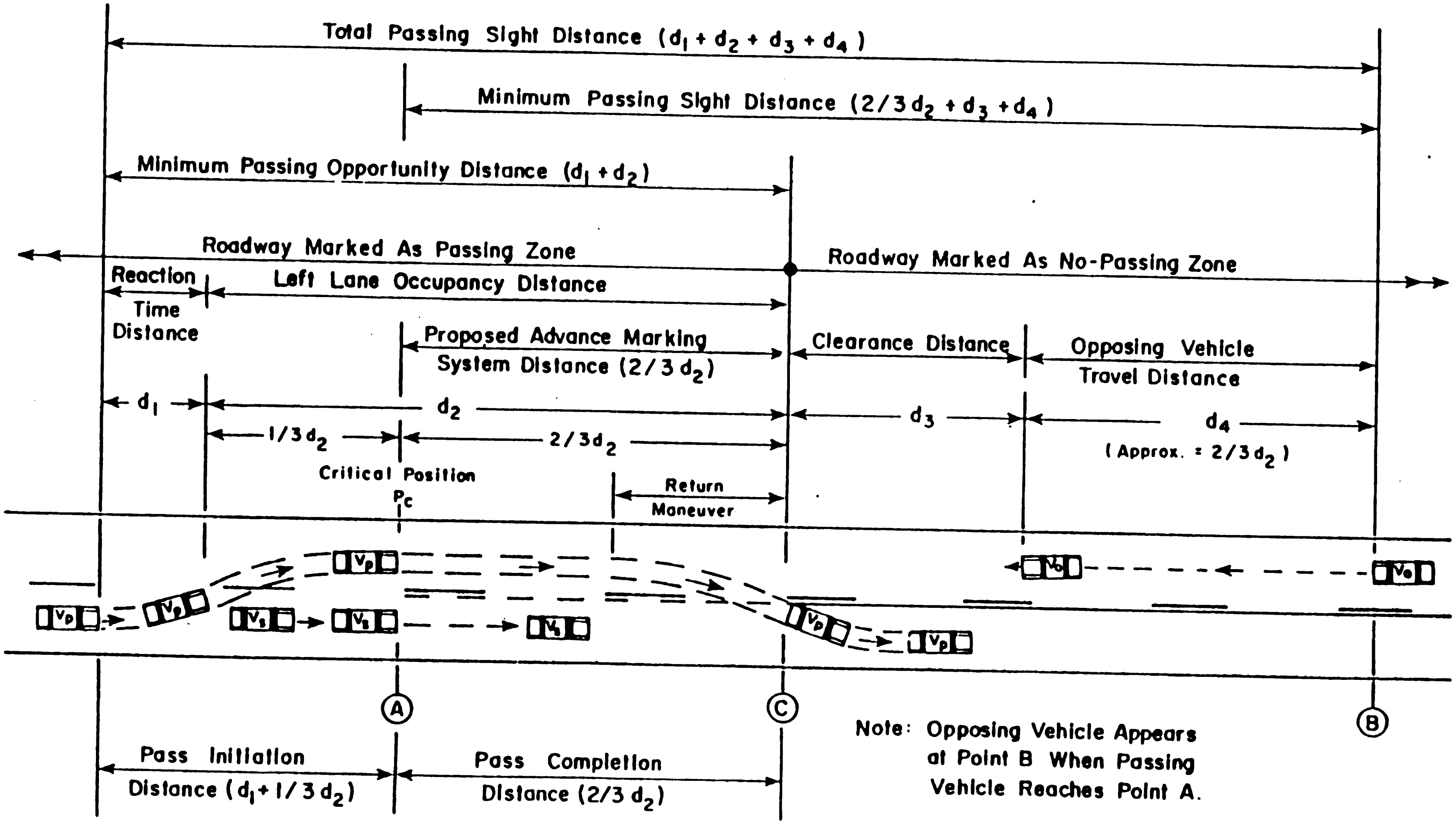


Figure 1. Passing Distance in Relation to Speed
(Gordon and Mast Study)(6)

"The previous research on human factors analysis of driver work load concluded that full driver concentration is considered necessary to accommodate 0.5 activities per second (1 activity per 2 secs). Work load in excess of this can be expected to produce load shedding to the degree that many activities of lower priority are ignored or accomplished to a lesser degree in conjunction with higher priority actions" [13].

"The individual tasks that should be performed in the total passing maneuver were identified and categorized into four primary tasks and the average time per activity was computed based on observed times in which the task were accomplished for different distances as shown in Figure 2. Task 1 is performed during the d_1 distance in which the driver determines that there is a need to pass, evaluates the relative safety and decides to attempt a passing maneuver. In task 2, the driver maneuvers the vehicle into the left lane, accelerates, re-evaluates the safety of the pass, counter steers to the right and brings the vehicle to a position centered in the left lane. In task 3, the driver continues to pass the slower vehicle and checks if clearance is sufficient. In task 4, the driver steers right to return to the right lane then left to center the vehicle in the right lane while checking clearance with the passed vehicle. The time per activity suggests that, during the passing maneuver, the driver is substantially over loaded during task 1 and task 2 and will have little time to search for traffic control information. During task 3, the work load is reduced slightly, providing a driver more time to search the visual field for traffic control information. Unfortunately, by this point, the driver is



Note: Opposing Vehicle Appears at Point B When Passing Vehicle Reaches Point A.

Figure 2. Proposed Distance Elements and Terminology Defining Passing and No-Passing Zones on Two-Lane Highways(14)

fully committed to pass regardless of the traffic control requirements. This suggests that the information source should be translated upstream to the point of decision where the passing driver can receive it in a timely manner" [14]. The driver work load factor is also considered in passing maneuver logic in the selected simulation model TWOPAS, used for this research.

Several of these studies were purely imperical and gave little attention to application of the results to current practice.

2.1.2. VEHICULAR CHARACTERISTICS

The vehicle is an integral component in the passing maneuver. Performance characteristics dictate the minimum distance in which one vehicle can pass another. The primary vehicle characteristic of concern is acceleration capability of the passing vehicle which mainly affects the d_1 phase of the maneuver. The results of Norman's study [15] indicated that drivers are now apparently more reluctant to attempt the passing maneuver on shorter sight distances (2400-3300 ft) than they were in the past. Results indicated that over the study period there was a 5 percent reduction in time needed to complete the passing maneuvers but about a 19 percent increase in the distance traveled in the left lane.

The second vehicle characteristic of concern is reduction of driver eye height. More recently, subcompact and compact passenger vehicles have assumed an increasingly larger share of the traffic mix. This trend toward smaller vehicles has resulted in a reduction of driver eye height and consequently a reduction in sight distance in certain critical situations. Passing zone marking, standardized for passenger cars, may not be adequate for trucks. Trucks require 50 percent more distance than passenger cars to pass on two-lane roads. The driver eye height advantage does not fully compensate, even on crest vertical curves, for the passing time disadvantage.

2.1.3. ROADWAY CHARACTERISTICS

Human factor laboratory studies [16] were conducted regarding driver's opinion of the influence of certain roadway features on their decision to pass. Crest vertical curves ranked higher in importance than horizontal curves, with horizontal curves to the right being more influential in the passing decision than curves to the left. The greater importance associated with a right curve could be due in part to the reduced visibility caused by the relative alignment of the passing and passed vehicle. Shoulders were ranked high in importance by drivers meeting an opposing vehicle. Lane width, shoulder width and pavement quality are considered in the selected simulation model TWOPAS and the influence of these factors are used indirectly in determining the distribution of desired speed of the drivers.

2.1.4. PASSING PRACTICES

Several studies were conducted regarding the driver's ability to estimate variables such as available sight distance, closure speed between the passing vehicle and the passed or opposing vehicle, required passing distance or time under various impedence conditions (either by an approaching vehicle or by available sight distance), and other judgement aspects of the passing maneuver.

Research was conducted by Hostetler and Seguin [17,18] to determine the singular and combined effects of impedence distance, impedence speed and traffic volume upon the acceptance and rejection of passing opportunities where sight distance is restricted. It was found that of all the variables studied, sight distance is the most important determinant of the probability that a driver will accept or reject a given passing opportunity. The lead car speed does not have any significant influence on the decision to pass. The reason may be that the final decision to accept or reject a passing opportunity will be based upon the physical evidence available (sight distance) rather than the driver's tolerance to impedence, which is more subjective in nature.

2.2. SAFETY AND OPERATIONAL PROBLEMS

More passing zone length may be needed for larger trucks than the distance recommended in the MUTCD. Larger trucks generally exhibit low speeds on the rising portion of crest vertical curves and high acceleration rates on the downstream portion. The low speeds can produce a queue of vehicles that is required to adopt the slower truck operating speed and causes delay. The high acceleration rates on the downward portion inhibits passing where sufficient sight distance may be provided because of high relative speeds. Trucks also inhibit visibility of the trailing driver due to greater

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height, width, and lack of through vision capability. A recent study by Suguin et. al. [18] concluded that the truck size (length and width) appears to be an intimidating factor in the lateral placement of vehicles during passing, as well as longitudinal separation (gap) from the following vehicle.

Vehicle acceleration performance is involved in the passing maneuver. For automobiles, the contribution of the initial acceleration part of the maneuver is approximately 15 percent of the total passing sight distance. However, some heavy trucks have sustained speeds on level ground of no more than 60 mph when fully loaded, and at speeds near 40 mph, distances on the order of 2,500 to 3,000 ft may be needed to accelerate to 50 mph. On the basis of these observations, the authors concluded that the AASHTO passing sight distance model used for automobiles does not appear to be appropriate for heavy trucks[19].

2.3. ALLEVIATION OF SAFETY AND OPERATIONAL PROBLEMS

The use of passing lanes and short four-lane sections has been suggested as a means of alleviating safety and operational problems on two-lane highways. A passing lane is an added lane provided in one or both directions of travel on a conventional two-lane highway to improve passing opportunities. A recent study by Harwood et. al. [20] attempted an operational and safety evaluation of passing lanes and short four-lane sections to improve traffic services on two-lane highways. Passing lanes and short four-lane sections were evaluated by using data collected at selected sites in 12 states that

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participated in the study. A traffic operational evaluation was based on field data collected at 12 passing-lane and 3 short four-lane sites. A safety evaluation was based on 1 to 5 years of accident data for each of 66 passing-lane and 10 short four-lane sites.

The authors concluded that passing lanes and short four-lane sections are likely to provide significant operational benefits on two-lane highways. Both types of added lanes increase the passing rate in the direction of travel compared with a conventional two-lane highway. Passing rates in passing lanes and short four-lane sections can be predicted as a function of flow rate, length of treated section, and upstream percentage of vehicles platooned.

A safety evaluation found that the installation of a passing lane on two-lane highways does not increase accident rates, in fact, they probably improve safety. No unusual safety problems were found to be associated with either lane addition or lane drop transition areas. The rate of accidents involving vehicles traveling in opposite directions was found to be the same or lower on passing lane sections than on untreated two-lane highways at all severity levels, even for passing lanes where passing by opposing direction vehicles is permitted.

A study [21] was conducted by D.W. Harwood et. al. regarding effective use of passing lanes on two lane highways. It was concluded that passing lanes are effective in improving overall traffic operations on two-lane highways, and they provide a lower cost alternative to four-laning extended sections of highways.

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Further study is needed to know the configuration of passing lanes for different traffic composition and different terrain. It would be desirable to optimize the number, length and location of passing lanes, so that entire two-way two-lane systems can be cost-effective in terms of less delay, higher average speed and less travel time.

CHAPTER 3

3.0 SIMULATION MODELS

3.1. SIMULATION MODELS FOR TWO-LANE HIGHWAYS

INTRODUCTION

A review of mathematical models described in the literature indicated that a majority of these models described only a particular aspect of traffic flow and that in none of these was the passing maneuver of primary importance. Though highway engineers developed empirical relations based on real-world observations, even these relations provide only a general idea of the nature of traffic operations. They are not sensitive enough to detect either roadway traffic-flow interactions for any individual design alternative or the differences in these interactions between two or more alternative designs. Computer simulation, on the other hand, has the capability of describing traffic behavior on a vehicle-by-vehicle basis, and the technique lends itself to a sensitivity analysis that permits one to test both the effect of input variables over a wide range of values and their interaction upon the output statistics. Different simulation models used to describe the phenomenon of the passing maneuver on two-lane two-way highways are discussed in detail below.

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3.1.1. FRANKLIN INSTITUTE RESEARCH LABORATORIES (FIRL) MODEL

One simulation model reviewed was developed at Franklin Institute Research Laboratories by Janoff and Cassel. "The FIRL model is a digital computer program written in FORTRAN IV that can simulate the movement of traffic along a two-lane roadway in both directions along with actual passing maneuvers. Vehicle speeds and headways are assigned to each individual vehicle after they have been generated according to a preset volume-speed and volume-headway relationship adopted from the Highway Capacity Manual (1965). The roadway configuration includes no-passing zones, sight distance restrictions, and grades for each traffic lane at any given location along the simulated roadway. Using roadway and traffic data as input, the model simulates traffic movement according to the conditions surrounding a particular vehicle. The initial assigned speed is treated as the desired speed and is used in all subsequent calculations as the speed at which the vehicle would travel if not impeded by traffic" [22].

3.1.2. NORTH CAROLINA STATE UNIVERSITY (NCSU) MODEL

"Heimbach and others modified the FIRL model and developed the NCSU model for the purpose of investigating the no-passing zone configuration on rural two-lane highways in relation to throughput volume. Two subroutines, designated truck-on-grade and car exit, and one main routine, called speed-headway, were added to the Franklin Institute model. The truck-on-grade subroutine makes it possible to duplicate the existing range of grades on two-lane primary roadways in North Carolina. The speed-headway program resulted from a need to generate speed and headway distributions for simulation that would match those found in the field. After comparing highway data in North Carolina with output data from calibrated headway distribution models such as the Negative Exponential, Pearson Type-III, Schuhl, Schuhl Pearson-III, Schuhl-Negative Exponential, and modified Schuhl models, they found the Schuhl model best fit the data collected from the field" [4].

The NCSU model contains some, but not all, of the required capabilities. In particular, only truck performance was included in the improved version. Driver use of performance capabilities was neglected, and the overtaking and following logic was over simplified.

3.1.3. SIMULATION OF VEHICULAR TRAFFIC (SOVT) MODEL

Another model was developed that simulates traffic flow on a general two-lane two-way roadway on a vehicle-by-vehicle basis. This SOVT model is written in FORTRAN. The model permits vehicles to follow each other in the same direction in an orderly fashion and also permits vehicles that are moving faster to overtake and pass slower-moving vehicles. In the latter case, the decision to pass is based on the oncoming traffic situation.

The upper limit for simulated traffic volumes is a function of traffic density and roadway length. Any directional distribution of traffic volume is acceptable. Any percentage distribution of five

vehicle types is also acceptable. Acceleration and deceleration characteristics for these vehicles are defined by the user. Individual input speed distributions for each type of vehicle is also defined by the user.

With respect to the simulation roadway, the model accepts roadway lengths of 2-12 km (1.25-7.5 miles). At any point along the roadway, the user is able to specify for each traffic lane the location of speed-restriction zones. These restrictions may be due to sharp horizontal curves. The user is also able to specify the magnitude of vertical gradients, both positive and negative, and no-passing zones.

The user is also able to designate as many as eight minor stop-controlled crossroads along the simulation section. The user can specify the total volume and vehicle composition of all vehicles entering and leaving the roadway as well as the percentage of directional turning movements at each minor intersection. Within the simulation roadway, the user has the option of designating the location of any climbing lane that permits traffic in one direction to operate over two traffic lanes in the same direction.

Limitations of this model include the provision that only truck performance was included in the improved version, driver use of performance capabilities was neglected, and the overtaking and following logic was over simplified. This program accepts only five vehicle types. This model can not evaluate the effects of inclusion of passing lanes on traffic operation [23, 24].

3.1.4. ROADSIM MODEL

Roadsim is a traffic simulation model for two-lane rural roads developed in 1980 by FHWA. Roadsim is a reprogrammed version of an earlier model (TWOWAF) with modified routines and adaptations from other models [25]. TWOWAF, a microscopic traffic simulation model, was developed in 1978 as part of a National Cooperative Highway Research Program (NCHRP) [26]. 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 speed 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. 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" [23, 24].

"Roadsim requires a free flow speed to be specified for the entire roadway or by individual link. This is used 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. To compare the selected MOEs, a similar number of field vehicle trips and simulation vehicle trips was necessary. To compensate for this, the input volume trips were required to be 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 same traffic volumes constraints the modeled speed distributions were found to approximate those observed in the field" [25].

As mentioned before Roadsim is a simplified version of the TWOWAF model. The main drawback of this model is that the program does not consider passing lanes and climbing lanes, and is thus not appropriate for the study of passing relief lane warrants.

3.1.5. AUSTRALIAN ROAD RESEARCH BOARD MODEL (TRARR)

The TRARR model has been developed as a research tool for use in the Australian Road Research Board (ARRB) rural traffic operation research program. TRARR requires fairly large amounts of

computer memory and process time. A typical run requires 27000 words memory, and the process time for one hour of traffic at 600 veh/hr over 9 km of two-lane road is approximately 480 s. The ratio of simulated time to process time varies from 50 to 2, depending on road length, traffic flow rate, and the ease of overtaking on the road.

The input data requirements can be considered as two broad categories. The first specifies vehicle and driver characteristics, which should only be varied for particular purposes, such as simulation experiments designed to examine the effects of change in driver behavior or vehicle performance. The second provides details of road geometry, traffic flows, simulation time and observing requirements.

A total of 52 vehicle driver characteristics may be specified in the input file for each of the 18 vehicle types. The use of 18 vehicle types in the model serves three purposes. First, it allows for a distribution of behavior characteristics over the vehicle population. Second, the model can respond to changes in traffic composition such as an increase in heavy trucks. Third, the vehicle type range allows special classes of vehicles to be added by the user. The traffic streams are generated by sampling from exponential headway distributions and a normal distribution of desired speed for each vehicle type. Initial platooning is achieved through the use of no-overtaking warm-up zones.

The characteristics of the simulated road are provided as a list of measures of each unit road segment (typical length 100 m) for each direction of travel. These measures consist of sight distance, overtaking barrier lines, auxillary lanes, speed limit indices, and grades (one direction only). To date, speed reduction factors are only provided for the effects of horizontal curves, these being based on empirical studies at ARRB. Further empirical work is required to determine factors representing the effects of pavement condition and cross-section.

The overtaking logic is based on a set of deterministic decision rules and overtaking safety factor values which can be specified for each vehicle type and a number of overtaking situations. Gap acceptance is determined by comparing the time gap available with the time required for an overtaking adjusted by a safety factor. The safety factor values are based on initial subjective assessments of overtaking behavior data collected at ARRB with subsequent refinements based on comparisons between simulated overtakings and those observed in the field [27].

The reliability of TRARR in predicting acceleration, merging, gap-acceptance or slowing down on grades has not yet been fully tested. Limited calibration and validation tests were conducted to compare simulated speeds, queuing and overtaking rates with field data. These tests indicated reasonable simulated behavior, though subsequent tests suggest that the model may under predict overtaking rates. Further field data is required to study driver behavior on auxillary lanes, up-grade vehicle performance, and overtaking behavior in constrained conditions [27].

3.1.6. MRI/TWOWAF MODEL

The TWOWAF computer program was developed at Mid West Research Institute (MRI) in 1974 as part of NCHRP Project 3-19 and the results of this study are presented in NCHRP Report 185[26].

The objectives of the simulation model, developed by the Midwest Research Institute (MRI), were to determine the effects of vehicle types and highway geometry on capacity, service and safety. To meet these requirements, the simulation needed to include an account of vehicle performance characteristics, driver use of performance characteristics, overtaking and following, and driver decisions in passing maneuvers. The input values are used in a stochastic process to assign each simulation vehicle a "design speed". This is the normal "desired speed" for the vehicle which is the vehicle's preferred speed of travel in the absence of unusual local geometry or impeding vehicles, provided it has the performance required. Within the simulation, the desired speed can be reduced in a horizontal curve on the approach to the curve, or on a long steep downgrade for trucks. A vehicle's desired speed is increased during a passing maneuver. The input distribution of desired speed is associated with the highway design speed and/or speed limit. The mechanics of vehicle up-grade performance are modeled in quite some detail. Overtaking gap-acceptance is based on the probability results developed at FIRL, supplemented by additional field data. The model includes a "driver workload" factor which serves to reduce the desired speed assigned to each simulated vehicle according to the overall frequency with which opposing vehicles are encountered.

This factor is claimed to be consistent with human factor theory but no direct empirical verification has been attempted.

Logic was added to the simulation to account for the "encounter workload". The logic which is an internal part of the simulation, keeps a separate, running average of the encounter frequencies for each direction of travel. The frequencies are used to modulate the desired speeds of vehicles already in the simulation. Another type of workload factor "passing workload" was also added to the simulation. The "passing workload" logic was based on the postulate that humans have an upper bound for nearly any task in multiple task jobs. It was considered likely that there was an upper limit on the frequency with which drivers would undertake passing maneuvers. The logic employed a separate running average of the passing workload in each direction. The running average was used to modulate desired speeds, primarily by modifying the standard deviation.

This simulation model seems to be close to the actual maneuvering for passing on two lane roads as it explicitly considers driver characteristics. This model was validated from field data for two-lane highways by St. John and Kobett [26] and by Messer [28]. While the original version of the model developed at MRI does not consider auxiliary lanes for overtaking, these have been incorporated in a modified version employed at the Institute of Transportation Studies, University of California. Further modification are currently being made with the aim of incorporating it into an overall traffic simulation system TRAF developed by the U.S. Federal Highway Administration. A new version of the model is known as TWOPAS.

3.1.7. TWOPAS MODEL

The TWOPAS model is an updated version of TWOWAF that incorporates the modifications and additions made in NCHRP project 3-28A, and is used in the development of Chapter 8 of the 1985 HCM[29]. It is a microscopic computer model of traffic operations on two-lane two-way highways. "The four major additions made to the TWOWAF model are : a) capability to simulate passing and climbing lane sections; b) entering traffic streams with user-specifiable percent of traffic platooned; c) platoon leaders that are rationally selected to reflect the consequences of upstream geometry; d) User-specifiable stations and subsections where spot data and overall data are collected. The added capability to simulate passing and climbing lanes was validated from field data by Harwood and St. John [30]. Good agreement was found between model results and field data for traffic platooning and traffic speeds upstream and downstream of passing lanes" [31].

Model Results

Figure 3. presents a conceptual illustration of the effect of a passing lane on traffic operations on a two-lane highway. Figure 4 illustrates the effects of passing lanes of various length on traffic platooning within a passing lane and downstream of a passing lane for flow rates of 400 and 700 veh/hr in one direction of travel. Figure 4 is based on the percentage of vehicles delayed in platoons at specific spot locations on the highway. The results in Figure 4 indicate that the effective length of a passing lane can

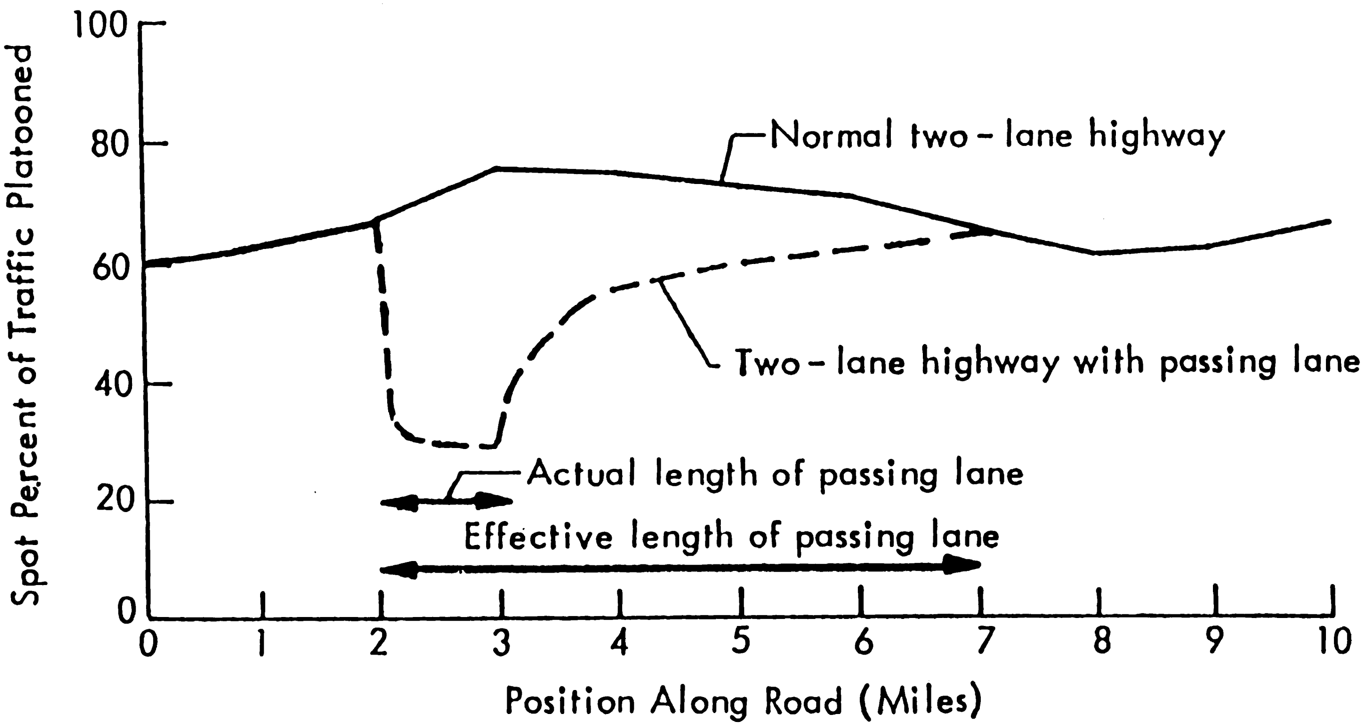
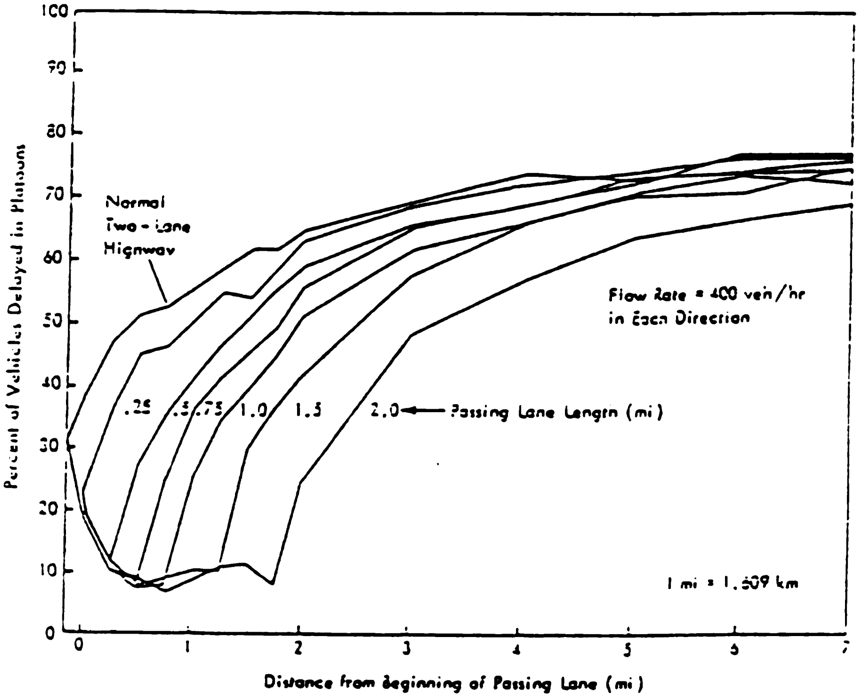


Figure 3. Example of the Effect of a Passing Lane on Two-Lane Highway Traffic Operations(21)



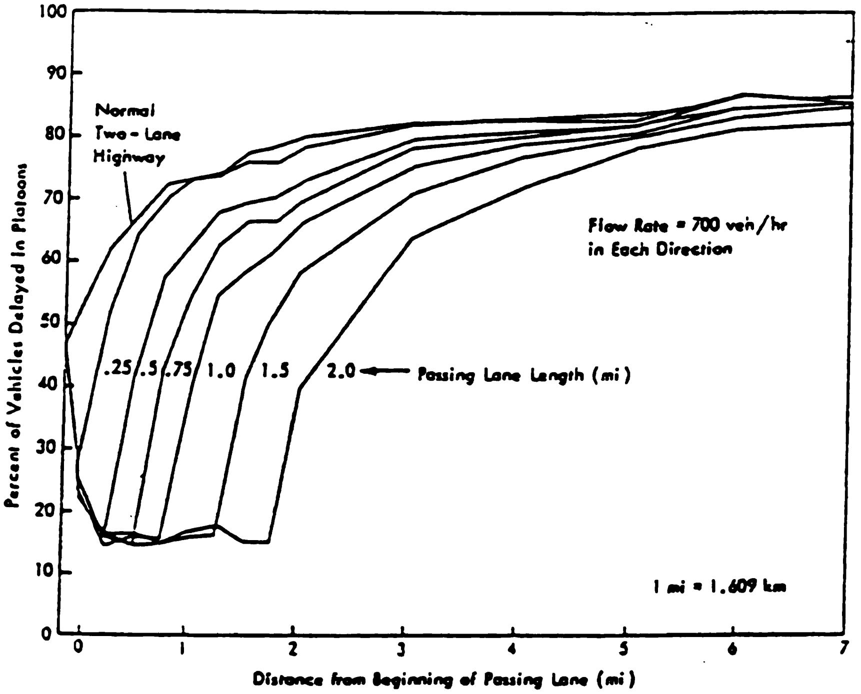


Figure 4. Gradual Increase in Percentage of Vehicles Delayed in Platoons Downstream of Passing Lanes(21)

vary from 3 to 8 miles depending on passing lane length, traffic flow and composition, and downstream passing opportunities. From Figure 4 it is evident that the reduction in percent of vehicles delayed in platoons is not significant beyond 4-5 miles downstream of the beginning of a passing lane. Table 1 presents the estimated reductions in percent time delay for different effective lengths and for different lengths of passing lanes. The effective length of the passing lane includes the downstream section of two-lane highways where platooning is lower than it would have been without the passing lane.

To establish warrants for passing relief lanes, it will be necessary to define this effective length of the passing lane for different combinations of traffic flow and composition, passing lane length, geometry of the road and downstream passing opportunities.

Further Study

The chosen model will be run with a wide variety of input values, including cases where a passing lane is already in place. Traffic and geometric characteristics of the candidate passing lane sites will be input and model runs will be made using various traffic volume, traffic mix and geometric values so that the warrants which result from the model runs will be widely applicable. The motorist delay or cost figures which result from the model runs will be used to construct the basis for a warrant for passing lane construction. The net benefit to the motoring public from construction of a passing lane for a certain combination of traffic and geometric features will be determined.

TABLE 1

EFFECT OF PASSING LANES ON PERCENT TIME DELAY OVER AN EXTENDED ROAD LENGTH(21)

EFFECTIVE LENGTH	PERCENT TIME DELAY PASSING LANE LENGTH (MILE)						
(MILE)	0	0.25	0.50	0.75	1.00	1.50	2.00
ONE-WAY FLOW RATE - 100 VPH							
3	33	30	20	17	17	17	17
5	33	31	25	22	19	17	17
8	33	32	28	26	24	22	20
ONE-WAY FLOW RATE - 200 VPH							
3	50	39	29	25	25	25	25
5	50	44	37	31	29	25	25
8	50	46	42	38	37	33	30
ONE-WAY FLOW RATE - 400 VPH							
3	70	67	57	49	43	35	35
5	70	68	62	57	54	49	38
8	70	69	65	62	60	57	50
ONE-WAY FLOW RATE - 700 VPH							
3	82	79	69	63	55	45	41
5	82	80	74	71	66	60	52
8	82	81	77	75	72	68	63

3.2. SIMULATION MODEL SELECTION CRITERIA

The use of simulation techniques appears to provide a means of assessing operational impacts (on delay, speed and passing maneuver) of increased truck traffic as well as altered roadway geometry (as reflected by various measures of no-passing zones). With the proper use of such simulation models it may be possible to quantify most of the operational effects. In selecting a computer simulation model for a two-lane highway, the following functional specifications are required:

1. Be capable of being understood well enough by the highway design practitioner that he or she would feel comfortable in using it to test design alternatives.
2. Permit user to locate speed restriction zones, no-passing zones, vertical grades, horizontal curves, minor side-road intersections, and passing lanes and climbing lanes at any point along the simulation route.
3. Be able to accomodate driver's characteristics during passing maneuver.
4. Be able to simulate maximum hourly traffic volumes and directional distribution by traffic lanes that are found in the field.
5. Be able to accomodate vehicle overtaking and passing maneuvers.
6. Be able to simulate a number of different types of passenger cars, trucks and recreational vehicles, each with different acceleration and deceleration capabilities, size and horse power.

7. Permit the user to input typical speed and headway distributions found in the field.
8. Provide for interaction between the vehicle acceleration and deceleration characteristics and the horizontal and vertical alignment and traffic control specified for the simulated roadway.
9. Provide real-time simulation that is efficient in terms of consumption of computer time.
10. Express throughput data characterizing simulation in statistics that are readily understood and usable by the roadway design practitioner in the evaluation of design alternatives.
11. Enable the user to output simulation data for a number of spot locations and user specified sub-sections throughout the simulation roadway.

A comparison of the features of the main four models i.e., SOVT, TWOWAF, TRARR and TWOPAS are given in Table (2). TRARR and TWOPAS models seem to be better in comparison to the SOVT and TWOWAF models mainly because of added capability to simulate the operational effects of passing and climbing lanes. Most of the features are common in these two models. The TWOPAS model also considers the driver workload factor in passing maneuver logic. It also gives output data for a number of spot locations and subsections specified by users. The TWOPAS model has already been calibrated and used in a few projects while the reliability of the TRARR model in predicting acceleration, merging, gap-acceptance or slowing down on grades has not yet been fully tested. Thus, the best suited simulation model for this study is TWOPAS.

TABLE 2

COMPARISON OF DIFFERENT SIMULATION MODELS DEVELOPED FOR TWO-LANE HIGHWAYS(27)

Model Name	SOVT	MRI/TWOWAF	TRARR	TWOPAS
Responsible Agency	Department of Civil Engineering North Carolina State University	Midwest Research Institute	Australian Road Research Board	FHWA
References	Wu and Heimbach (1978)	St. John and Kobbet (1982)	Robinson (1982)	FHWA (1986)
Computer Language	FORTRAN	FORTRAN	FORTRAN	FORTRAN
Vehicle Classes	Five Vehicle Classes	Cars, Recreational Vehicles, 5 Classes of Trucks	Up to 18 Vehicles Types may be Specified	Cars, Recreational Vehicles, 5 Classes of Trucks
Entry Process	Schuhl Headway	Schuhl Headway plus Warm-Up Zone	Warm-Up Zone	Schuhl Headway plus Warm-up Zone
Vehicle Performance Characteristics	Explicitly Modelled	Explicitly Modelled for Acceleration and Speed Capabilities of All Types of Vehicles	Explicitly Modelled	Explicitly Modelled for Acceleration and Speed Capabilities of All Types of Vehicles
Road Effects on Vehicle Speed	Up-grades Speed Restriction Zones	Up-grades Horizontal Alignment Steep Down-Grades	Up-Grades Horizontal Alignment Steep Down-Grades Passing Sight Distance	Up-Grade Horizontal Alignment

TABLE 2 (Con'd.)

Overtaking Logic	Gap Acceptance Probability for Accelerative Overtaking and Opposing Traffic	Gap Acceptance Probability for Opposing Traffic and Sight Distance Limited Gaps	Deterministic Rules Based on User Specified Safety Factors for Different Overtaking Situations	Gap Acceptance Probab -ility for Opposing Traffic and Sight Distance gapes Position in Platoon Horizontal Curvature, Location within Passing Zone
Road Geometry Input Data	Vertical Profile Speed Restriction Zones, No-Overtaking Minor Side Roads	Vertical Profile Horizontal Alignment Sight Profile No-Overtaking Zones	Vertical Profile Horizontal Alignment Sight Profile No-Overtaking Zones Auxiliary Lanes	Vertical Profile Horizontal Alignment Sight Profile No-Overtaking Zones Auxiliary Lane
Traffic Input Data	Traffic Flows Traffic Mix	Traffic Flows Traffic Mix	Traffic Flows Traffic Mix	Traffic Flows, Traffic Platooning in Entering Traffic Stream, Traffic Mix
Driver and Vehicle Input Data	Desired Speed Distribution	Desired Speed Distribution	Desired Speed Distributions Power/Weight Values Aggression Indices	Desired Speed Distribution Acceleration and Speed Capabilites and Length of Vehicles
Output Data	Travel Times Spot Speed and Headways Speed Change Cycles Overtaking Rates	Travel Times, Speed and Delays, Overtaking Rates and Safety Margins, Acceleration Noise, Fixed Instant of Time Description	Spot Speeds and Headways, Travel Times, Overtaking and Safety Margins, Platooning, Fuel Consumption	Travel Times, Speeds and Delays, Headways and Platooning, Overtaking Rates and Safety Margins, Accleration Noise, Traffic Status During Simulation, Summary output for User-specified Stations and Subsections

3.3. FEATURES OF SELECTED MODEL TWOPAS

The TWOPAS model simulates traffic operations on two-lane highways by reviewing the position, speed, and acceleration of each individual vehicle on a simulated roadway at 1-sec intervals and advancing those vehicles along the roadway in a realistic manner. The model takes into account the effects on traffic operations of road geometry, traffic control, driver preferences, vehicle size and performance characteristics, and the oncoming and same direction vehicles that are in sight at any given time. The model incorporates realistic passing and pass abort decisions by drivers in two-lane highway passing zones. The model can also simulate traffic operations in added passing and climbing lanes on two-lane highways including the operation of the lane addition and lane drop transition areas and lane changing within the passing or climbing lane section. Spot data, space data, vehicle interaction data, overall travel data are accumulated and processed, and various statistical summaries are printed. The model also gives output at different specified spot locations and subsections along the simulated roadway.

3.3.1. FEATURES OF INPUT VARIABLES

The model requires extensive field data and different parameters to define driver characteristics and vehicle performance. In order to achieve realistic results, the data required incorporate the major features listed below [31]:

Entering Traffic

. Flow rates

. Vehicle mix

. Platooning

. Immediate upstream alignment

Geometry

. Grades

. Horizontal curves

. Lane width, shoulder width, and pavement quality

. Passing sight distance

. Passing and climbing lanes

Traffic Control

. Passing and no-passing zones

. speed limits

Vehicle Characteristics

. Vehicle acceleration and speed capabilities

. Vehicle lengths

Driver Characteristics and Preferences

. Desired speeds

. Preferred acceleration levels

. Limitations on sustained use of maximum power

. Passing and pass-abort decisions

. Realistic behavior in passing and climbing lanes

The characteristics and application of each feature in the simulation model is described in Appendix A.

3.3.2. FEATURES OF OUTPUT VARIABLES

Output is printed by the TWOPAS model at four times. First, the input data are printed as they are read. Second, data are printed while they are being prepared for application in the simulation. Third, the status of vehicles can be printed during simulation processing in snapshots at user-specified intervals as a method to monitor the simulation operation. Fourth, the simulation results are summarized after the simulation run is completed. The data required for the study are those printed after completion of the simulation run. The output printed after completion of the simulation run is listed below [31].

- Space-averaged data and operating speeds.
- Overall and desired speeds
- Travel times and delays
- Overall speed histograms
- Time margins in passes and pass aborts
- Data on passing and pass aborts rates, platoon leaders, and percent of time unimpeded
- Headway and platoon data
- Overtaking event data classified by speed differences
- Overtaking events classified by initial acceleration and summary of acceleration noise
- Summary output for user specified stations
- Summary data for user-specified subsections

The calculation and detailed features of each parameter are described in the user's manual of the model.

CHAPTER 4

4.1. APPROACH

Driver, vehicular and roadway characteristics, which have a significant impact on the passing maneuver, have already been discussed in the literature review. The literature indicated that passing lanes are effective in improving overall traffic operations on two-lane highways, and they provide a lower cost alternative to constructing extended sections of four lane highways.

The passing maneuver is a complex phenomenon and can not be described fully through a mathematical model. Computer simulation, on the other hand, has the capability of describing traffic behavior on a vehicle by vehicle basis. Different simulation models used to describe the phenomenon of the passing maneuver on two-lane two-way highways have already been discussed in detail in Chapter 3. On the basis of the selection criteria, the model best suited for this study was selected. Features of the selected model (TWOPAS), input data required and output data produced by the model, have been discussed in Chapter 3.

The model selected (TWOPAS) will be calibrated for Michigan drivers, traffic and roadway conditions. This model gives the average delay, travel time, speed and other information at different specified locations throughout the simulated roadway length. Previous studies show that the effective length of a passing lane can vary from 3 to 8 miles depending on passing lane length, traffic flow and downstream passing opportunities. The calibrated model will be used to determine the effective length of passing lanes and operational benefits in terms of reduced delay and average increase in speed for different traffic volumes, compositions and roadway geometry.

The accident rates with and without the passing lane on two-lane rural highways throughout Michigan will be used to calculate the safety benefits in terms of savings in accident cost. Savings in operating cost will be determined in terms of reduction in delay. The construction and maintenance costs of passing lanes and savings in operating and accident costs will be used in a benefit-cost analysis. The following benefit measures will be used for the evaluation analysis.

.Decrease in total vehicle delay due to passing lanes.

.Decrease in accidents, injuries, and fatalities per mile.

This information and analysis will be used to provide guidelines for warrants for construction of passing lanes.

CHAPTER 5

5.0 DATA COLLECTION

5.1. FIELD DATA REQUIREMENT

Field data are required to calibrate the simulation model. Input data, other than field data, required for calibration of the model are discussed in the next chapter. The field data required include traffic data and geometric data of the roadway.

5.1.1. TRAFFIC DATA

The traffic data required are hourly volume, desired speed, traffic composition and headways.

Hourly Volume

Hourly volume data are required for both directions of flow.

Desired Speed

The number of vehicles in specified speed intervals for both directions of flow are required to calculate the mean and standard deviation of desired speed (ft/sec).

Traffic Composition

The fraction of each type of vehicle in the mix is required for both directions of flow. The model can take up to thirteen types of vehicles.

Headways

The extent of platooning on a two-lane road reflects the balance between passing demand and supply, and the degree of constraint or freedom experienced by drivers. The revised Highway Capacity Manual (HCM) recommends a platoon definition based on a 5 sec headway. Platooning is thus measured by the percentage of vehicles following at headways (time gaps) of less than 5 sec.

5.1.2. GEOMETRIC DATA

To calibrate the model detailed geometric data are required for the entire length of the simulated roadway. The field data required for simulation are :

- Horizontal Curves
- Vertical Curves/Grades
- Passing Zones, No-passing Zones and Passing Lanes

Horizontal Curves

The position coordinate of the beginning of each curve is required for traffic in direction No.1 only. Radius of the curve, superelevation and degree of the curve, are also required for each horizontal curve along the road.

Vertical Curve

The position coordinates and percent grades, are required at the beginning and at the end of each grade region. The grade data are required only for direction No.1.

Passing Zones, No-Passing Zones and Passing Lanes

The position coordinate of the beginning of each zone (ft) is required, where the beginning is based on the appropriate direction of travel, but the position must be expressed in direction No.1 coordinates.

5.2. FIELD DATA COLLECTION

5.2.1. SITE SELECTION

In Michigan there are 44 sections on two-lane rural highways which have passing lanes. Out of these, 22 sections are in lower Michigan and 22 sections are in the Upper Peninsula. These sections and other information are given in Table 3. Lower Michigan was selected for this study. Two sections having passing lanes, one on US-37 in Lake county and the other on M-115 in Clare county, were selected for extensive field data collection to calibrate the simulation model. The features of these sites are shown in Figures 5 and 6. These sites were selected mainly because they are on the main routes leading towards Traverse City, one of the widely used recreational spots in Michigan.

5.2.2. DATA COLLECTION

Special data recording machines(VC-1900), recommended by FHWA, were used to record traffic volume, speed, headway and vehicle mix. The main feature of this machine is the ability to classify the vehicles into thirteen different categories on the basis of total number of axles on a vehicle. These classifications are listed in Table 4. Three sets of machines were installed at a location 0.5 mile upstream of the passing lane and two sets of machines were installed at two locations, 0.5 mile and 1.5 miles, downstream of the passing lane. The set up of machines are shown in Figures 5 and 6 for both the sites. The upstream three machines were used to

TABLE 3

LIST OF PASSING LANES IN MICHIGAN

COUNTY	HIGHWAY NUMBER	LOCATIONS** MILE POINTS				LENGTH OF PASSING LANE(S) (MILES)		ADT (1983)
Osceolla	M-115	4.04-5.03	NW			0.99		5600
Wexford	M-37	2.51-3.11	NB			0.60		4100
Manistee	US-31	3.79-4.46	NB			0.67		4200
Traverse	M-37	7.48-8.59	SB			1.11		4900
Traverse	US-31	1.76-3.60	SB			1.84		13000
Traverse	M-72	0.34-1.13	SE			0.79		8300
Traverse	M-72	5.51-6.32	WB			0.81		6900
Traverse	M-72	3.89-4.37	WB			0.48		7800
Traverse	M-72	20.01-22.40	WB			2.39		5000
Kalkaska	M-72	14.60-16.39	WB			1.79		2750
Ionia	M-66	5.42-6.27	SB			0.85		1800
Lenawee	US-127	5.13-5.83	SB			0.70		8800
Antrim	US-131	13.98-16.17	SB			2.19		2450
Kent	M-57	13.19-13.54	EB,	0.00-0.34	EB	0.35	0.34	9500
Traverse	M-72	7.27-7.92	EB,	8.20-7.80	WB	0.65	0.40	6900
*Lake	M-37	2.13-3.24	NB,	2.74-3.77	SB	1.11	1.03	2450
Wexford	M-115	1.26-2.95	EB,	6.55-8.78	WB	1.69	2.23	4100
Ottawa	M-45	15.01-15.13	EB,	15.37-14.91	WB	0.12	0.46	1000
*Clare	M-115	8.29-9.19	SE,	9.55-8.55	NW	0.90	1.00	4100
Osceolla	M-115	8.39-9.10	SE,	9.42-8.67	NW	0.71	0.75	4500
Osceolla	M-115	2.14-3.01	SE,	3.52-2.20	NW	0.87	1.32	5600
Benzie	US-31	1.66-2.90	EB,	3.76-2.36	WB	1.24	1.40	5200

* Sites Used For Model Calibration

* Sites With Passing Lane(s) In Lower Michigan

TABLE 3 (Cont'd.)

COUNTY	HIGHWAY NUMBER	LOCATIONS* MILE POINTS	LENGTH OF PASSING LANE(S) (MILES)	ADT (1983)
Iron	US-2	4.32-4.81 WB	0.49	1000
Iron	US-2	5.74-6.62 EB	0.88	1300
Iron	US-2	0.00-0.48 EB	0.48	1000
Iron	US-2	1.85-2.20 WB	0.35	1000
Iron	US-2	4.72-6.50 WB	1.78	2800
Iron	US-2	8.17-8.70 EB	0.53	2800
Iron	US-2	10.37-11.37 WB	1.00	2800
Iron	US-2	13.17-13.65 EB	0.48	1300
Iron	US-2	15.62-15.78 EB	0.96	2500
Iron	US-2	14.62-15.07 EB, 14.81-15.07 WB	0.45	2500
Iron	US-2	8.22-8.97 NB, 8.47-9.67 SB	1.45	2500
Iron	US-141	12.00-13.19 NB	1.19	700
Iron	US-141	3.70-5.06 NB	1.36	1200
Iron	US-141	0.00-0.50 SB	0.50	1900
Alger	M-28	1.14-2.86 EB	1.72	3700
Alger	M-28	23.65-25.10 EB	1.45	3800
Alger	M-28	17.03-19.95 EB	2.92	2800
Alger	M-28	4.78-8.10 EB	3.32	2400
Ontonagon	M-26	5.52-6.72 WB	1.20	1500
Ontonagon	M-45	9.17-13.15 NB	3.98	1000
Houghton	M-26	10.79-13.59 NB	2.80	4000
Baraga	US-41	14.30-16.10 EB	1.80	5100

* Locations With Passing Lanes In Upper Michigan

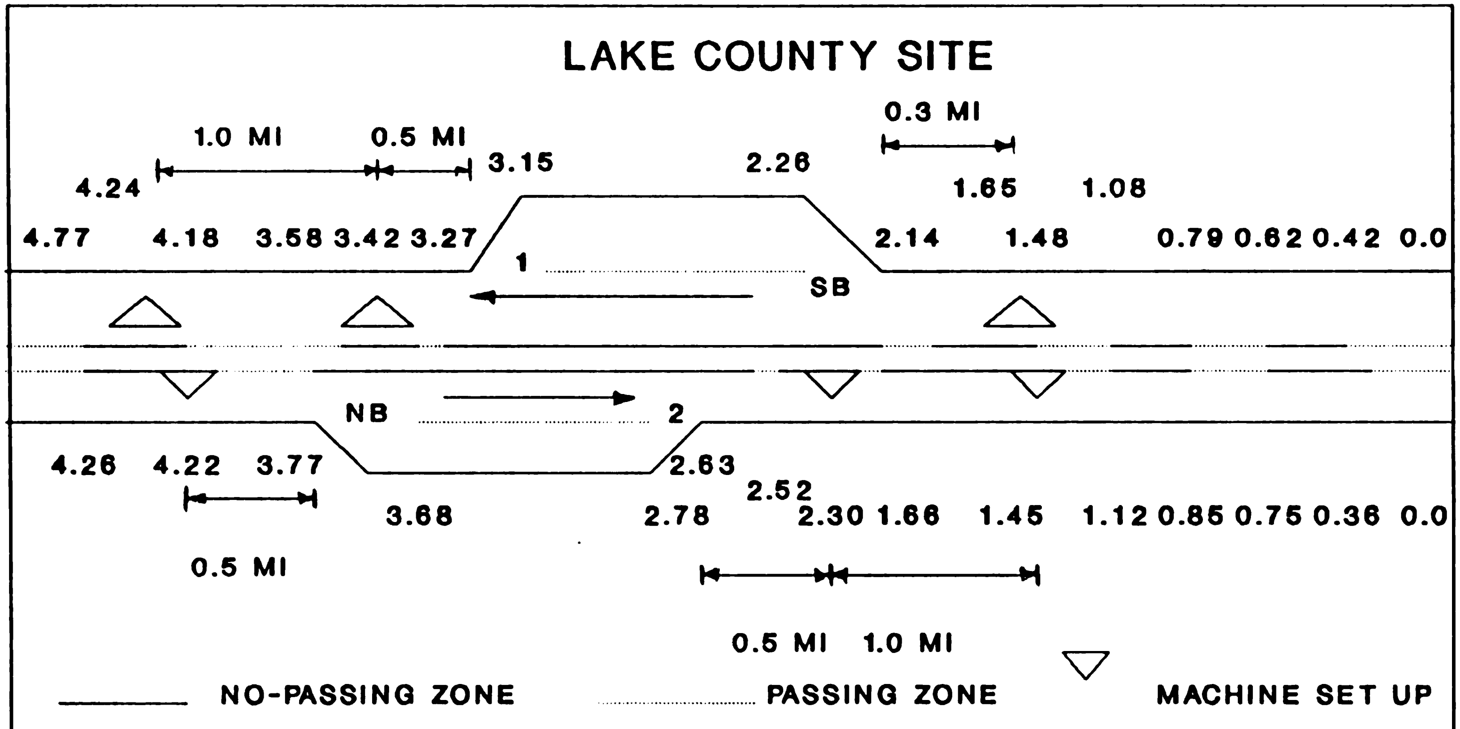


FIGURE 5. MACHINE SET UP FOR DATA COLLECTION AT LAKE SITE

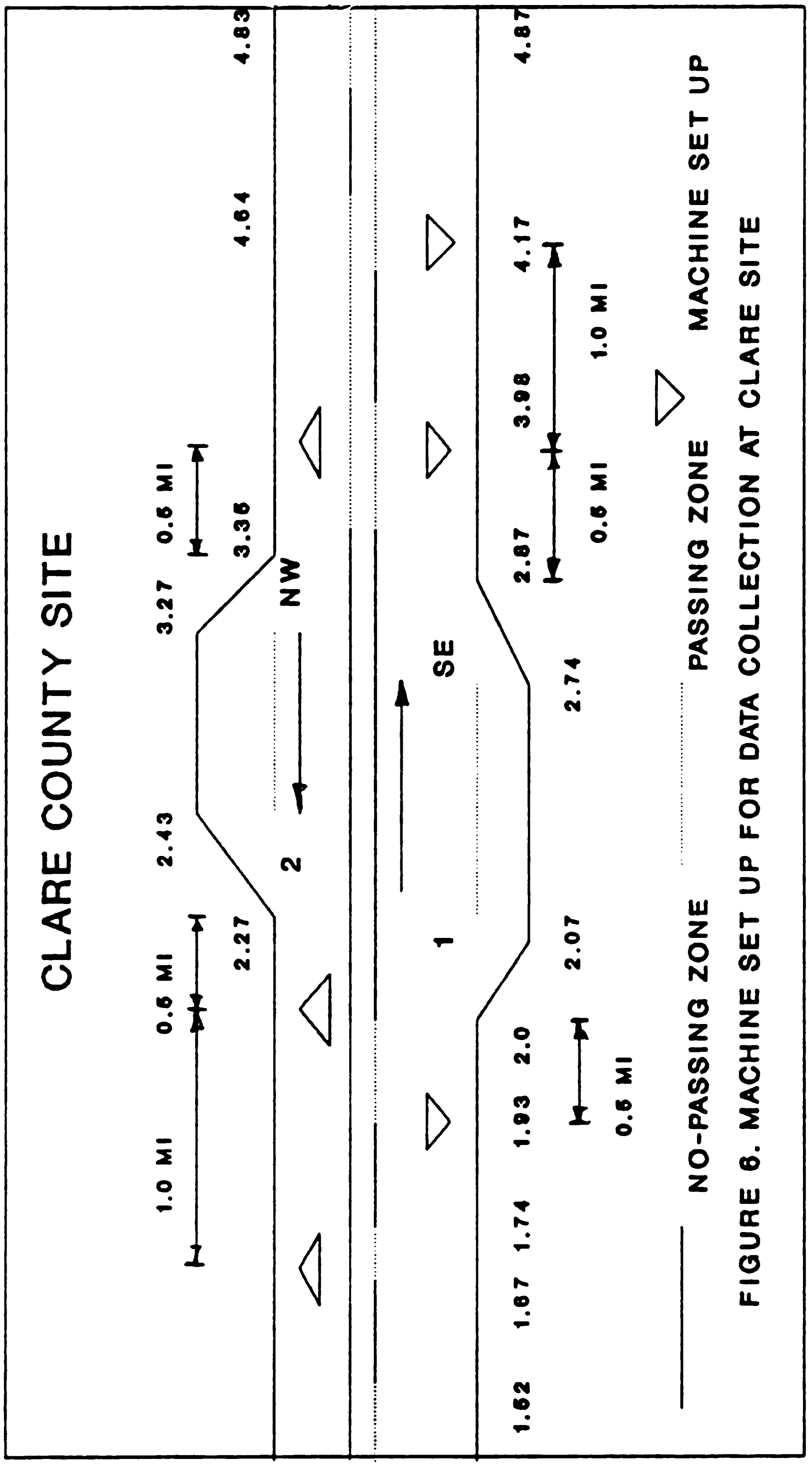


FIGURE 6. MACHINE SET UP FOR DATA COLLECTION AT CLARE SITE

TABLE 4

VEHICLE CLASSIFIED BY VC-1900 MACHINE USED FOR DATA COLLECTION

VEHICLE TYPE	CLASSIFICATION CATEGORY	NO. OF AXLES
Motorcycle	1	2
Car or Light Pickup	2	2
Car + Trailer	2	3
Car + 2 Axle Trailer	2	4
Heavy Pickup	3	2
Heavy Pickup + Trailer	3	3
Heavy Pickup + 2 Axle Trailer	3	4
Heavy Pickup + 3 Axle Trailer	3	5
Bus 2 Axle	4	2
Bus 3 Axle	4	3
Truck 2 Axle	5	2
Truck + 3 Axle Trailer	5	5
Truck 3 Axle	6	3
Truck 4 Axle (Triaxle)	7	4
Truck Semi 2S1	8	3
Truck Semi 2S2	8	4
Truck Semi 3S1	8	4
Truck Semi 3S2	9	5
Truck Tandem + 2 Axle Trailer	9	5
Truck + 3 Axle Trailer	9	5
Truck (4 Axle) + 2 Axle Trailer	10	5
Truck Semi 3S3	10	5
Truck + Double Bottom 2S1-2	11	5
Truck + Double Bottom 3S1-2	12	6
Vehicle with 7 or more Axles	13	7+

collect speed, headway and vehicle classification separately and the downstream machines were used to collect speed and headway data. Data were collected on Friday for six hours from 12:00 noon to 6:00 p.m. in one direction and on Sunday for the same six hours in the other direction. The same machine set up, timings and days of the week were used for both locations.

Speed data were collected in different speed intervals to get the speed distribution and to calculate the percentage of vehicles with speed greater than 55 mph. This speed distribution also gives the mean and standard deviation of speed in the field. The speed distribution at 0.5 mile upstream of the passing lane for the SE direction of flow at the Clare county site is shown in Figure 7. The median speed is 58.0 mph (85.0 ft/sec) and the standard deviation is 6 mph (8.8 ft/sec). Vehicles having a headway less than 5 seconds were counted separately to get the percentage of vehicles in platoon.

The VC-1900 machine uses the FHWA Scheme F Classification Algorithm in counting the number of axles on a vehicle and measuring the axle spacing to classify the vehicles in thirteen different categories. For a given number of axles the logic applies a series of tests to the axle spacings to determine which category the vehicle will be classified into. For the simulation run, trucks were divided into three categories. The trucks classified by the machine as 5, 6, 7, were taken as high performance trucks, trucks classified as 8, 9, 10, were taken as medium performance trucks and trucks classified as 11, 12, 13, were taken as low performance trucks for the simulation run. The model accepts three types of trucks and one

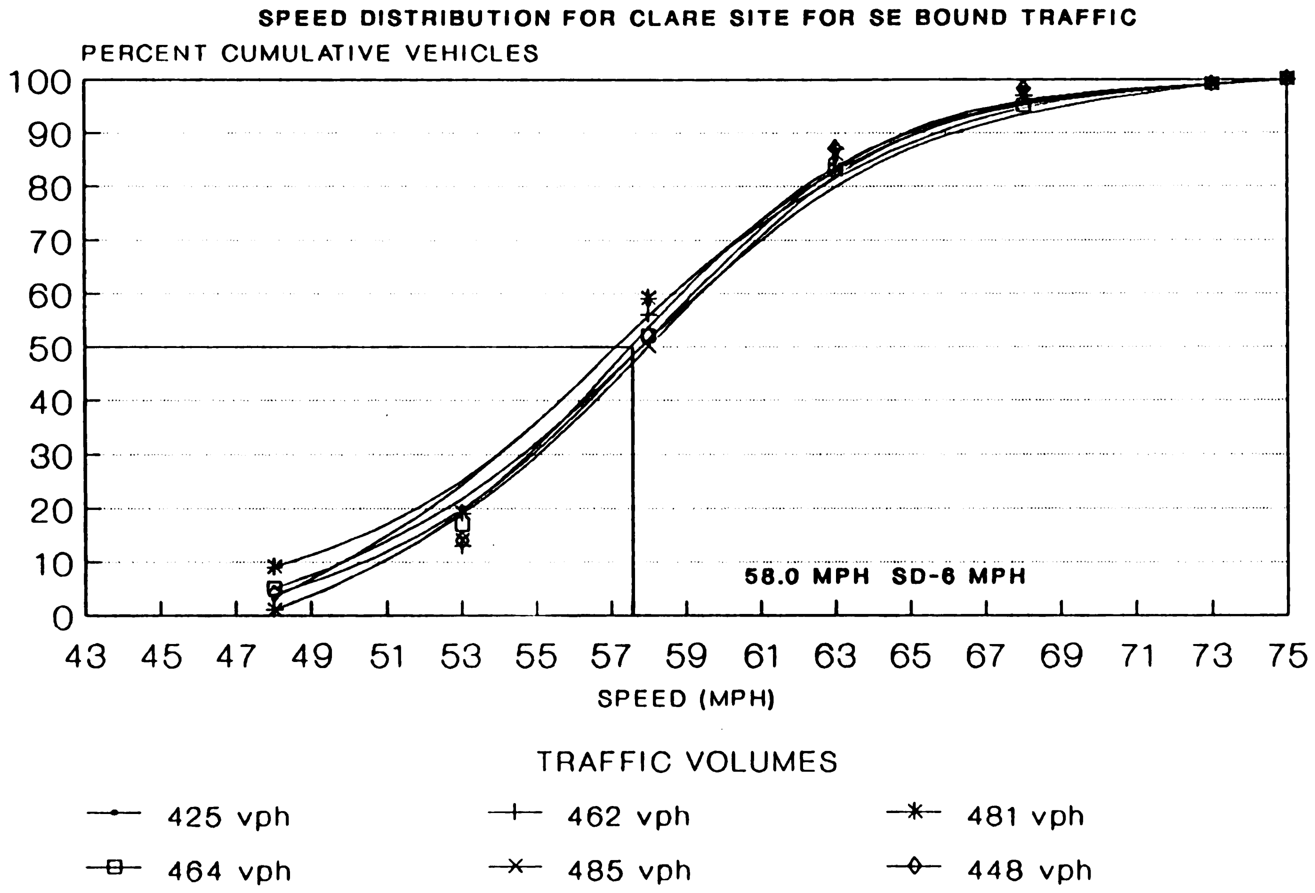


FIGURE 7. SPEED DISTRIBUTION AT 0.5 MILE UPSTREAM OF PL

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type of bus. This machine does not distinguish recreational vehicles as a single category, but classifies them as trucks with similar axle spacing. The machine classifies cars and pickup trucks separately. These two categories were taken as two high performance types of cars in the model. Overall three types of trucks, one type of bus, and two types of car/pickups were used to calibrate the model. Hourly volume, percentage vehicles having speed greater than 55 mph, percentage of the vehicles in platoon, and fraction of traffic mix are given in Tables 5 and 6, for the Lake and Clare county sites respectively.

Geometric data were collected by using the Michigan Automated Recording System (MARS) vehicle. This vehicle gives complete details of the alignment of the road. It measures location and different elements of vertical and horizontal curves as it moves along the road. Geometric data collected by the MARS vehicle are given in Tables 7 and 8, for the Lake and Clare county sites respectively. The values of position coordinate, length and the percentage change in grade at the beginning and end of each grade region are given in these tables. The values of position coordinate where the horizontal curves begin, radius of curve, superelevation and degree of curves are also given in these tables. The location and length of passing zones and no-passing zones and passing lanes were noted from the photolog films of the roads for both directions. These no-passing zones along the road for both the directions are shown in Figure 5, for the Lake county site and in Figure 6, for the Clare county site.

TABLE-5

TRAFFIC DATA FOR LAKE COUNTY SITE

PERIOD (P.M.)	HOURLY VOLUME vph	PERCENTAGE SPEED>55mph AT LOCATIONS*			HEADWAY<5sec % PLATOON AT LOCATIONS*			FRACTION OF VEHICLES IN TRAFFIC MIX					
								TRUCK TYPES			BUS	CAR TYPES	
		1	2	3	1	2	3	HEAVY 1	MEDIUM 2	LIGHT 3		CAR 1	PICKUP 2
DIRECTION-1 (SUNDAY)													
12.00-1.00	322	58	-	75	52	56	-	0.000	0.019	0.006	0.009	0.642	0.324
1.00-2.00	380	58	-	71	55	56	-	0.000	0.017	0.009	0.009	0.653	0.312
2.00-3.00	372	63	-	80	59	61	-	0.003	0.022	0.005	0.005	0.655	0.310
3.00-4.00	423	62	-	69	62	60	-	0.000	0.022	0.015	0.007	0.678	0.278
4.00-5.00	473	61	-	73	65	63	-	0.002	0.018	0.008	0.002	0.675	0.294
5.00-6.00	388	66	-	80	60	61	-	0.000	0.017	0.007	0.007	0.679	0.290
DIRECTION-2 (FRIDAY)													
12.00-1.00	178	59	82	70	40	38	36	0.000	0.078	0.012	0.018	0.615	0.277
1.00-2.00	180	57	82	63	37	39	38	0.000	0.035	0.018	0.006	0.643	0.298
2.00-3.00	191	59	80	64	41	38	34	0.000	0.061	0.006	0.011	0.667	0.255
3.00-4.00	196	58	78	66	36	32	31	0.006	0.033	0.011	0.028	0.657	0.265
4.00-5.00	270	63	83	73	49	43	41	0.008	0.045	0.013	0.016	0.622	0.292
5.00-6.00	268	60	93	78	52	48	45	0.004	0.046	0.015	0.019	0.673	0.243

*Location 1- 0.5 Miles Upstream of Passing Lanes
*Location 2- 0.5 Miles Downstream of Passing Lanes
*Location 3- 1.5 Miles Downstream of Passing Lanes

TABLE-6

TRAFFIC DATA FOR CLARE COUNTY SITE

TABLE-6

TRAFFIC DATA FOR CLARE COUNTY SITE

PERIOD (P.M.)	HOURLY VOLUME VPH	PERCENTAGE SPEED>55mph AT LOCATIONS*			HEADWAY<5sec % PLATOON AT LOCATIONS*			FRACTION OF VEHICLES IN TRAFFIC MIX					
								TRUCK TYPES			BUS	CAR TYPES	
								HEAVY	MEDIUM	LIGHT		CAR	PICKUP
		1	2	3	1	2	3	1	2	3		1	2
DIRECTION-1 (SUNDAY)													
12.00-1.00	415	80	-	88	59	54	53	0.003	0.020	0.010	0.007	0.712	0.248
1.00-2.00	458	87	-	94	64	62	60	0.003	0.030	0.007	0.010	0.695	0.255
2.00-3.00	461	81	-	94	65	56	57	0.002	0.030	0.011	0.007	0.664	0.286
3.00-4.00	447	82	-	82	65	63	61	0.002	0.022	0.007	0.013	0.703	0.252
4.00-5.00	469	86	-	94	62	61	59	0.009	0.031	0.002	0.009	0.712	0.237
5.00-6.00	432	86	-	96	63	57	56	0.003	0.035	0.004	0.008	0.725	0.225
DIRECTION-2 (FRIDAY)													
12.00-1.00	226	78	-	83	32	32	35	0.018	0.062	0.013	0.007	0.610	0.290
1.00-2.00	228	66	-	85	34	33	35	0.040	0.040	0.004	0.016	0.660	0.240
2.00-3.00	247	83	-	90	38	34	38	0.005	0.040	0.028	0.007	0.676	0.244
3.00-4.00	278	74	-	90	41	35	37	0.007	0.024	0.004	0.025	0.705	0.235
4.00-5.00	337	83	-	88	49	44	39	0.006	0.030	0.003	0.012	0.688	0.261
5.00-6.00	390	82	-	93	49	43	47	0.003	0.033	0.007	0.007	0.720	0.230

*Location 1- 0.5 Miles Upstream of Passing Lanes
*Location 2- 0.5 Miles Downstream of Passing Lanes
*Location 3- 1.5 Miles Downstream of Passing Lanes

VERTICAL CURV

BEG. OF THE REGION (MILE)
29.13
31.23
31.26
31.44
31.53
31.96
32.06
32.36
32.46
32.98
33.08
33.21
33.41
33.54
34.17
34.20
34.27

HORIZONTAL CU

BEG. OF THE CURVE (FT)
30.45
30.58
30.82
31.06
31.56
31.66
31.80
34.32
34.88

TABLE 7 (a)

VERTICAL CURVE DATA COLLECTED BY MARS VEHICLE AT LAKE COUNTY SITE

BEG. OF THE REGION (MILE)	END OF THE REGION (MILE)	LENGTH OF THE REGION (FT)	GRADE IN THE BEGINNING (%)	GRADE IN THE END (%)
29.13	31.23	11088	0.00	0.00
31.23	31.26	158	0.37	1.54
31.26	31.33	370	1.54	0.21
31.44	31.53	475	0.21	0.84
31.53	31.67	739	0.84	-2.34
31.96	32.06	528	-0.61	2.21
32.06	32.14	422	2.21	0.12
32.36	32.46	528	1.52	-2.33
32.46	32.70	1267	-2.33	1.15
32.98	33.08	528	1.15	-2.00
33.08	33.11	158	-2.00	-1.28
33.21	33.26	264	-1.28	-2.41
33.41	33.54	686	-2.38	1.03
33.54	33.64	528	1.03	-0.98
34.17	34.20	158	-0.75	1.30
34.20	34.27	370	1.30	-0.23
34.27	35.77	7920	0.00	0.00

TABLE 7 (b)

HORIZONTAL CURVE DATA COLLECTED BY MARS VEHICLE AT LAKE COUNTY SITE

BEG. OF THE CURVE (FT)	RADIUS OF THE CURVE (FT)	SUPERELEVATION	DEGREE OF THE CURVE
30.45	3784	0.091	1.5
30.58	5679	0.093	1.0
30.82	5142	0.087	1.1
31.06	2900	0.090	-2.0
31.56	2565	0.097	-2.2
31.66	5165	0.078	1.1
31.80	5521	0.081	1.0
34.32	7957	0.091	-0.7
34.88	5495	0.084	-1.0

VERTICAL CURVE

BEG. OF THE REGION (MILE)	EN RE
11.45	
12.15	
13.15	
13.28	
13.47	
13.50	
13.57	
14.55	
15.30	
16.04	
16.32	
16.38	

HORIZONTAL CURV

BEG. OF THE CURVE (MILE)	R
13.58	
13.85	
16.03	

TABLE 8 (a)

VERTICAL CURVE DATA COLLECTED BY MARS VEHICLE AT CLARE COUNTY SITE

BEG. OF THE REGION (MILE)	END OF THE REGION (MILE)	LENGTH OF THE REGION (FT)	GRADE IN THE BEGINNING (%)	GRADE IN THE END (%)
11.45	12.15	3696	0.00	0.00
12.15	12.20	264	0.24	-0.58
13.15	13.28	686	-0.46	0.40
13.28	13.47	1003	0.40	-1.05
13.47	13.50	158	-1.05	1.42
13.50	13.57	370	1.42	1.05
13.57	13.64	370	1.05	-2.46
14.55	14.57	106	0.20	-0.81
15.30	15.34	211	0.01	-1.56
16.04	16.13	475	-0.17	-1.10
16.32	16.38	317	-1.10	-0.15
16.38	18.08	8976	0.00	0.00

TABLE 8 (b)

HORIZONTAL CURVE DATA COLLECTED BY MARS VEHICLE AT CLARE COUNTY SITE

BEG. OF THE CURVE (MILE)	RADIUS OF THE CURVE (FT)	SUPERELEVATION	DEGREE OF THE CURVE
13.58	904	0.075	6.3
13.85	2689	0.040	2.1
16.03	5872	0.025	1.0

5.3. ACCIDENT

The acci
of passing la
accidents on
from the state
two-lane highw
five years fro
of the accide
from 1983 to 1
rates and sev
lane roads wit
lane highways
ADT levels i.e
than 10000. Th

5.3. ACCIDENT DATA REQUIRED

The accident data is required to determine the effectiveness of passing lanes in reducing total accidents and severity of accidents on two-lane highways. The accident data were separated from the state data file for those sections having passing lanes on two-lane highways throughout Michigan. These data were separated for five years from 1983 to 1987. The files contain types and severity of the accidents. The values of accidents by severity for each year from 1983 to 1987 are given in Table 9. To compare the accident rates and severity of the accidents within the passing lane and two lane roads without passing lanes, the entire accident data on two-lane highways in Michigan were segregated on the basis of different ADT levels i.e., less than 5000, between 5000 to 10000 and greater than 10000. These accident data are given in Table 10.

TABLE 9

NUMBER OF ACCIDENTS WITH SEVERITY IN PASSING LANES AREA IN MICHIGAN

HIGHWAY NUMBER	COUNTY	NUMBER OF ACCIDENT WITH SEVERITY IN LOWER MICHIGAN																								
		FATAL ACC.					PERSONS INJURED					INJURY ACC.					PERSONS INJURED					PDO ACC.				
		83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87

TOTAL ACC.*				
83	84	85	86	87

TABLE 9

NUMBER OF ACCIDENTS WITH SEVERITY IN PASSING LANES AREA IN MICHIGAN

HIGHWAY NUMBER	COUNTY	NUMBER OF ACCIDENT WITH SEVERITY IN LOWER MICHIGAN																													
		FATAL ACC.					PERSONS INJURED					INJURY ACC.					PERSONS INJURED					PDO ACC.					TOTAL ACC.*				
		83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87
M-37	LAKE	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	0	0	2	0	3	3	5	3	1	4	3	5
M-115	CLARE	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	1	0	0	2	3	4	3	2	2	4	5	3	2
US-31	MANISTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	5	2	1	2	0	5	2	1
M-37	TRAVERSE	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1	6	0	0	0	8	4	5	3	4	9	6	5	3	4
US-37	WEXFORD	0	0	0	0	0	0	0	0	0	0	2	0	4	2	0	2	0	7	2	0	0	0	3	1	0	2	0	7	3	0
M-115	OSCEOLLA	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0	1	1	3	2	3	0	3	3	4	3	1	4	5	5
M-115	OSCEOLLA	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	3	0	0	1	1	0	1	6	4	5	1	1	6	5	6
M-115	OSCEOLLA	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	3	4	6	11	13	5	4	6	11	13
M-45	OTTAWA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	6	5	4	9	5	6	5	5	9	5
M-115	WEXFORD	0	0	0	0	0	0	0	0	0	0	2	3	3	3	2	4	4	3	3	4	3	2	7	5	5	5	5	10	8	7
US131	ANTRIM	0	0	0	0	0	0	0	0	0	0	0	1	2	0	3	0	1	3	0	6	1	4	4	2	3	1	5	6	2	6
US-31	BENZIE	1	0	0	0	0	1	0	0	0	0	2	1	2	5	3	2	1	8	10	8	8	7	9	6	6	11	8	11	11	9
US-31	TRAVERSE	0	0	0	0	0	0	0	0	0	0	5	5	7	12	8	9	10	13	22	14	13	17	14	33	26	18	22	21	45	34
M-72	TRAVERSE	0	0	0	0	0	0	0	0	0	0	3	3	2	1	1	8	4	2	2	1	1	2	3	3	2	4	5	5	4	3
M-72	TRAVERSE	0	0	0	0	0	0	0	0	0	0	1	0	5	1	2	1	0	6	1	3	1	2	2	5	0	2	2	7	6	2
M-72	TRAVERSE	0	0	0	0	0	0	0	0	0	0	2	0	3	0	3	2	0	3	0	7	5	6	3	6	5	7	6	6	6	8
M-72	TRAVERSE	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	2	2	4	2	5	6	3	5	3	5	7	4
M-72	LEELANDU	0	0	0	0	0	0	0	0	0	0	3	1	2	2	2	4	1	2	5	2	16	17	12	15	16	19	18	14	17	18
M-72	KALKASKA	0	0	0	1	0	0	0	0	1	0	0	2	0	1	2	0	6	0	1	2	3	4	6	5	3	3	6	6	7	5
M-66	IONIA	0	0	0	0	0	0	0	0	0	0	2	4	6	4	8	2	5	12	4	11	10	10	4	18	9	12	14	10	22	17
US127	LENAWEE	0	0	0	0	0	0	0	0	0	0	0	3	2	1	1	0	4	2	1	1	4	2	3	9	6	4	5	5	10	7
M-57	KENT	1	0	0	0	0	1	0	0	0	0	0	0	0	1	3	0	0	0	1	4	1	0	4	2	4	2	0	4	3	7

*Total Accident = Fatal Accident + Injury Accident + PDO Accident

TABLE 9 (Con'd.)

HIGHWAY NUMBER	COUNTY	NUMBER OF ACCIDENT WITH SEVERITY IN UPPER MICHIGAN																													
		FATAL ACC.					PERSONS INJURED					INJURY ACC.					PERSONS INJURED					PDO ACC.					TOTAL ACC.*				
		83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87
[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 9 (Con'd.)

HIGHWAY NUMBER	COUNTY	NUMBER OF ACCIDENT WITH SEVERITY IN UPPER MICHIGAN																													
		FATAL ACC.					PERSONS INJURED					INJURY ACC.					PERSONS INJURED					PDO ACC.					TOTAL ACC.*				
		83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87	83	84	85	86	87
US41	BARAGA	0	0	0	0	0	0	0	0	0	0	3	2	1	2	1	6	2	2	7	2	0	8	7	8	6	3	10	8	10	7
M-26	HOUGHTON	0	0	0	0	0	0	0	0	0	0	1	3	1	2	1	1	3	2	3	1	3	3	6	4	1	4	6	7	6	2
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0	1	0	0	1	1	0	0	0	2	1	1	0
US-2	IRON	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	3	1	2	0	2	4	1	2	1	2
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	I	0	0	2	0	1	0	0
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1	2
US-2	IRON	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	3	4	4	0	2	4	4	5	1	2
US-2	IRON	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0	1	0	1	1	2	1	0	1	1
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	6	2	3	2	7	6	2	3
US-2	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	0	1	2	7	8	7	1	2	7	9	7
US14	IRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	1	1	1	2	3
US14	IRON	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	3	2	3	3	3	3	3	3	3	3
US14	IRON	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	4	2	1	1	1	4	2	1
M-26	ONTONAGON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
M-45	ONTONAGON	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	8	8	2	3	11	8	9	2	3	11
M-28	ALGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	3	5	5	2	2	3	5	5	3
M-28	ALGER	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	2	5	0	1	1	3	4	9	0	1	4	5	9	1	2
M-28	ALGER	0	0	0	0	0	0	0	0	0	0	3	0	5	1	0	4	0	8	1	0	5	3	7	10	3	8	3	12	11	3
M-28	ALGER	0	0	0	1	0	0	0	0	1	0	2	4	4	2	2	3	6	7	2	2	4	8	10	7	2	6	12	14	10	4

*Total Accident = Fatal Accident + Injury Accident + PDO Accident

TABLE 10

ACCIDENT NUMBER AND RATES BY SEVERITY ON TWO-LANE RURAL HIGHWAYS IN MICHIGAN

YEAR	INJURY ACC.	INJURY RATE	FATAL ACC.	FATAL RATE	P.D.O. ACC.	TOTAL ACC.	TOTAL NUMBER	NUMBER OF ROAD

TABLE 10

ACCIDENT NUMBER AND RATES BY SEVERITY ON TWO-LANE RURAL HIGHWAYS IN MICHIGAN

YEAR	INJURY ACC. RATE	INJURY RATE	FATAL ACC. RATE	FATAL RATE	P.D.O. ACC. RATE	TOTAL ACC. RATE	TOTAL NUMBER ACCS.	NUMBER OF ROAD MILES
FOR ADT 1-5000								
1983	61.0	99.7	2.2	2.8	203.1	266.3	11073	4754.29
1984	61.8	97.6	2.3	2.8	221.9	286.0	12119	4608.78
1985	60.4	97.0	2.3	2.9	242.6	305.3	12791	4498.59
1986	60.0	95.8	2.5	2.8	255.6	318.1	13186	4433.34
1987	59.5	92.8	2.5	3.1	259.5	321.5	13066	4345.98
FOR ADT 5001-10000								
1983	72.5	122.1	2.1	2.7	169.1	243.7	6486	1091.72
1984	75.7	125.7	2.6	3.1	172.9	251.2	7515	1200.67
1985	79.0	129.2	2.6	3.0	210.0	291.6	8757	1218.93
1986	72.0	118.9	2.9	3.3	210.1	285.0	9084	1289.62
1987	73.1	120.7	2.6	3.2	204.5	280.2	9864	1425.26
FOR ADT 10001-15000								
1983	103.8	168.3	1.5	1.6	199.6	304.9	2005	148.22
1984	109.4	183.4	2.8	3.3	217.5	329.7	2549	178.19
1985	97.7	162.4	3.0	3.7	228.9	329.6	3224	226.48
1986	99.9	163.3	2.2	2.5	245.4	347.5	3461	231.12
1987	98.9	166.3	3.0	4.1	223.0	324.9	3954	281.43

NOTE: Rates = Accidents Per 100 Million Vehicle Miles

6.0 SIMULATION MO

6.1 STUDY DESIGN

The TWOPAS
validated for the
to conduct this
Michigan driver's
on Michigan two
performance para
outputs given by
values. The model
platoon, percent
delay at a partic
simulated roadway

The paramet
percentage vehic
before, these lo
passing lane and
Speed and headway
each of the four
of the percentage
speed greater th
the traffic mix w

CHAPTER 6

6.0 SIMULATION MODEL CALIBRATION

6.1 STUDY DESIGN

The TWOPAS model selected for the study has previously been validated for the range of geometric and traffic parameters required to conduct this study. However, the model has to be calibrated for Michigan driver's and the speed at which they are willing to drive on Michigan two-lane roadways. To calibrate the model, driver performance parameters were varied, and the values of selected outputs given by the simulation model were compared to the field values. The model output includes the percentage of vehicles in platoon, percentage vehicles at or above the desired speed, average delay at a particular location and delay for a specified section of simulated roadway.

The parameter selected to calibrate the model was the percentage vehicles in platoon at different locations. As mentioned before, these locations are taken as 0.5 mile upstream of the passing lane and 0.5 and 1.5 miles down stream of the passing lanes. Speed and headway data were collected at these three locations for each of the four passing lanes used in the calibration. The values of the percentage vehicles in platoon, percentage vehicles with speed greater than 55 mph and fraction of each type of vehicle in the traffic mix were given in Tables 5 and 6 (Chapter 5).

Simulation

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simulation valu

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values of these

match the field

these parameter

roadway environme

6.2. INPUT DATA

To run the s

Most of these da

although a few va

default values.

- Entering T
- Geometric
- Traffic Co
- Vehicle Ch
- Driver Cha

6.2.1. ENTERING T

Flow Rates

The progra

response to a user

Simulation runs were made using each hourly volume and traffic mix collected in the field for both directions of flow. The simulation values of percentage vehicles in platoon were compared with the field values at the same locations for each hour. In each run the parameters defining driver characteristics (desired speed and car following sensitivity factor values) were changed. The values of these parameters for which the simulation results best match the field values were determined. The calibrated model with these parameters was taken to represent drivers using the Michigan roadway environment and was used for further study.

6.2. INPUT DATA REQUIRED

To run the simulation model, the following data are required. Most of these data were collected in the field as discussed before, although a few values were taken directly from the user's guide as default values.

- Entering Traffic Data
- Geometric Data
- Traffic Control Data
- Vehicle Characteristics
- Driver Characteristics

6.2.1. ENTERING TRAFFIC DATA

Flow Rates

The program logic creates an entering traffic stream in response to a user specified flow rates for both directions.

Platooning

The percent
for both directi

Vehicle Mix

The model
recreational ve
requires the fra
directions of f
of trucks, one t
both locations.

6.2.2. GEOMETRIC

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Horizontal curve

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Platooning

The percentage of the entering traffic in platoons are required for both directions.

Vehicle Mix

The model accepts four types of trucks/bus, four types of recreational vehicles (RV's) and five types of cars/pickup. It requires the fraction of each type of vehicle in the mix for both directions of flow. The traffic mix was classified into three types of trucks, one type of bus, and two types of car/pickup trucks for both locations.

6.2.2. GEOMETRIC DATA

Grades

The position coordinate and the percent grade values are required at the beginning and at the end of each grade region. The grade data are required only for direction No.1. Program logic supplies the data for direction No.2. Positive grades represent an upgrade and negative grades represent a downgrade.

Horizontal curves

The position coordinate where the curve begins for traffic in direction No.1 is required. Radius of the curve, superelevation and degree of the curve are also required. Program logic considers lane width, shoulder width and pavement quality indirectly through distribution of

drive.

Passing Sight Dis

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6.2.3. TRAFFIC CO

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distribution of the desired speed at which drivers are willing to drive.

Passing Sight Distance

The position coordinate and passing sight distance values are required at the beginning and at the end of each sight distance region, expressed in direction No.1 coordinates. Sight distance data needs to be entered only for the region where the sight distance differs from the nominal value, which was taken as 2,000 ft. It takes the minimum sight distance value whenever the sight distance is less than the nominal value. This minimum value was taken as 800 ft.

Passing lane

The position coordinate of the beginning of the passing lane is required in the appropriate direction of travel.

6.2.3. TRAFFIC CONTROL DATA

Passing Zones and No-Passing Zones

The position coordinate of the beginning of these zones is required in the appropriate direction of travel. The codes used to identify passing zones and no-passing zones were taken as 1 and -1 respectively. These values were noted from the photolog films of the roads. Program logic considers speed limit indirectly through the user specified distribution of desired speed.

6.2.4. VEHICLE CH

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6.2.4. VEHICLE CHARACTERISTICS DATA

Acceleration and Speed Capabilities

All vehicle types for which a fraction of the flow is specified for either direction of travel must be defined in terms of performance capabilities. The model takes the following factors as performance capabilities of trucks and bus.

Weight/Net Horse Power Ratio(lb/NHP)

The value of this factor was taken as 266(lb/NHP) for low performance trucks, 196(lb/NHP) for medium performance trucks, 128(lb/NHP) for high performance trucks and 72(lb/NHP) for a bus.

Weight/Projected Frontal Area

The value of this factor was taken as 620(lb/ft^2) for low performance trucks, 420(lb/ft^2) for medium performance trucks, 284(lb/ft^2) for high performance trucks and 158(lb/ft^2) for a bus. The length of trucks and buses was taken as 65 ft and 30 ft respectively.

Factor Correcting Horsepower to Local Elevation

The value of the factor correcting horse power to local elevation for all types of trucks and the bus was taken as 1.0 (the default value from the manual).

Factor Correcting

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6.2.5. DRIVER CHA

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Factor Correcting Aerodynamic Drag to Local Elevation

The value of this factor was taken as 0.957 for all types of trucks and the bus (the default value from the manual).

The performance capabilities of cars were considered in terms of the following factors.

Maximum Acceleration Using Maximum Available Horsepower

The value of this factor was taken as 10.43 ft/sec^{2}for cars and 11.2 ft/sec^{2}for pickups.

Limitations on Sustained Use of Maximum Horse Power

This factor is to be used on maximum grade to account for horse power restraint. This value was taken as 0.90 for this study. The value of the factor to be used on maximum acceleration was taken as 0.81 for this study.

6.2.5. DRIVER CHARACTERISTICS AND PREFERENCES

Desired Speed

The mean desired speed and standard deviation of desired speed are required in the model. This speed distribution gives the speed at which drivers are willing to drive at given roadway conditions and indirectly represents the driver characteristics.

Different car-following models were developed to explain how driver behaves in a traffic stream and most of them took the form:

$$\text{Response} = \text{function (sensitivity, stimuli)}$$

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The response was always represented by acceleration (or deceleration) of the following vehicle, while stimuli was always represented by the relative velocity of the lead and following vehicle. The difference in the models was represented by the sensitivity factor. The first model assumed that the sensitivity term was constant and the model formulation is shown in the following equation:

$$\ddot{X}_{n+1}(t+\Delta t) = \alpha\,[\dot{X}_n(t) - \dot{X}_{n+1}(t)]$$

where: Δt = reaction time

α = sensitivity parameter

The stimuli term could be positive, negative or zero, which could cause the response to be an acceleration, deceleration or constant speed. Improved modelling resulted when the sensitivity term included distance headway and the speed of the following vehicle. The concept was that as the vehicles get closer and closer together, the sensitivity term becomes larger and larger, and as the speed of the traffic stream increases, the driver of the following vehicle would be more sensitive to the relative velocity between the lead and following vehicle.

The simulation model used for this study takes 10 types of drivers defined in terms of risk taking characteristics and car following sensitivity factors. The values were taken directly from NCHRP Project Report 3-28 A(28). These suggested values are 0.43, 0.51, 0.57, 0.65, 0.76, 0.91, 1.13, 1.34, 1.58 and 2.12 and are defined as stochastic driver type factors. The car-following sensitivity factor was taken as 0.8.

6.3. DATA CODIN

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6.3. DATA CODING

To run the model, coding is done according to the specifications given in the manual [31]. The first 10 data cards must be coded in the order presented in the manual. In the first card the length of test period and length of review interval were coded as 60 minutes and 1 sec respectively for all the runs. The total length of simulated roadway was coded as 27456 ft in card 2. Traffic volume and percentage of entering traffic in platoon were coded for each hour for both the directions of flow in card 3. Fraction of vehicle mix was coded according to the classification given in the manual for direction 1 and direction 2 in cards 4 and 5 respectively. Mean desired speed (ft/sec) and standard deviation (ft/sec) were coded in card 6. The upper bound speed was coded as 150 (ft/sec) for each type of vehicle in card 7 and 8 for direction 1 and direction 2 respectively. All values coded in card 9 were taken as default values since fuel consumption is not being considered in this study. The values of the car following sensitivity factor and the factor for driver types were coded as previously discussed.

The remaining cards can be coded in any order, except that the station location (SL) cards must appear last. The first optional card requires a speed for random number generation used to select entering headways and vehicle types in both directions. These values were taken as the default values given in the manual.

Each GD card presents the vertical alignment for a specified length of roadway, referred to as grade region. Position coordinates

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of the beginning and end of each region and percent grade values for each region were coded as collected in the field and are given in Tables 7 and 8. Each CV card describes one horizontal curve on the simulated roadway. Position coordinate of beginning of each curve, radius of the curve, superelevation and degree of curve were coded as collected in the field and are also given in Tables 7 and 8.

Each VC card defines the characteristics of each type of vehicle. The values of the performance parameter and size of each type of vehicle were coded as discussed in the previous chapter.

Each PS card defines the beginning of a passing zone, a no-passing zone or an added passing or climbing lane on the simulated highway. The values of the position coordinate of the beginning of each type of zone were coded as shown in Figures 5 and 6, for Lake and Clare County sites respectively. Each ST card defines passing sight distance for one sight distance region in a particular direction of travel. Position coordinate of the beginning and end of sight distance regions and passing sight distance at beginning and end of the sight distance region for each no-passing zone were coded for each direction of flow.

Station location (SL) cards define the locations on the simulated roadway at which spot speed and platooning data are collected during the simulation run. The data obtained are equivalent to what is obtained in the field by using machines for volume, speed, and platooning. These points were coded as 0.5 mile upstream of passing lane and 0.5 and 1.5 miles down stream of passing lane. At the same locations field data were collected for speed, volume and platooning for both the sites.

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6.4. MODEL CALI

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Other input parameters were taken as mentioned in the previous section. Input data coding for calibration of the model for two locations, one in Lake County and the other in Clare County are given in Appendix B.

6.4. MODEL CALIBRATION

Subsequent runs were made for different distributions of desired speed. Average desired speed were taken as 88 ft/sec(60 mph), 92.4 ft/sec(63 mph) and 95.4 ft/sec(65 mph) and the standard deviation were taken as 8.58 ft/sec(5.9 mph), 10.98 ft/sec(7.5 mph) and 12.0 ft/sec(8.2 mph) for different runs for the Lake County roadway and traffic conditions. The simulation and field values of percentage vehicles in platoon and percentage vehicles with speed greater than 55 mph are given in Tables 11 and 12 respectively, for each average desired speed and a standard deviation of 8.58 ft/sec.

Subsequent runs were made using different values of the car following sensitivity factor with a desired speed of 92.4 ft/sec(63 mph) and standard deviation 8.58 ft/sec(5.9 mph) for Lake County. A value of the sensitivity factor of 0.5 brings the simulation values closest to the field values. The values of percentage vehicles in platoon and percentage vehicles with speed greater than 55 mph are given in Tables 11 and 12 respectively.

For the same values of desired speed and car following sensitivity factor, different runs were made for each hourly volume for Clare County roadway conditions. The coding was done in the same way as was done for the Lake County site. The simulation and field

TABLE 11

PERCENTAGE PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES
(SITE-LAKE COUNTY)

PERCENTAGE VEHICLES IN PLATOON (HEADWAY < 5 SECONDS)

(FIELD VALUES)

DIR-1 AT DIR-2 AT

AVERAGE**

TABLE 11

PERCENTAGE PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES (SITE-LAKE COUNTY)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED		PERCENTAGE VEHICLES IN PLATOON (HEADWAY < 5 SECONDS)													
			(SIMULATION VALUES)								(FIELD VALUES)					
			AT BEG. OF ROAD			AT END OF ROAD			AVERAGE**		DIR-1 AT LOCATIONS*		DIR-2 AT LOCATIONS*		AVERAGE**	
	FT/SEC	MPH	DIR 1	DIR 2	AVG. BOTH	DIR 1	DIR 2	AVG. BOTH	DIR 1	DIR 2	1	2	1	2	DIR 1	DIR 2
473/270	88.0	60	73	57	67	73	60	68	73	59	65	63	49	43	64	46
	92.4	63	68	52	62	65	55	61	67	53	65	63	49	43	64	46
	95.3	65	74	57	68	74	62	70	74	59	65	63	49	43	64	46
423/196	88.0	60	62	44	60	70	48	62	66	46	62	60	36	32	61	34
	92.4	63	62	39	54	64	35	55	63	37	62	60	36	32	61	34
	95.3	65	68	43	60	71	45	63	69	44	62	60	36	32	61	34
388/268	88.0	60	73	62	62	70	62	67	71	62	60	61	52	48	61	50
	92.4	63	70	58	65	62	57	60	66	59	60	61	52	48	61	50
	95.3	65	73	62	68	69	64	67	71	63	60	61	52	48	61	50
380/180	88.0	60	63	44	57	69	50	62	66	47	55	56	37	39	56	38
	92.4	63	58	40	52	56	39	51	57	39	55	56	37	39	56	38
	95.3	65	64	44	57	67	47	61	65	45	55	56	37	39	56	38
372/191	88.0	60	64	46	61	62	52	60	63	49	59	61	41	38	60	40
	92.4	63	62	44	56	57	48	54	59	46	59	61	41	38	60	40
	95.3	65	67	48	61	69	54	64	67	51	59	61	41	38	60	40
322/178	88.0	60	66	47	59	64	52	59	65	49	52	56	40	38	54	39
	92.4	63	60	41	53	57	47	53	58	44	52	56	40	38	54	39
	95.3	65	65	46	61	65	53	61	65	49	52	56	40	38	54	39

* Location 1 - 0.5 Miles Upstream of Passing Lane
* Location 2 - 0.5 Miles Downstream of Passing Lane
* Location 3 - 1.5 Miles Downstream of Passing Lane
** Average - Average of Values in the Beginning and End of the Road.

TABLE 12

PERCENTAGE VEHICLES SPEED >55 MPH AT DIFFERENT DESIRED SPEED AND VOLUMES
(SITE-LAKE COUNTY)

VOLUME	DESIRED	PERCENTAGE VEHICLES WITH SPEED >55 MPH

TABLE 12

PERCENTAGE VEHICLES SPEED >55 MPH AT DIFFERENT DESIRED SPEED AND VOLUMES (SITE-LAKE COUNTY)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED		PERCENTAGE VEHICLES WITH SPEED >55 MPH									
			SIMULATION VALUES			FIELD VALUES						
						DIRECTION-1 AT LOCATIONS*			DIRECTION-2 AT LOCATIONS*			
	FT/SEC	MPH	DIR 1	DIR 2	AVERAGE BOTH	1	3	AVG.	1	2	3	AVG.
473/270	88.0	60	74	51	65	61	73	67	63	83	73	73
	92.4	63	73	79	75	61	73	67	63	83	73	73
	95.3	65	65	78	70	61	73	67	63	83	73	73
423/196	88.0	60	66	42	58	62	69	66	58	78	66	67
	92.4	63	73	86	78	62	69	66	58	78	66	67
	95.3	65	69	84	73	62	69	66	58	78	66	67
388/268	88.0	60	70	62	66	66	80	73	60	93	78	77
	92.4	63	76	70	73	66	80	73	60	93	78	77
	95.3	65	71	69	70	66	80	73	60	93	78	77
380/180	88.0	60	60	44	55	58	71	64	57	82	63	67
	92.4	63	79	83	80	58	71	64	57	82	63	67
	95.3	65	76	85	79	58	71	64	57	82	63	67
372/191	88.0	60	59	45	54	63	80	71	59	80	64	68
	92.4	63	80	86	82	63	80	71	59	80	64	68
	95.3	65	75	88	79	63	80	71	59	80	64	68
322/178	88.0	60	64	44	58	58	75	66	59	82	70	70
	92.4	63	79	82	79	58	75	66	59	82	70	70
	95.3	65	75	80	74	58	75	66	59	82	70	70

* Location 1- 0.5 Miles Upstream of Passing Lane
* Location 2- 0.5 Miles Downstream of Passing Lane
* Location 3- 1.5 Miles Downstream of Passing Lane

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values for percentage vehicles in platoon and percentage vehicles with speed greater than 55 mph at different locations are given in Tables 13 and 14 respectively.

The vertical alignment of the road for both the sites are almost flat as no grade is greater than 2.5 percent and the segment of the vertical curve is not greater than 1000 ft. According to the Highway Capacity Manual (HCM)[29], the performance of any type of truck will not be affected at this mild vertical curve of small length as shown in Figure 8. Thus, the precise vehicle stratifications are not considered essential for the use of the model under these conditions.

To calibrate the model the percentage vehicles in platoon was taken as the main variable to compare the field values to the simulation values. The field values of percentage vehicles in platoon were plotted against the values obtained by the simulation for various volumes for both the sites as shown in Figure 9. The field values are scattered closely to the simulation values along the center line, which indicates that field values are in good agreement with simulation values and the model is accurately simulating the Michigan roadway environment for the desired speed of 92.4 ft/sec (63.0 mph) with standard deviation of 8.58 ft/sec and a car following sensitivity factor of 0.5.

The calibrated model with a desired speed of 92.4 ft/sec, a standard deviation of 8.58 ft/sec and a car following sensitivity factor of 0.5 were used to develop the warrants for passing lanes with different roadway and traffic conditions.

TABLE 13

PERCENTAGE PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT VOLUMES
(SITE-CLARE COUNTY)

TABLE 13

PERCENTAGE PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT VOLUMES (SITE-CLARE COUNTY)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED		PERCENTAGE VEHICLES IN PLATOON (HEADWAY <5 SECONDS)																
			(SIMULATION VALUES)								(FIELD VALUES)								
	FT/SEC	MPH	AT BEG. OF ROAD			AT END OF ROAD			AVERAGE		DIR1 AT LOCATIONS*			DIR2 AT LOCATIONS*			AVERAGE	
			DIR 1	DIR 2	AVG. BOTH	DIR 1	DIR 2	AVG. BOTH	DIR 1	DIR 2	1	2	3	1	2	3	DIR 1	DIR 2
415/226	92.4	63	61	32	51	63	45	56	62	38	59	54	53	32	32	35	55	33
458/228	92.4	63	68	39	58	68	40	58	68	39	64	62	60	34	33	35	62	34
461/247	92.4	63	69	39	58	68	43	60	68	41	65	56	57	38	34	38	59	37
447/278	92.4	63	68	44	59	67	52	61	67	48	65	63	61	41	35	37	63	38
469/337	92.4	63	62	50	57	68	55	62	65	52	62	61	59	49	44	39	61	44
432/390	92.4	63	69	51	60	68	62	65	68	56	63	57	56	49	43	47	59	46

* Location 1- 0.5 Miles Upstream of Passing Lane
* Location 2- 0.5 Miles Downstream of Passing Lane
* Location 3- 1.5 Miles Downstream of Passing Lane

TABLE 14

PERCENTAGE VEHICLES >55 MPH AT DIFFERENT DESIRED SPEED AND VOLUMES (SITE-CLARE COUNTY)

VOLUME	DESIRED	PERCENTAGE VEHICLES WITH SPEED >55 MPH

TABLE 14

PERCENTAGE VEHICLES >55 MPH AT DIFFERENT DESIRED SPEED AND VOLUMES (SITE-CLARE COUNTY)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED		PERCENTAGE VEHICLES WITH SPEED >55 MPH								
			SIMULATION VALUES			FIELD VALUES					
						DIR1 AT LOCATIONS*			DIR2 AT LOCATIONS*		
	FT/SEC	MPH	DIR 1	DIR 2	AVERAGE BOTH	1	3	AVG.	1	3	AVG.
415/226	92.4	63	75	86	79	80	88	84	78	83	80
458/228	92.4	63	69	86	74	87	94	90	66	85	75
461/247	92.4	63	67	84	73	81	94	87	83	90	86
447/278	92.4	63	71	83	75	82	82	82	74	90	82
469/337	92.4	63	70	77	73	86	94	90	83	88	85
432/390	92.4	63	68	75	71	86	96	91	82	93	87

* Location 1- 0.5 Miles Upstream of Passing Lane
* Location 2- 0.5 Miles Downstream of Passing Lane
* Location 3- 1.5 Miles Downstream of Passing Lane

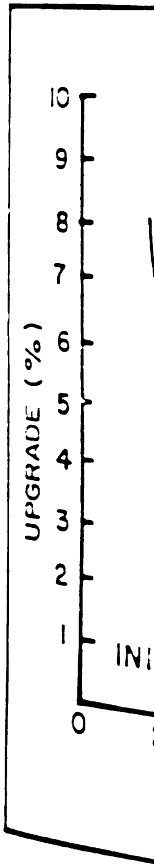


Figure 8. Spee

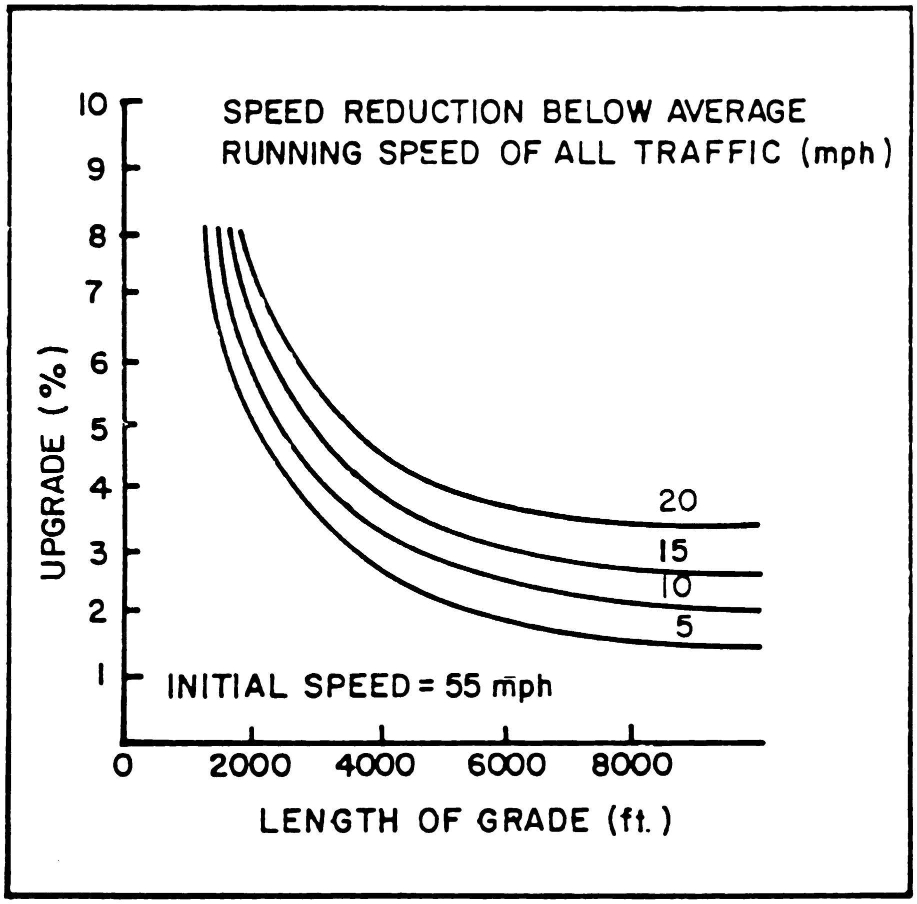
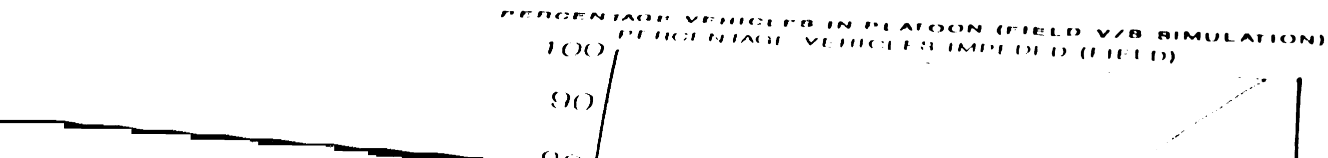


Figure 8. Speed Reduction Curve for a 200-lb/hp Truck (HCM)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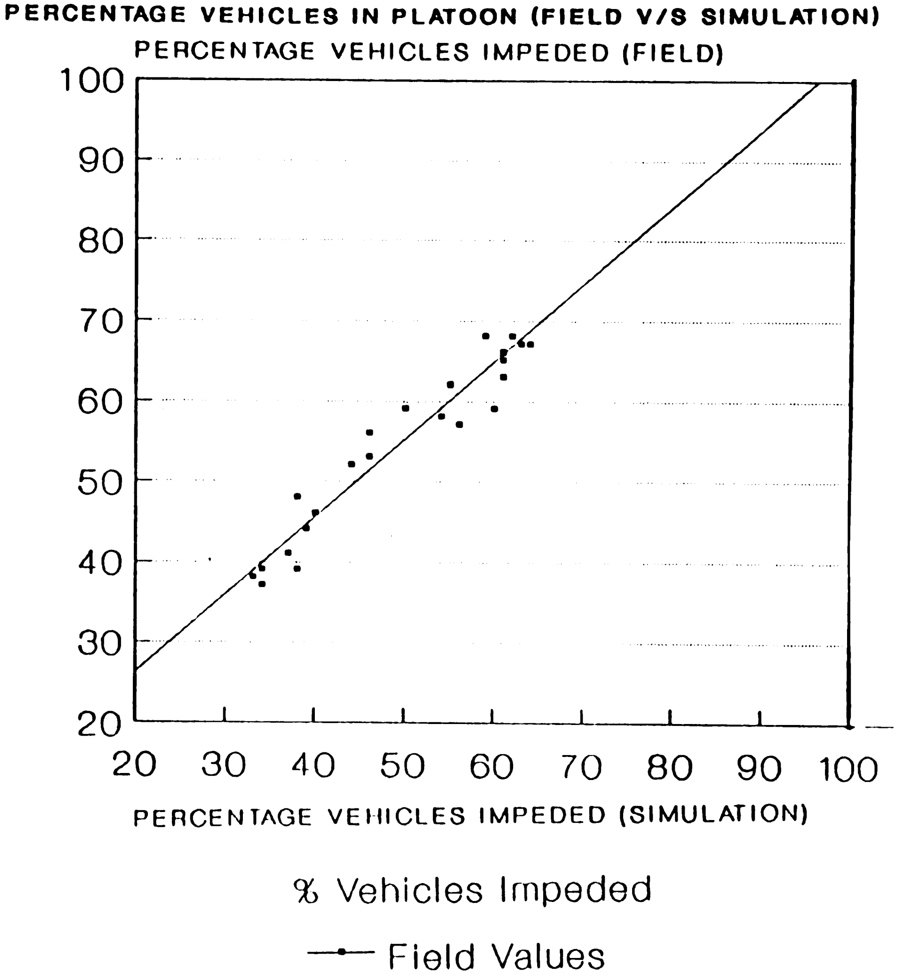

FIGURE 9. PERCENTAGE VEHICLES IMPEDED FOR SPEED 92.4 FT/SEC
(SIMULATION V/S FIELD VALUES)

6.5. SENSITIVIT

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6.5. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to determine the effect of the directional distribution of traffic volume and the percentage of light trucks in the traffic mix on average delay.

The analysis included three values of the directional distribution of traffic volumes i.e. 70/30, 60/40 and 50/50. Simulation runs were made for a simulated roadway length 8 miles with one passing lane in direction one only for different traffic volumes and directional distributions. The value of average delay for the entire length of simulated roadway for both directions were obtained. These values were plotted for different volumes and directional splits in Figure 10. Figure 10 shows that there is no significant differences in average delay for different directional splits, although a 50/50 split gives slightly higher values of delay for low as well as for higher volumes. The directional split of 50/50 was taken for further study.

The field data shows that the percentage of light trucks are quite low on the selected sites in comparison to the average percentage of light trucks on rural highways in Michigan. The sensitivity analysis was conducted to determine if there is any significant difference in average delay due to a variation in light trucks in the traffic mix. Three values of light trucks were taken for the study. In the first set the existing percentage of light trucks were considered. In the second set the percent of light trucks was increased to 6 percent, and in the third set to 11 percent. Simulation runs were made for the Lake county site

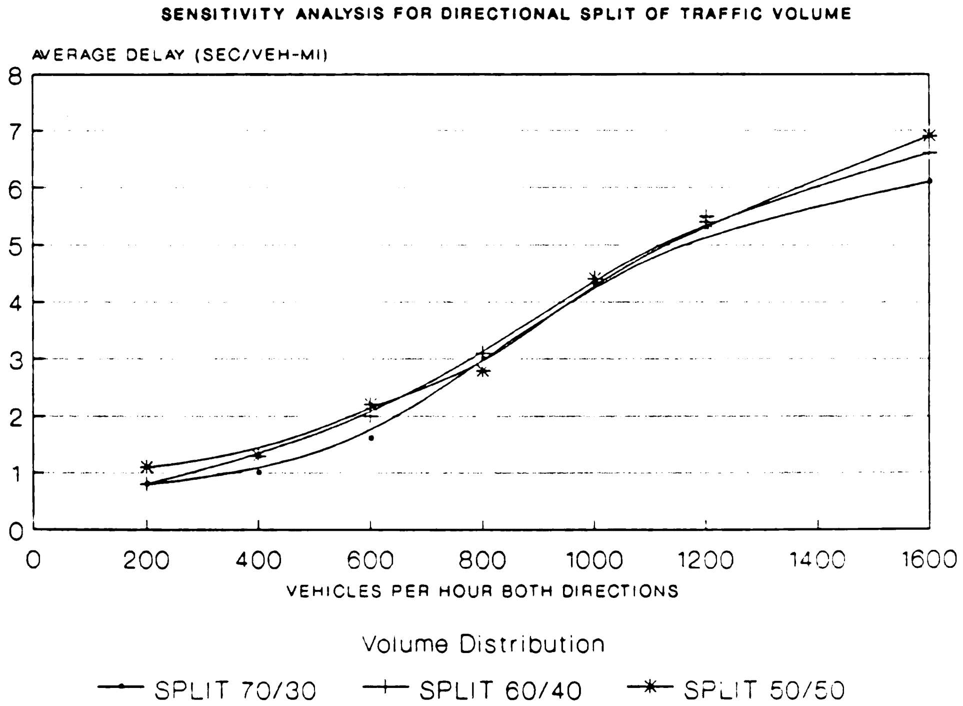

FIGURE 10. EFFECT OF DIRECTIONAL TRAFFIC SPLIT ON DELAY (WITH ONE PASSING LANE IN DIRECTION ONE)

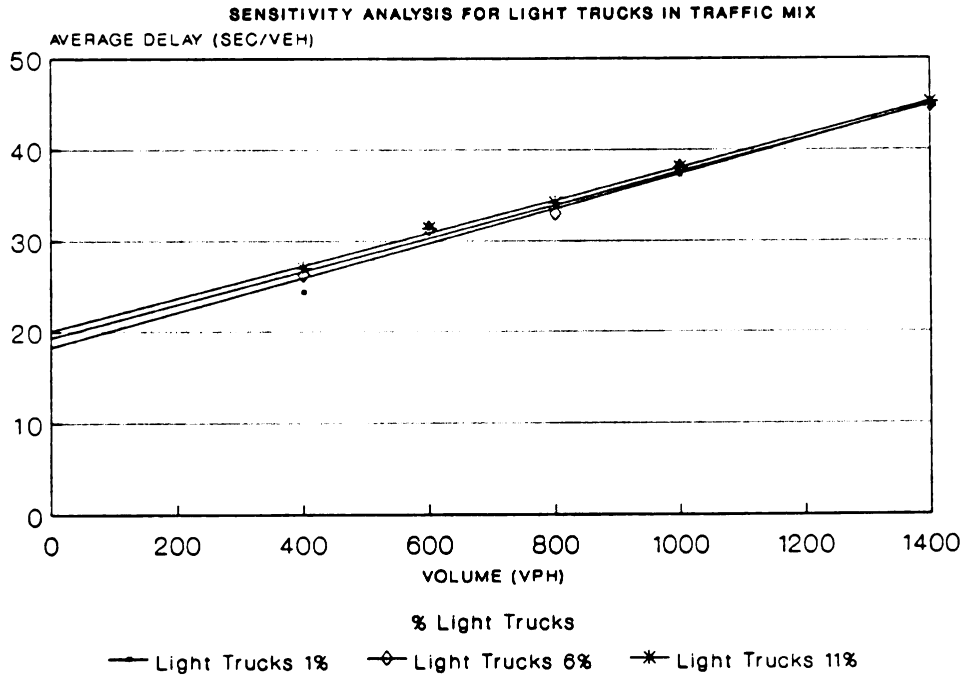

FIGURE 11. SENSITIVITY ANALYSIS FOR LIGHT TRUCKS

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geometric conditions for 1, 6 and 11 percent light trucks and for different traffic volumes. The values of average delay for the entire length of simulated roadway length are plotted in Figure 11. Figure 11 shows that there is no significant difference in delay for a different percentage of light trucks in the traffic mix.

7.0 SIMULATI

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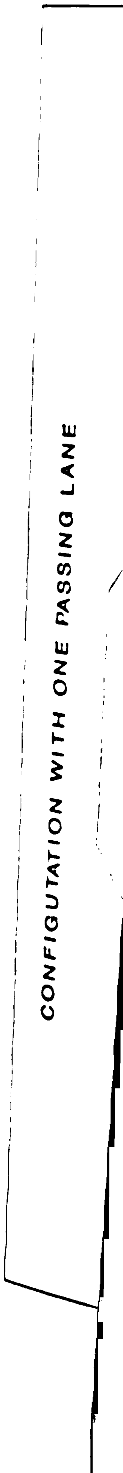
CHAPTER 7

7.0 SIMULATION RUNS FOR THE STUDY

7.1. STUDY DESIGN

The input data required, data coding and calibration of the simulation model has been discussed in detail in the previous chapter. This calibrated model was used to study the operational benefit gained by providing passing lanes on two-lane highways. The main output values given by the model are: space mean speed, travel times and delays, overall speed histograms and percentage of vehicles in platoon. According to the Highway Capacity Manual (HCM) the main parameters which define the level of service on two-lane highways, are delay and percentage of vehicles in platoon. These two parameters were selected to study the operational benefits due to passing lanes.

For this study two configurations of passing lanes were considered. In the first case a single passing lane was provided in the road and in the second case two passing lanes of equal length were provided at equal distances along the simulated road length as shown in Figure 12. Previous studies show that it may not be economical to provide passing lanes that are either too short or too long. The length of the passing lane used was taken as 1.0 mile for both cases.


CONFIGUTATION WITH ONE PASSING LANE

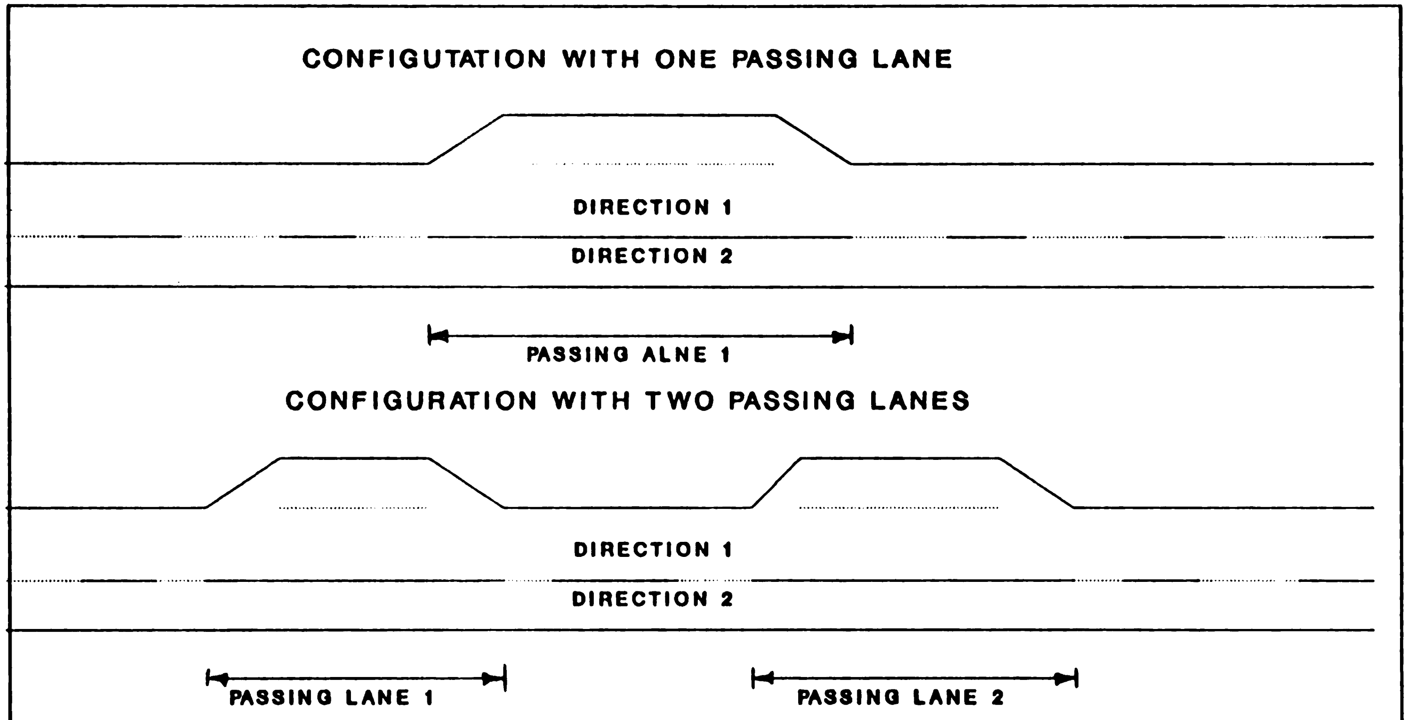


FIGURE 12. PASSING LANE CONFIGURATION WITHIN SIMULATED ROAD

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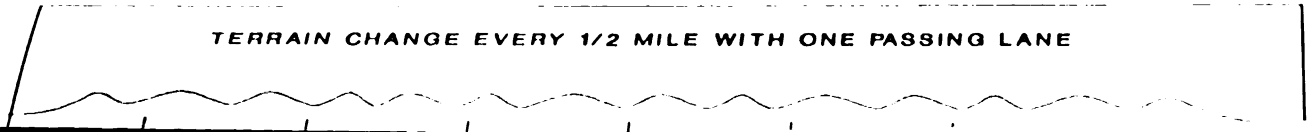
For these two cases, different geometric conditions of the roadway were considered. Two types of alignments were considered, one case included a grade region change every mile, and the second case included a grade change every 1/2 mile. Both geometric conditions with one passing lane and with two passing lanes are shown in Figures 13 and 14 respectively. Three grades were considered for each of these region changes. In the first set of runs, the grade of each region was taken as 6 percent to represent hilly terrain. The grade was then changed to 4 percent to represent moderately hilly or rolling terrain, and finally to 2 percent to represent flat terrain.

No-passing zones were provided near the summit of the vertical curves. Three values of percent of no-passing zones were taken for this study. These values are 75, 50 and 25 percent of the total length of the simulated roadway.

To determine the effectiveness of passing lanes in reducing delay a series of simulation runs was conducted for different traffic and roadway conditions. One set of runs was made with one passing lane and a second set of runs was made with two passing lanes. Both sets of runs were made over the same range of volumes, truck percentages and geometric conditions. The directional split was held constant at 50 percent each way. The values of average delay and percentage vehicles in platoon were noted for different locations and specified sections of the roadway. The operational benefits in terms of reduced delay for each case were calculated for use in a benefit-cost analysis.


TERRAIN CHANGE EVERY 1/2 MILE WITH ONE PASSING LANE

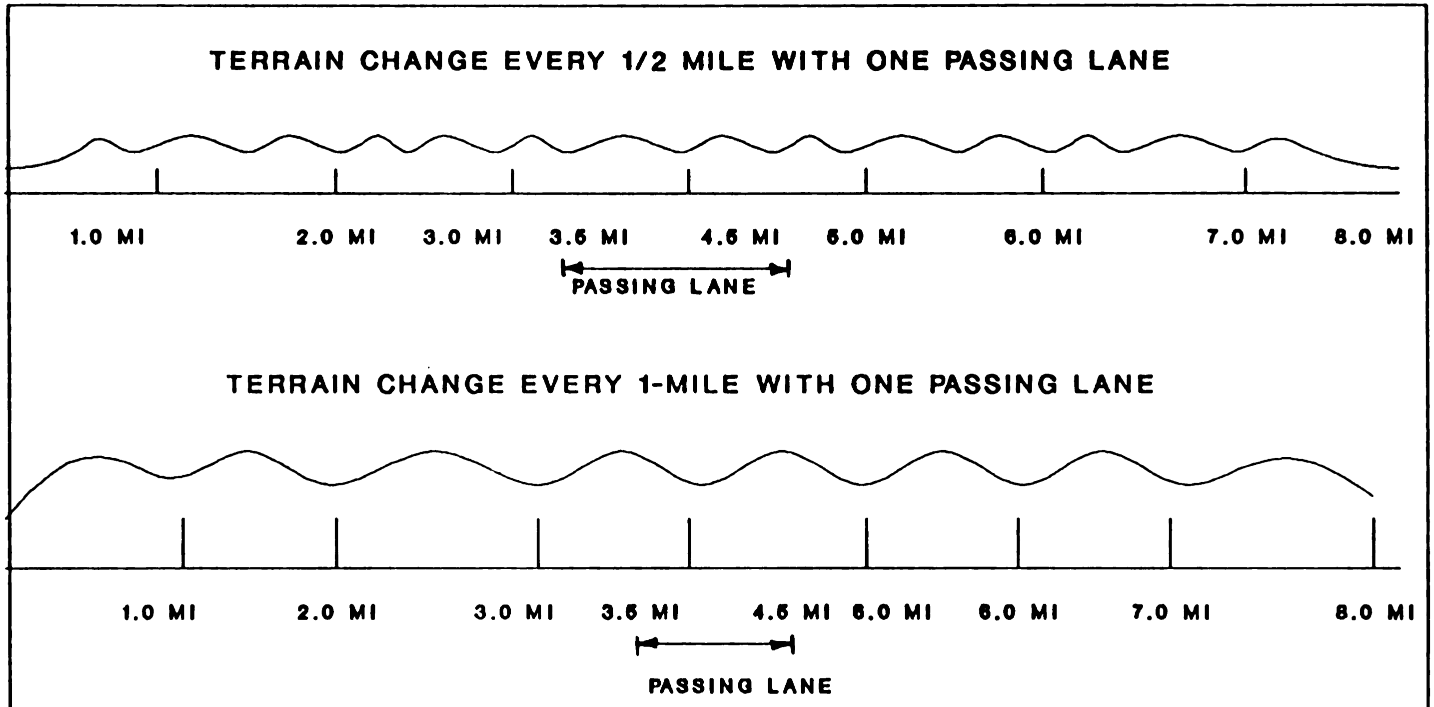
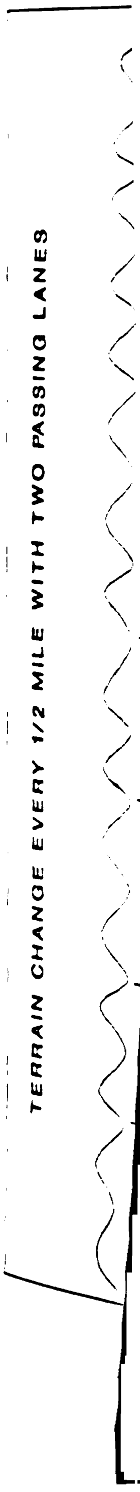
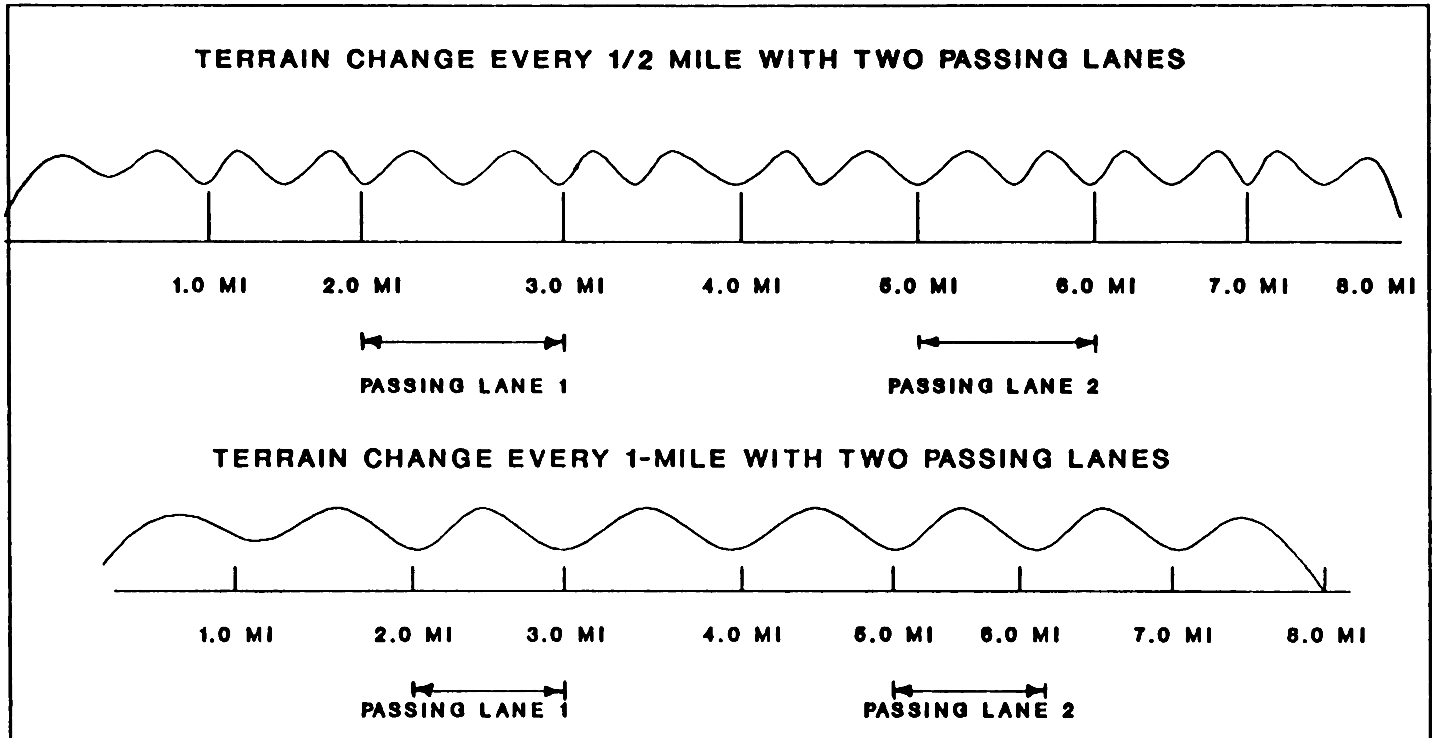


FIGURE 13. TERRAIN CHANGE PROFILE WITH ONE PASSING LANE


TERRAIN CHANGE EVERY 1/2 MILE WITH TWO PASSING LANES



TERRAIN CHANGE EVERY 1/2 MILE WITH TWO PASSING LANES

TERRAIN CHANGE EVERY 1-MILE WITH TWO PASSING LANES

FIGURE 14. TERRAIN CHANGE PROFILE WITH TWO PASSING LANES

7.2. DATA CODING

7.2.1. DATA REQUIRED

The following data were taken for traffic volume, traffic mix and highway geometry for different simulation runs.

Traffic volumes of 1000, 1400, 1800 and 2000 vph for both directions were taken for different runs. Directional split was taken as 50/50.

The truck percentage was taken as 5, 10 and 20. The fraction of each type of truck was taken approximately the same as that obtained in the field. Vehicle performance parameters consistent with the calibration data were used.

Different grades and change of grade regions along the roadway were considered for different simulation runs as discussed. No-passing zones were provided for each vertical curve for both directions of flow. No-passing zones were provided on 25 percent, 50 percent and 75 percent of the entire length of the simulated roadway on successive runs.

7.2.2. DATA CODING

The coding details have already been discussed in a previous chapter. The first 10 cards must be coded in the order presented in the manual [31]. On the first card, the length of test period and length of review period were taken as 30 minutes and 1 sec respectively for each run. For this study the length of road was taken as 8.0 miles (42240 ft). The length of simulated roadway was coded as 44240 ft, which includes 1000 ft warmup length in each direction of flow. Traffic volume and percentage of entering traffic in a platoon were coded for both directions of flow in card 3. The vehicle mix was coded for each percentage of truck in the traffic stream for both directions in cards 4 and 5. Mean desired speed of 92.4 ft/sec and standard deviation of 8.58ft/sec were coded in card 6. Cards 7, 8 and 9 were coded as discussed before. The values of the factor for driver types were coded as discussed before and the value of the car following sensitivity factor was taken as 0.5 for each run.

In VC cards the characteristics of each type of vehicle were used as discussed in Chapter 5. In the GD card, the position coordinate of the beginning and end of each region were coded. Coding was done for two different cases of terrain change and the grades were taken as 6, 4 and 2 percent for each region. These values were coded separately for both cases, one with one passing lane and the other with two passing lanes. The coding for region changes every mile and every 1/2 mile are given in Appendix B for the roadway having one passing lane and a 4 percent grade. The coding for region changes every 1 mile and every 1/2 mile are also given in Appendix B for a roadway having two passing lanes and a 4 percent grade.

The values of the position coordinate of the beginning of each no passing zone were coded in each PS card. The position coordinate of the beginning and end of each sight distance region were coded in each ST card. These values are also given in Appendix B for road conditions having 50 percent no-passing zones.

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Coding was done differently for each configuration of passing lanes in SL cards. For a single passing lane, the upstream section was taken from 0.0 to 3.5 miles, the passing lane was taken from 3.5 to 4.5 miles and the other three sections were taken as 4.5 to 5.5 miles, 5.5 to 6.5 miles and 6.5 to 8.0 miles down stream of the passing lane. These values are given in Appendix B. For two passing lanes the upstream section was taken from 0.0 to 2.0 miles, the first passing lane was taken from 2.0 to 3.0 miles and down stream sections were taken from 3.0 to 4.0 miles and 4.0 to 5.0 miles. The second passing lane was taken from 5.0 to 6.0 miles and down stream sections were taken from 6.0 to 7.0 miles and from 7.0 to 8.0 miles. These values are also given in Appendix B.

The coding for 6 and 2 percent grades and 25 and 75 percent no-passing zones was done in the same manner as given in Appendix B for 4 percent grade and 50 percent no-passing zones.

7.3. SIMULATION RUNS AND OUTPUT VALUES

The simulation runs were made for different traffic volumes and geometric conditions. The values of percentage vehicles in platoon and average delay at different specified sections of the simulated highway were noted. The percentage of vehicles in platoon at various locations for one passing lane configuration with 50 percent no-passing zones and a terrain change every 1 mile are given in Table 15 for a 4 percent grade. The percentage of vehicles in platoon for terrain changes every 1/2 mile and a 6 percent grade are given in Table 16. The percentage of vehicles in the platoon for a terrain change every 1 mile and a 2 percent grade are given in Table 17.

TABLE 15

PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES AND PERCENTAGE TRUCKS (WITH ONE-PL GRADE-4% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME	PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS								
(VPH)	DIRECTION-1						DIRECTION-2		
DIR. SPLIT 50/50	BEG. OF ROAD MP 0.0	0.2 MI UP PL MP 3.3	MIDDLE OF PL MP 4.0	1.0 MI DN PL MP 5.5	2.0 MI DN OF MP 6.5	3.0 MI DN OF MP 7.5	BEG. OF ROAD MP 0.0	MIDDLE OF RD MP 4.0	END OF RD MP 8.0
TRUCK-5%									
1000	25	65	10	43	55	61	25	67	76
1400	30	72	16	56	66	72	27	73	79
1800	29	73	17	62	73	77	28	77	83
2000	31	75	20	67	75	79	30	80	85
TRUCK-10%									
1000	24	63	15	46	55	61	24	69	75
1400	30	70	16	54	66	69	26	72	78
1800	28	69	17	61	70	74	27	78	80
2000	30	71	20	64	71	73	30	80	80
TRUCK-20%									
1000	22	56	15	39	52	59	24	64	70
1400	29	60	16	54	64	63	24	69	75
1800	29	65	19	60	69	67	28	70	75
2000	30	64	19	61	70	68	29	72	73

TABLE 16

PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES AND PERCENTAGE TRUCKS (WITH ONE-PL GRADE-6% TERRAIN CHANGE @ 1/2-MI NO-PASSING ZONE-50%)

VOLUME	PERCENTAGE VEHICLES IMPEDED AT DIFFERENT LOCATIONS								
(VPH)	DIRECTION-1						DIRECTION-2		
DIR. SPLIT 50/50	BEG. OF ROAD MP 0.0	0.2 MI UP PL MP 3.3	MIDDLE OF PL MP 4.0	1.0 MI DN PL MP 5.5	2.0 MI DN OF MP 6.5	3.0 MI DN OF MP 7.5	BEG. OF ROAD MP 0.0	MIDDLE OF RD MP 4.0	END OF RD MP 8.0
TRUCK-5%									
1000	25	67	22	45	58	59	25	68	75
1400	30	72	20	58	67	72	27	74	80
1800	29	74	25	64	73	78	27	79	82
2000	31	77	23	67	78	81	30	82	83
TRUCK-10%									
1000	23	64	17	46	58	62	24	68	73
1400	30	69	22	60	71	73	26	75	79
1800	28	71	19	65	71	74	27	79	80
2000	30	74	24	68	74	75	30	82	81
TRUCK-20%									
1000	22	59	13	45	53	55	24	70	70
1400	30	64	19	54	64	67	24	71	74
1800	29	67	22	62	71	69	28	74	73
2000	29	68	21	69	71	70	29	77	75

TABLE 17

PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES AND PERCENTAGE TRUCKS (WITH ONE-PL GRADE-2% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME	PERCENTAGE VEHICLES IMPEDED AT DIFFERENT LOCATIONS								
(VPH)	DIRECTION-1						DIRECTION-2		
DIR. SPLIT 50/50	BEG. OF ROAD MP 0.0	0.2 MI UP PL MP 3.3	MIDDLE OF PL MP 4.0	1.0 MI DN PL MP 5.5	2.0 MI DN OF MP 6.5	3.0 MI DN OF MP 7.5	BEG. OF ROAD MP 0.0	MIDDLE OF RD MP 4.0	END OF RD MP 8.0
TRUCK-5%									
1000	25	65	18	50	60	65	25	71	74
1400	31	73	9	58	68	65	27	67	79
1800	29	76	12	65	71	77	28	76	81
TRUCK-10%									
1000	24	61	10	44	58	61	24	61	77
1400	30	71	12	54	66	70	17	76	71
1800	28	74	9	62	73	76	27	76	80
TRUCK-20%									
1000	22	59	8	46	57	63	24	60	68
1400	30	64	7	59	67	72	24	69	76
1800	29	68	11	59	69	74	27	72	76

These values were plotted for different volumes and percent of trucks and are shown in Figures 15 and 16 for 6 and 4 percent grades respectively. Similarly, the percentage of vehicles in the platoon at various locations for the two-passing lanes configuration with 50 percent no-passing zones and a terrain change every 1 mile are given in Table 18 for a 6 percent grade. The percentage of vehicles in the platoon for terrain change every 1/2 mile and a 4 percent grade are given in Table 19. The percentage of vehicles in the platoon for a terrain change every 1 mile and a 2 percent grade are given in Table 20. These values were plotted for different volumes and percent of trucks and are shown in Figure 17 and 18 for 6 and 4 percent grades respectively.

The average delay for different specified sections of the simulated roadway were noted. The average delay for different specified sections of the roadway for one passing lane configuration with 50 percent no-passing zones and a terrain change every 1 mile are given in Table 21 for a 4 percent grade. The average delay for a terrain change at every 1/2 mile and a 6 percent grade are given in Table 22. The average delay for a terrain change every 1 mile and a 2 percent grade are given in Table 23. Similarly, the average delay for the two passing lanes configuration with 50 percent no-passing zones and a terrain change every 1 mile are given in Table 24 for a 6 percent grade. The average delay for a terrain change every 1/2 mile and a 4 percent grade are given in Table 25. The average delay for a terrain change at every 1 mile and a 2 percent grade are given in Table 26. These values are given for different traffic volumes and truck percentages. Similar values were obtained for 75 and 25 percent no-passing zones also.

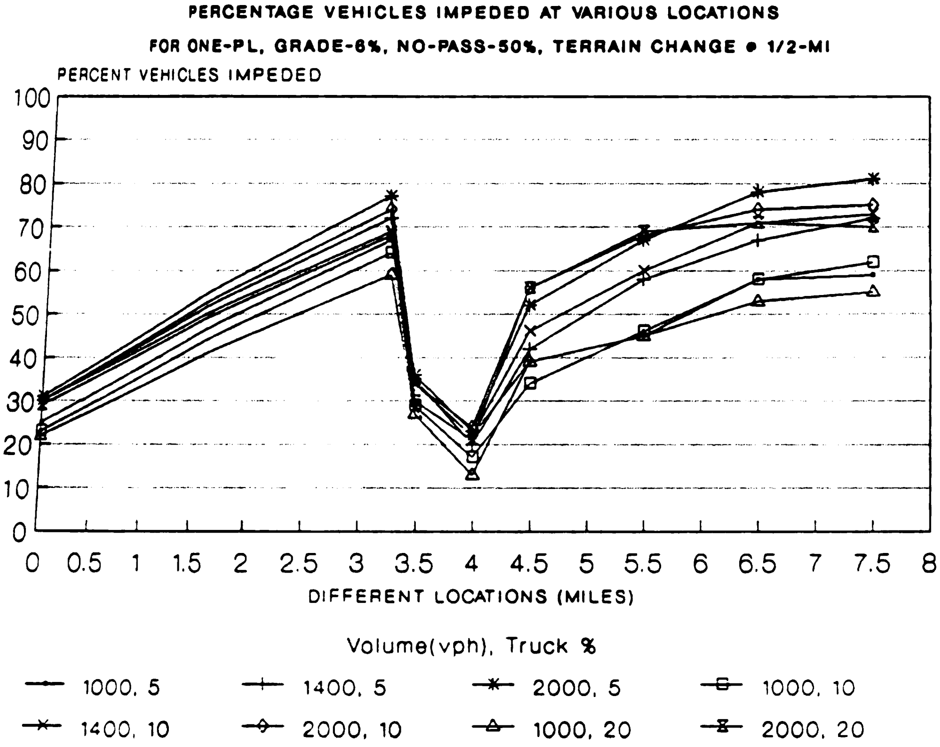


FIGURE 15. PERCENTAGE VEHICLES IMPEDED FOR 6% GRADE, TERRAIN CHANGE @ 1/2-MI WITH ONE PASSING LANE

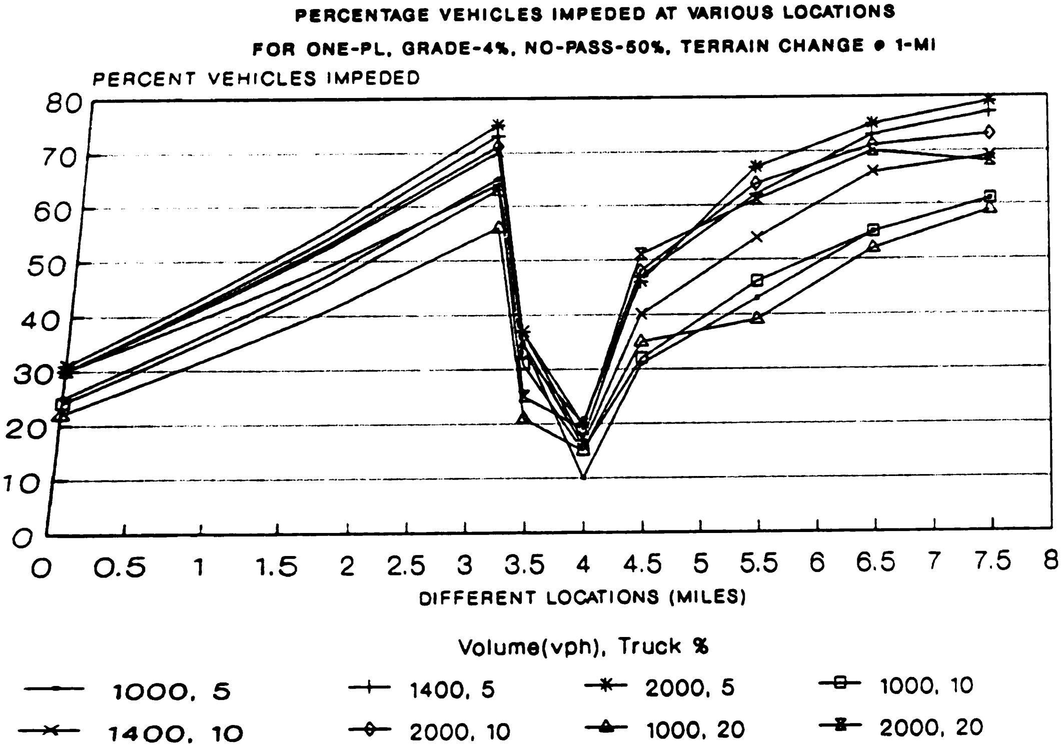


FIGURE 16. PERCENT VEHICLES IMPEDED FOR 4% GRADE, TERRAIN CHANGE @ 1-MI WITH ONE PASSING LANE

TABLE 18

PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUME AND PERCENTAGE TRUCKS (WITH TWO-PLS GRADE-6% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME (VPH)	PERCENTAGE VEHICLE IMPEDED AT VARIOUS LOCATIONS												
	DIRECTION-1										DIRECTION-2		
DIR. SPLIT 50/50	BEG OF RD MP 0.0	0.5 MI UP PL1 MP 1.5	MIDDLE OF PL1 MP 2.5	0.5 MI DN PL1 MP 3.5	1.0 MI DN PL1 MP 4.0	1.5 MI DN PL1 MP 4.5	MIDDLE OF PL2 MP 5.5	0.5 MI DN PL2 MP 6.5	1.0 MI DN PL2 MP 7.0	2.0 MI DN PL2 MP 8.0	BEG. OF ROAD	MID. OF ROAD	END OF ROAD
TRUCK-5%													
1000	26	56	8	27	44	44	8	42	51	58	26	72	78
1400	30	63	11	50	56	66	14	50	59	69	28	73	79
1800	30	68	12	54	62	68	18	68	69	72	28	77	79
2000	32	70	12	60	66	74	15	68	74	73	30	80	81
TRUCK-10%													
1000	26	63	13	44	49	56	14	40	48	54	26	69	74
1400	31	68	14	51	59	67	11	60	63	67	27	75	78
1800	29	71	13	58	65	72	19	69	70	75	28	76	78
2000	31	75	14	66	67	73	17	74	69	73	31	78	77
TRUCK-20%													
1000	23	64	10	48	48	59	13	44	46	54	27	68	72
1400	31	65	12	61	58	61	12	60	59	58	27	70	72
1800	30	70	21	68	64	72	15	67	65	63	29	70	71
2000	30	70	18	68	65	73	18	71	64	65	31	72	68

TABLE 19

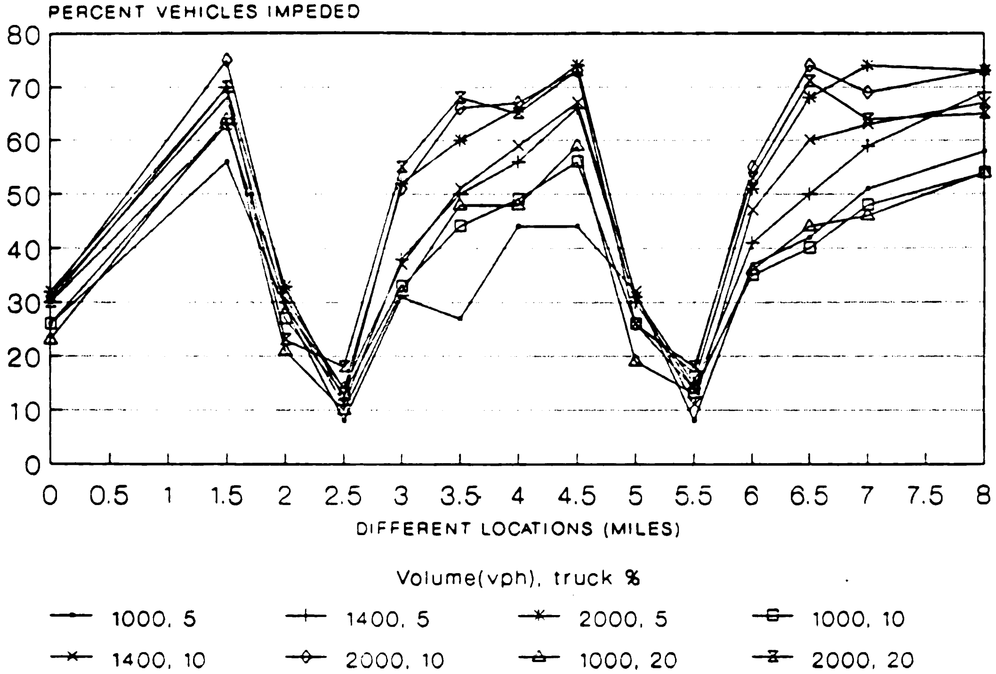
PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES AND PERCENTAGE TRUCKS(WITH TWO-PLS GRADE-4% TERRAIN CHANGE @ 1/2-MI NO-PASSING ZONE-50%)

VOLUME				PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS									
(VPH)						DIRECTION-1					DIRECTION-2		
DIR. SPLIT 50/50	BEG. OF ROAD MP 0.0	0.5 MI UP PL1 MP 1.5	MIDDLE OF PL1 MP 2.5	0.5 MI DN PL1 MP 3.5	1.0 MI DN PL1 MP 4.0	1.5 MI DN PL1 MP 4.5	MIDDLE OF PL2 MP 5.5	0.5 MI DN PL2 MP 6.5	1.0 MI DN PL2 MP 7.0	2.0 MI DN PL2 MP 8.0	BEG. OF ROAD	MID. OF ROAD	END OF ROAD
TRUCK-5%													
1000	25	53	13	43	51	58	19	43	49	57	25	71	77
1400	30	63	15	47	56	62	19	47	53	62	27	73	81
1800	29	68	19	54	61	66	21	56	62	72	28	79	82
2000	31	71	20	61	68	72	22	59	63	71	30	82	86
TRUCK-10%													
1000	24	53	15	39	45	53	16	39	43	53	24	70	77
1400	30	62	13	48	59	62	19	52	59	65	26	73	79
1800	28	67	19	56	61	69	21	59	66	71	27	76	81
2000	30	71	20	61	65	71	24	57	63	73	30	80	82
TRUCK-20%													
1000	22	55	13	35	39	48	15	40	50	59	24	69	71
1400	30	63	16	47	55	59	16	49	52	61	24	71	77
1800	28	68	18	55	62	64	23	60	63	67	28	74	77
2000	30	67	20	57	60	65	25	61	63	67	29	75	79

TABLE 20

PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES AND PERCENTAGE TRUCKS (WITH TWO-PLS GRADE-2% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

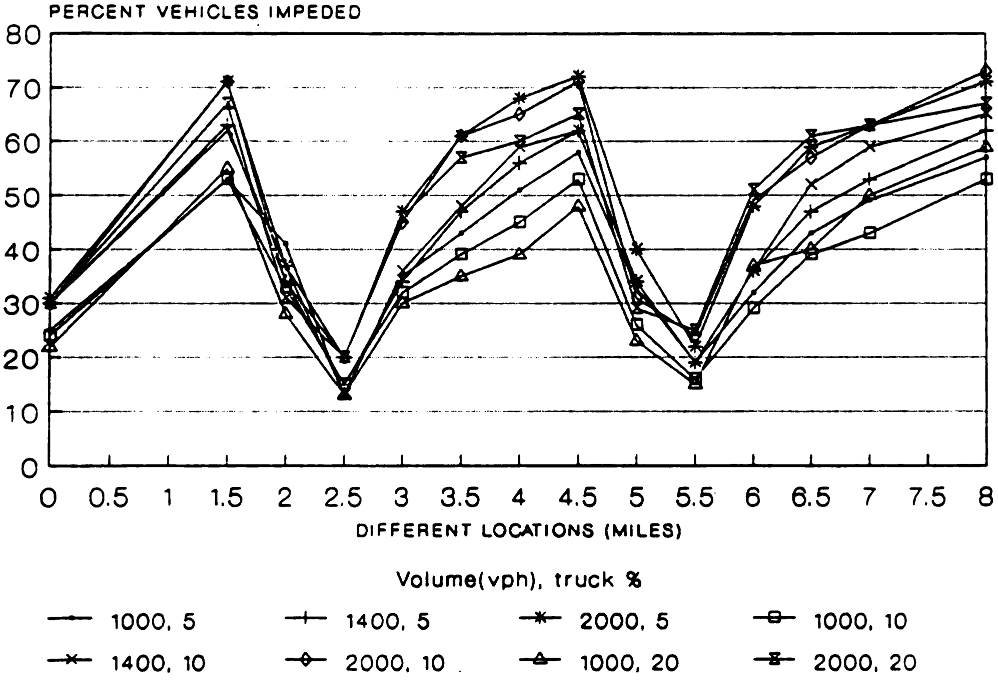
VOLUME	PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS												
(VPH)	DIRECTION-1										DIRECTION-2		
DIR. SPLIT 50/50	BEG. OF ROAD MP 0.0	0.5 MI UP PL1 MP 1.5	MIDDLE OF PL1 MP 2.5	0.5 MI DN PL1 MP 3.5	1.0 MI DN PL1 MP 4.0	1.5 MI DN PL1 MP 4.5	MIDDLE OF PL2 MP 5.5	0.5 MI DN PL2 MP 6.5	1.0 MI DN PL2 MP 7.0	2.0 MI DN PL2 MP 8.0	BEG. OF ROAD	MID. OF ROAD	END OF ROAD
TRUCK-5%													
1000	25	57	10	43	53	55	7	38	48	55	25	68	77
1400	31	64	11	49	57	62	8	49	56	66	27	72	81
1800	29	67	10	54	63	67	12	57	61	72	28	79	84
TRUCK-10%													
1000	24	53	10	48	55	30	9	39	44	52	24	66	79
1400	31	63	11	49	58	52	10	44	52	65	26	69	79
1800	28	67	8	54	62	66	11	56	60	70	27	77	79
TRUCK-20%													
1000	23	51	6	43	48	51	11	34	39	53	25	66	72
1400	31	60	8	47	55	56	9	52	55	67	24	66	75
1800	29	63	12	51	58	61	15	55	61	69	28	70	74



PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS

FOR TWO-PLS, GRADE-6%, NO-PASS-50%, TERRAIN CHANGE @ 1-MI

FIGURE 17. PERCENTAGE VEHICLES IMPEDED FOR 6% GRADE, TERRAIN CHANGE @ 1-MI WITH TWO PASSING LANES



PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS

FOR TWO-PLS, GRADE-4%, NO-PASS-50%, TERRAIN CHANGE @ 1/2-MI

FIGURE 18. PERCENTAGE VEHICLES IMPEDED FOR 4% GRADE, TERRAIN CHANGE @ 1/2-MI WITH TWO PASSING LANES

TABLE 21

AVERAGE DELAY FOR SPECIFIED SECTIONS OF THE SIMULATED ROADWAY (WITH ONE-PL GRADE-4% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME (VPH) DIR. SPLIT 50/50	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)					
	DIRECTION-1					DIRECTION-2
	FROM MP 0.0 TO MP 3.5	FROM MP 3.5 TO MP 4.5 (PL)	FROM MP 4.5 TO MP 5.5	FROM MP 5.5 TO MP 6.5	FROM MP 6.5 TO MP 7.5	FROM MP 8.0 TO MP 0.0
TRUCK-5%						
1000	7.1	2.7	5.0	5.7	7.1	8.9
1400	7.8	3.5	7.6	8.3	9.7	10.4
1800	8.6	3.3	8.1	9.3	11.3	11.4
2000	8.9	3.7	11.7	10.2	11.4	12.0
TRUCK-10%						
1000	7.8	3.0	5.8	7.5	9.0	9.7
1400	8.3	3.6	7.7	8.9	10.4	11.0
1800	9.0	3.3	9.5	10.4	10.8	11.9
2000	9.5	3.7	12.3	10.8	11.6	12.8
TRUCK-20%						
1000	9.8	4.0	10.0	8.3	10.1	10.9
1400	10.4	4.5	12.2	11.4	12.3	12.0
1800	10.8	5.6	14.2	12.4	13.6	13.0
2000	11.2	5.6	14.3	13.3	14.8	13.6

TABLE 22

AVERAGE DELAY FOR SPECIFIED SECTIONS OF THE SIMULATED ROADWAY (WITH ONE-PL GRADE-6% TERRAIN CHANGE @ 1/2-MI NO-PASSING ZONE-50%)

VOLUME (VPH) DIR. SPLIT 50/50	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)					
	DIRECTION-1					DIRECTION-2
	FROM MP 0.0 TO MP 3.5	FROM MP 3.5 TO MP 4.5 (PL)	FROM MP 4.5 TO MP 5.5	FROM MP 5.5 TO MP 6.5	FROM MP 6.5 TO MP 8.0	FROM MP 8.0 TO MP 0.0
TRUCK-5%						
1000	7.0	3.5	5.4	6.0	7.7	9.0
1400	7.9	3.8	7.2	8.1	10.3	10.4
1800	8.5	3.9	8.7	9.8	11.3	11.5
2000	8.8	4.4	11.3	10.6	12.1	12.2
TRUCK-10%						
1000	7.8	3.8	6.2	7.5	8.7	9.7
1400	8.4	4.2	10.5	9.6	11.1	11.5
1800	9.0	4.6	11.9	10.3	11.4	11.9
2000	9.4	5.1	12.2	11.1	11.7	13.0
TRUCK-20%						
1000	9.6	4.5	10.7	9.1	9.8	11.3
1400	10.6	5.1	12.5	11.8	13.2	12.8
1800	11.1	6.0	15.0	13.1	13.1	13.2
2000	11.3	7.2	15.5	14.7	14.7	14.3

TABLE 23

AVERAGE DELAY FOR SPECIFIED SECTIONS OF THE SIMULATED ROADWAY (WITH ONE-PL GRADE-2% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME (VPH) DIR. SPLIT 50/50	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)					
	DIRECTION-1					DIRECTION-2
	FROM MP 0.0 TO MP 3.5	FROM MP 3.5 TO MP 4.5 (PL)	FROM MP 4.5 TO MP 5.5	FROM MP 5.5 TO MP 6.5	FROM MP 6.5 TO MP 8.0	FROM MP 8.0 TO MP 0.0
TRUCK-5%						
1000	6.4	4.3	4.4	5.6	7.1	8.8
1400	7.2	5.1	6.0	7.7	8.9	10.3
1800	7.9	5.4	7.4	8.4	9.4	11.3
TRUCK-10%						
1000	6.5	5.6	4.0	5.0	6.7	9.1
1400	7.3	6.1	5.5	7.1	8.7	10.6
1800	8.0	6.4	7.6	3.5	10.1	11.4
TRUCK-20%						
1000	6.7	8.5	6.5	5.6	6.8	9.5
1400	7.7	9.4	9.7	7.8	9.3	11.2
1800	8.3	8.7	9.8	8.4	10.1	11.9

TABLE 24

AVERAGE DELAY AT SPECIFIED SECTION OF SIMULATED ROADWAY (WITH TWO-PLS GRADE-6% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

VOLUME (VPH)	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)							
	DIRECTION-1							DIRECTION-2
DIR. SPLIT 50/50	FROM MP 0.0 TO MP 2.0	FROM MP 2.0 TO 3.0 (PL1)	FROM MP 3.0 TO MP 4.0	FROM MP 4.0 TO MP 5.0	FROM MP 5.0 TO 6.0 (PL2)	FROM MP 6.0 TO MP 7.0	FROM MP 7.0 TO MP 8.0	FROM MP 8.0 TO MP 0.0
TRUCK-5%								
1000	8.9	4.1	5.2	8.8	4.7	8.5	10.0	9.8
1400	9.5	4.7	9.7	12.3	4.9	12.2	12.4	11.4
1800	11.3	4.7	10.2	13.4	6.6	12.9	13.0	11.9
2000	11.6	5.6	14.5	16.2	7.7	13.9	14.0	13.4
TRUCK-10%								
1000	12.1	6.1	11.2	16.5	6.5	12.0	12.9	12.8
1400	12.2	5.7	12.9	18.8	6.3	16.2	15.8	15.1
1800	14.4	5.7	13.7	20.3	7.3	20.3	16.8	16.3
2000	15.2	6.9	19.6	20.4	7.1	23.0	18.9	17.1
TRUCK-20%								
1000	17.5	7.9	20.1	21.3	8.5	19.2	15.2	18.3
1400	18.2	7.7	23.1	25.8	9.4	25.2	18.5	19.6
1800	19.9	9.8	24.3	28.0	11.7	28.1	22.1	21.9
2000	21.5	9.6	27.3	28.6	10.9	28.7	23.3	23.6

TABLE 25

AVERAGE DELAY AT SPECIFIED SECTION OF SIMULATED ROADWAY (WITH TWO-PLS GRADE-4% TERRAIN CHANGE @ 1/2-MI NO-PASSING ZONE-50%)

VOLUME (VPH) DIR. SPLIT 50/50	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)							
	DIRECTION-1							DIRECTION-2
	FROM MP 0.0 TO MP 2.0	FROM MP 2.0 TO 3.0 (PL1)	FROM MP 3.0 TO MP 4.0	FROM MP 4.0 TO MP 5.0	FROM MP 5.0 TO 6.0 (PL2)	FROM MP 6.0 TO MP 7.0	FROM MP 7.0 TO MP 8.0	FROM MP 8.0 TO MP 0.0
TRUCK-5%								
1000	5.5	2.1	3.9	5.4	2.7	5.4	5.4	9.0
1400	6.3	2.3	5.4	6.8	2.5	5.9	6.8	10.4
1800	6.9	2.7	6.6	7.8	3.0	8.5	8.3	11.3
2000	7.0	2.6	8.1	8.5	3.1	8.0	8.3	12.1
TRUCK-10%								
1000	5.5	2.1	4.1	5.6	2.2	4.1	4.8	9.2
1400	6.2	2.6	6.0	7.5	3.3	7.5	7.3	10.6
1800	7.0	2.9	7.1	8.1	2.9	9.4	8.6	11.4
2000	7.1	3.1	9.5	8.6	3.3	10.4	8.3	12.2
TRUCK-20%								
1000	6.2	2.8	5.2	5.2	3.0	8.7	6.1	9.6
1400	7.2	3.3	8.0	7.5	3.2	8.4	7.8	11.2
1800	7.7	3.4	8.9	8.6	4.6	9.8	9.1	11.9
2000	7.9	3.8	9.2	8.9	4.7	10.6	9.1	12.4

TABLE 26

AVERAGE DELAY AT SPECIFIED SECTION OF SIMULATED ROADWAY
(WITH TWO-PLS GRADE-2% TERRAIN CHANGE @ 1-MI NO-PASSING ZONE-50%)

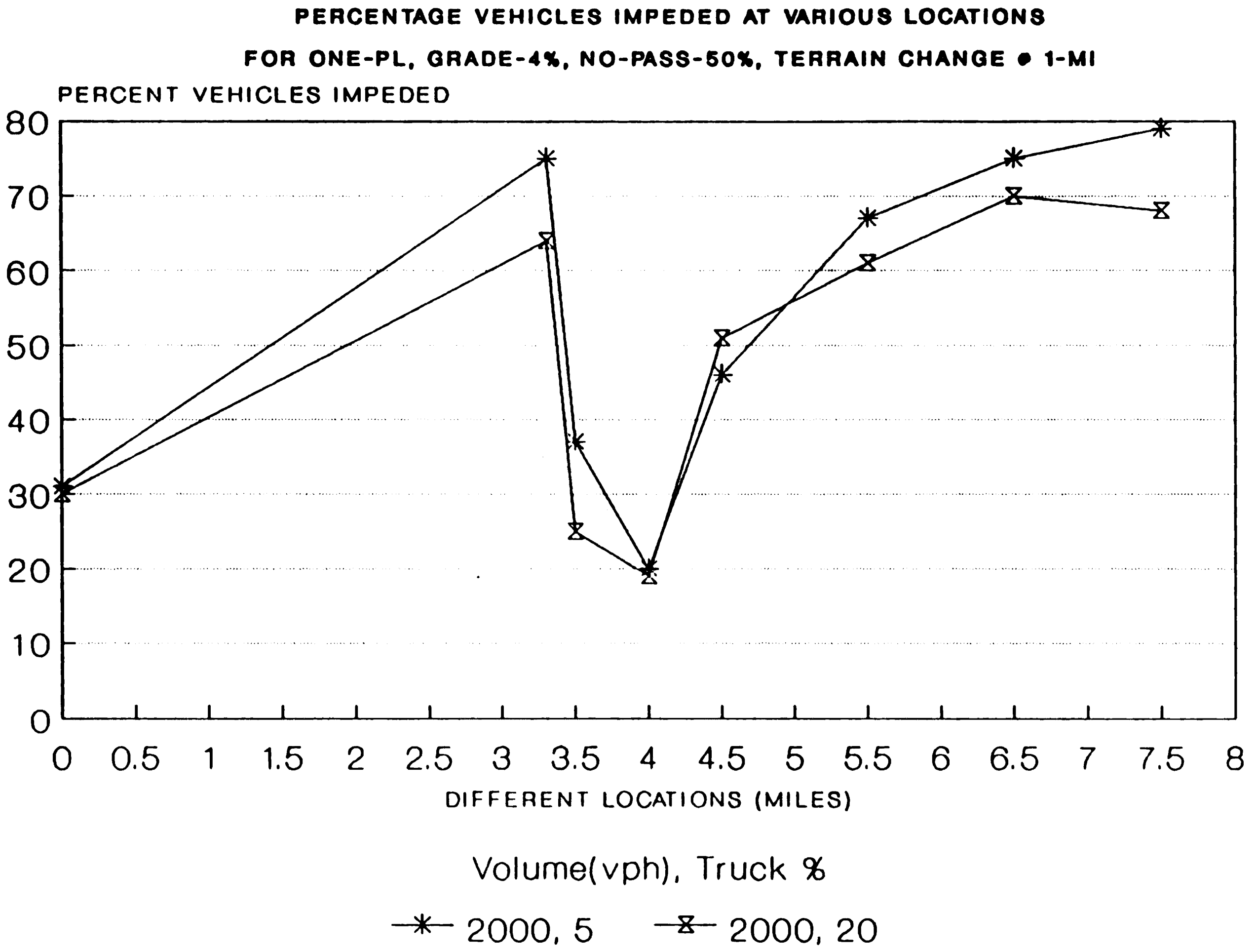
VOLUME (VPH) DIR. SPLIT 50/50	AVERAGE DELAY FOR SPECIFIED SECTIONS (SEC/VEH-MI)							
	DIRECTION-1							DIRECTION-2
	FROM MP 0.0 TO MP 2.0	FROM MP 2.0 TO 3.0 (PL1)	FROM MP 3.0 TO MP 4.0	FROM MP 4.0 TO MP 5.0	FROM MP 5.0 TO 6.0 (PL2)	FROM MP 6.0 TO MP 7.0	FROM MP 7.0 TO MP 8.0	FROM MP 8.0 TO MP 0.0
TRUCK-5%								
1000	5.1	4.3	4.2	5.6	3.8	3.7	4.8	9.1
1400	5.8	4.7	5.4	7.2	4.6	6.0	7.0	10.5
1800	6.3	5.1	6.2	7.6	5.1	7.2	8.4	11.4
TRUCK-10%								
1000	5.2	5.2	4.6	5.7	5.4	4.8	5.2	9.6
1400	5.7	5.5	6.2	7.3	5.3	4.8	6.9	11.0
1800	6.4	5.5	6.6	8.0	5.8	7.5	8.2	11.8
TRUCK-20%								
1000	5.8	8.2	6.2	6.8	7.1	4.3	5.3	10.6
1400	6.4	8.4	6.3	6.9	8.4	7.4	8.1	12.0
1800	7.0	8.5	7.4	7.8	10.3	10.1	8.6	12.7

7.4. RESULT INTERPRETATION AND COMPILATION

Figures 15 and 16 show that the percentage of vehicles impeded before the passing lane reduces drastically within the passing lane, and the percentage of vehicles in platoon remains at a lower value for up to 3 miles beyond the passing lane. This indicates the benefit in terms of reducing platooning and delays exists for upto 3 miles downstream of a passing lane. The percentage of vehicles impeded increases as the volume increases. Similarly, Figure 17 and 18, shows that the percentage vehicles impeded before the passing lanes reduces drastically within the passing lane and reduces at a lower level after the passing lanes.

In Figure 19 the percentage vehicles in platoon were plotted for a traffic volume of 2000 vph and for 5 and 20 percent trucks to explain how the percent increase in trucks changes the percentage of other vehicles in platoon. This Figure shows that with 5 percent trucks, 79 percent of the cars are impeded (or 75 percent of all vehicles), while with 20 percent trucks 81 percent of the cars are impeded (or 65 percent of all vehicles) just before the passing lane. Similarly, at 3.5 miles downstream of the passing lane with 5 percent trucks, 84 percent of the cars are impeded while with 20 percent trucks 86 percent of the cars are impeded.

The benefit in terms of less delay due to a passing lane were calculated. The delay benefit was calculated for each specified section of the simulated roadway in the direction provided with a passing lane in comparison to the delay in the direction without the passing lane. The summation of these values gives the total benefit



PERCENTAGE VEHICLES IMPEDED AT VARIOUS LOCATIONS
FOR ONE-PL, GRADE-4%, NO-PASS-50%, TERRAIN CHANGE @ 1-MI

FIGURE 19. PERCENT VEHICLES IMPEDED FOR 4% GRADE, TERRAIN CHANGE @ 1-MI WITH ONE PASSING LANE

in delay (sec/hr) for the entire length of roadway. The values calculated for a terrain change every 1 mile and every 1/2 mile with 50 percent no-passing zones and 4 percent grade are given in Table 27. The values calculated for a terrain change every 1/2 mile and every 1 mile with 50 percent no-passing zones and 6 percent grade are given in Table 28. The values calculated for a terrain change every 1 mile and every 1/2 mile with 50 percent no-passing zones and 2 percent grade are given in Table 29. Total benefit values were also calculated for the remaining combination of grade, number of passing lanes, volumes, percent trucks and percent no-passing zones. These values of the operational benefit in terms of reduced delay for each case were used in a benefit-cost analysis.

TABLE 27

DELAY BENEFIT FOR DIFFERENT VOLUMES WITH 50% NO-PASSING AND 4% GRADE

HOURLY VOLUME (VPH)	DELAY BENEFIT SEC/VEH					
	TERRAIN CHANGE @ 1-MILE			TERRAIN CHANGE @ 1/2-MILE		
	TRUCK-5%	TRUCK-10%	TRUCK-20%	TRUCK-%	TRUCK10%	TRUCK-20%
WITH ONE PASSING LANE						
1000	22.3	20.5	15.5	25.3	26.0	24.7
1400	22.0	23.2	13.1	25.7	27.1	24.1
1800	23.5	24.3	13.6	28.6	23.2	20.3
2000	22.2	25.0	14.2	31.8	29.6	26.0
WITH TWO PASSING LANES						
1000	35.1	31.1	28.4	36.1	39.7	33.4
1400	38.1	36.3	19.0	40.9	38.2	37.0
1800	36.8	34.1	19.2	39.7	38.2	35.4
2000	35.4	36.2	24.6	44.2	40.2	37.1

TABLE 28

DELAY BENEFIT FOR DIFFERENT VOLUMES WITH 50% NO-PASSING AND 6% GRADE

HOURLY VOLUME (VPH)	DELAY BENEFIT (SEC/VEH)					
	TERRAIN CHANGE @ 1-MILE			TERRAIN CHANGE @ 1/2-MILE		
	TRUCK-5%	TRUCK 10%	TRUCK-20%	TRUCK-5%	TRUCK-10%	TRUCK-20%
WITH ONE PASSING LANE						
1000	6.5	3.8	0.7	21.1	19.8	17.8
1400	10.2	6.2	4.7	21.0	21.7	19.1
1800	9.0	13.6	7.5	22.9	19.8	13.0
2000	5.1	3.9	7.5	22.4	25.2	15.4
WITH TWO PASSING LANES						
1000	19.3	13.0	19.2	34.1	26.7	34.0
1400	16.0	20.7	10.7	35.8	35.9	32.5
1800	12.4	17.5	11.4	33.7	33.9	27.1
2000	12.1	10.5	17.4	31.9	41.3	30.1

TABLE 29

DELAY BENEFIT FOR DIFFERENT VOLUMES WITH 50% NO-PASSING AND 2% GRADE

HOURLY VOLUME (VPH)	DELAY BENEFIT (SEC/VEH)					
	TERRAIN CHANGE @ 1-MILE			TERRAIN CHANGE @ 1/2-MILE		
	TRUCK-5%	TRUCK-10%	TRUCK-20%	TRUCK-5%	TRUCK-10%	TRUCK-20%
WITH ONE PASSING LANE						
1000	23.1	25.4	21.8	28.7	26.3	27.0
1400	25.1	27.5	21.8	27.0	28.9	27.0
1800	27.5	30.6	24.1	30.0	27.0	29.1
WITH TWO PASSING LANES						
1000	36.2	35.5	35.3	40.7	39.0	36.0
1400	37.5	40.6	37.7	42.1	41.0	39.2
1800	39.0	40.0	34.9	43.8	41.1	37.9

CHAPTER 8

8.0 BENEFIT-COST ANALYSIS

The benefits produced by a passing lane can be obtained in terms of reductions in delay and accidents. The road user cost saving associated with these benefits were evaluated over a range of traffic volumes and compared to the cost of constructing and maintaining passing lanes. A description of the procedure used to evaluate each component of road user cost savings and the passing lane cost follows.

8.1. OPERATING COST SAVINGS

The reduction in delay provided by a passing lane results in operational cost saving to the road users. In order to determine the effectiveness of a passing lane in reducing delay a series of simulation runs was conducted for different traffic and roadway conditions. For every combination of volumes, truck percentages, and geometric conditions the effect of a passing lane on delay was computed as the differences between the average delay in the two directions of flow. These values are given in Tables 27, 28, 29, and were discussed in the previous chapter. The reduction in delay was used to compute the time cost savings. The hourly time cost savings were computed with the following equation.

TCS = (1.07) (1.54) (DT) (A) /3600 --------------(1)

TCS = time cost savings provided by a passing lane (dollars per hour),

\$ 1.07 = unit value of time (dollars per person-hour),

1.54 = average vehicle occupancy on two-lane highways in Michigan (persons per vehicle),

DT = reduction in delay (seconds per vehicle),

A = approach volume (vph), and

3600 = number of seconds per hour

8.1.1. UNIT VALUE OF TRAVEL TIME

A value is placed on travel time savings by selecting a unit value of time, usually expressed in dollars per traveler or vehicle hour, and multiplying this unit value by the amount of (traveler or vehicle) time saved. Besides the need for updating such values to current price levels, travel time value is sensitive to trip purpose, travelers income levels and the amount of time saving per trip. According to AASHTO [32], the time saving is divided into three categories and can be expressed as a function of time saved in a trip and type of trip.

1. For low time saving (0 - 5 minutes):

   For work trips and average trips, the value of time per traveler hour are suggested as \$0.48 (6.4% of average hourly family income) and \$0.21 (2.8% of average hourly family income) respectively.

2. For medium time saving (5 - 15 minutes):

   For work trips and average trips, the value of time per traveler hour are suggested as \$2.40 (32.2% of average hourly family income) and \$1.80 (24.2% of average hourly family income) respectively.

3. For high time saving (over 15 minutes):

   For work trips and average trips, the value of time per traveler hour is suggested as \$3.90 (52.3% of average hourly family income).

The unit value of time in equation 1 was that established by AASHTO [32] for the year 1975 and updated to the year 1988 on the basis of the change in the National Consumer Price Index [33, 34]. The unit value of travel time was \$ 0.48 per traveler hour for low time savings for a work trip in 1975. The Consumer Price Index (CPI) was 161.2 and 360.3 in 1975 and 1988 respectively. The updated unit value of travel time (0.48 x 360.3/161.2 - 1.07 per person-hour) was chosen for this example analysis. Clearly, the appropriate choice of a value for travel time depends on the mix of work trips and recreation trips, and the percentage of no-passing zones encountered. The most appropriate value of travel time would be based on the total time savings per trip, not the time savings from a single passing lane.

8.1.2. ANNUAL DELAY COST

In converting daily cost to annual cost, the annual operational cost savings provided by passing lane(s) were computed by multiplying the hourly operational cost saving from equation-1 by a factor of 10, and multiplying this sum by 365 days in a year. Figure 20 of the Highway Capacity Manual shows that the peak hour traffic

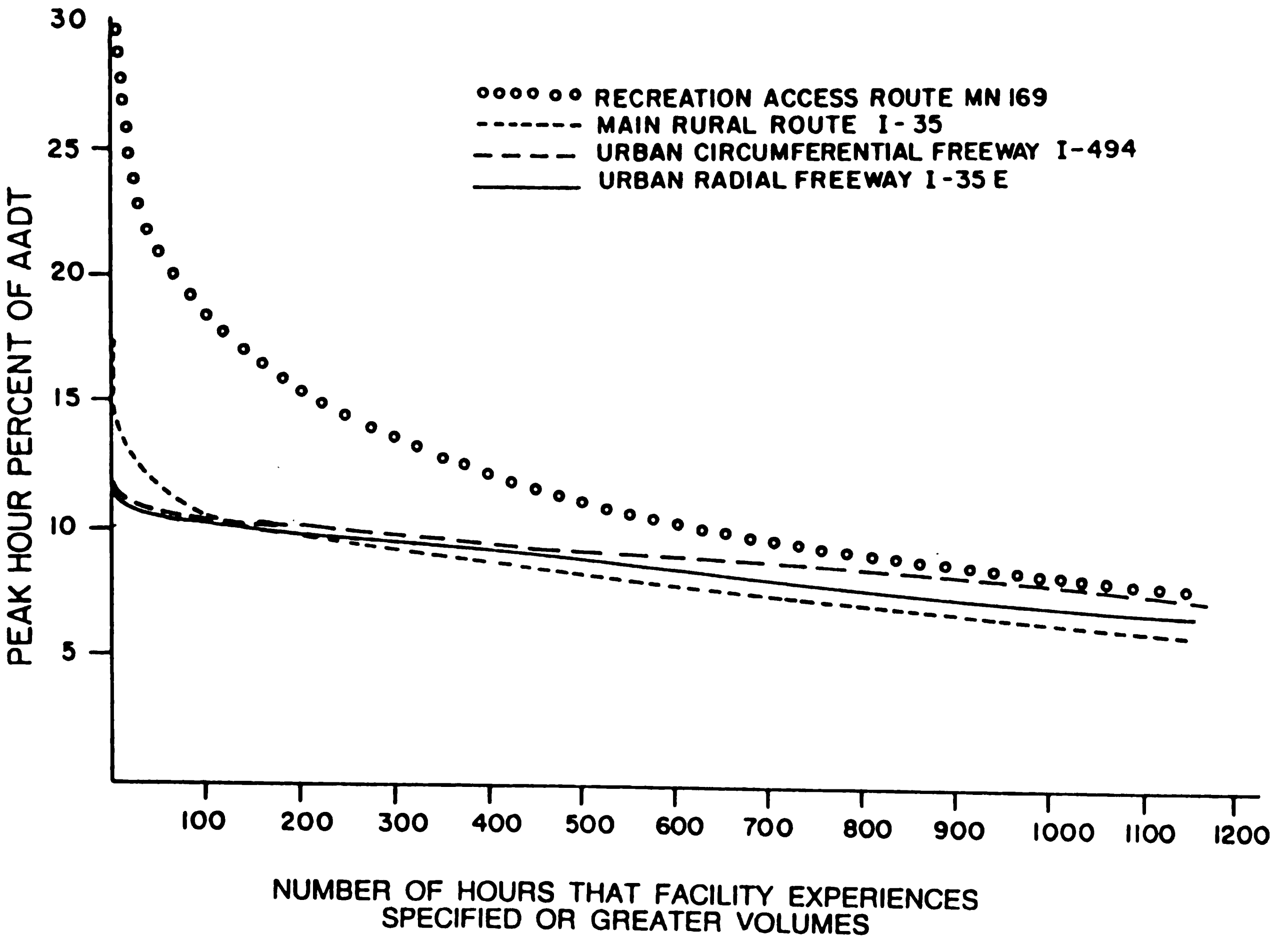


Figure 20. Ranked Hourly Volumes on Minnesota Highways (Source: Minnesota Department of Transportation 1980-1982) (HCM)

can be taken as 10 percent of the ADT on rural two-lane highways. So the factor 10 was taken to convert peak hour volume into ADT. These values were calculated for each hourly flow of (1000, 1400, 1800 and 2000) and for each truck percentage (5, 10 and 20) for different roadway conditions.

8.2. ACCIDENT COST SAVINGS

8.2.1. AVERAGE REDUCTION IN ACCIDENTS

An analysis of accidents on two lane highways with and without passing lanes was conducted to determine the effectiveness of a passing lane in reducing accidents. For the purpose of this analysis, the accident data were obtained from the state file for all road sections having passing lanes on two-lane rural highways throughout Michigan for five years from 1983 to 1987. The number of accidents for these road segments are given in Table 9. The accident rates (by severity) were calculated and the values are given in Table 30 for different ADT ranges.

To compare the accident rates within the passing lane and the rest of the road, the accident data on all two-lane highways in Michigan were segregated on the basis of different ADT levels. The number and rates of the accidents for these roads are given in Table 10, for each year from 1983 to 1987. The mean accident rates for different ADT ranges were calculated for the sections with and without passing lane(s). An average reduction in accidents was computed for each accident type for each ADT range. These values are given in Table 31. This table indicates that passing lanes are effective in reducing accidents on two-lane highways.

TABLE 30

ACCIDENT RATES BY SEVERITY FOR PASSING LANES IN MICHIGAN

AVERAGE DAILY TRAFFIC	FATAL ACC. RATE	PERSON KILLED RATE	INJURY ACC. RATE	PERSON INJURED RATE	PROPERTY DAMAGE RATE	TOTAL ACC. RATE
AVERAGE DAILY TRAFFIC < 5000						
2650	0.0	0.0	39.4	39.4	159.6	199.0
4440	0.0	0.0	28.0	42.2	192.4	220.4
4550	0.0	0.0	0.0	0.0	180.2	180.2
4440	0.0	0.0	166.0	228.2	81.6	247.6
4875	0.0	0.0	24.0	23.6	393.4	417.4
4440	0.0	0.0	68.0	93.8	113.0	181.0
2650	0.0	0.0	54.0	89.6	130.8	184.8
2980	9.8	9.8	51.0	93.8	215.8	276.6
1080	0.0	0.0	207.0	314.6	210.0	417.0
1410	0.0	0.0	90.6	90.6	360.4	451.0
1410	0.0	0.0	0.0	0.0	260.0	260.0
2710	0.0	0.0	0.0	0.0	131.6	131.6
2710	0.0	0.0	0.0	0.0	316.2	316.2
3030	0.0	0.0	31.0	31.0	135.0	166.0
3030	0.0	0.0	74.0	148.0	100.0	174.0
3030	0.0	0.0	0.0	0.0	364.0	364.0
2710	0.0	0.0	13.4	93.8	340.6	354.0
2060	0.0	0.0	0.0	0.0	416.2	416.2
1300	0.0	0.0	32.2	64.4	433.4	465.6
760	0.0	0.0	63.2	63.2	481.2	544.4
1620	0.0	0.0	0.0	0.0	28.2	28.2
1080	0.0	0.0	13.2	13.2	408.0	421.2
2600	0.0	0.0	5.8	5.8	108.0	113.8
3030	0.0	0.0	25.0	57.4	107.6	132.6
4110	0.0	0.0	84.8	122.4	256.4	341.2
4010	7.6	7.6	112.0	161.0	248.0	248.0
4330	0.0	0.0	36.8	45.8	78.2	115.0
1080	0.0	0.0	0.0	0.0	0.0	0.0
1080	0.0	0.0	0.0	0.0	104.0	104.0
Average	0.6	0.6	42.0	62.8	219.1	261.7

TABLE 30 (Con'd.)

AVERAGE DAILY TRAFFIC	FATAL ACC. RATE	PERSON KILLED RATE	INJURY ACC. RATE	PERSON INJURED RATE*	PROPERTY DAMAGE RATE	TOTAL ACC. RATE
FOR 5000 < AVERAGE DAILY TRAFFIC < 10000						
5300	0.0	0.0	30.0	70.0	227.8	257.8
6060	0.0	0.0	44.8	62.0	117.0	161.8
6066	0.0	0.0	19.4	33.4	101.8	121.2
9530	0.0	0.0	57.8	66.4	194.6	252.4
5630	5.0	5.0	58.6	129.2	166.6	230.2
8980	0.0	0.0	79.4	136.8	84.4	163.8
8440	0.0	0.0	120.8	147.0	134.8	255.6
7470	0.0	0.0	121.4	178.2	384.4	505.8
7470	0.0	0.0	31.6	46.4	157.0	188.6
5410	0.0	0.0	42.6	59.2	322.8	365.4
5520	0.0	0.0	51.2	107.0	160.0	211.2
Average	0.5	0.5	59.8	94.1	186.5	246.8
FOR 10000 < AVERAGE DAILY TRAFFIC						
10820	0.0	0.0	11.0	33.0	319.2	330.2
14070	0.0	0.0	77.4	142.4	214.8	292.2
12770	0.0	0.0	117.6	166.6	253.8	371.4
10280	8.4	8.4	29.0	36.2	83.2	120.6
Average	2.1	2.1	58.8	94.6	217.8	278.7

*Rate - Per 100 Million Vehicle Miles

TABLE 31

AVERAGE ACCIDENT BENEFIT (PER 100 MVM) DUE TO PASSING LANE

	AVERAGE ACCIDENT BENEFIT DUE TO PASSING LANE					
	FATAL ACC. RATE	PERSON KILLED RATE	INJURY ACC. RATE	PERSON INJURED RATE	PDO ACC. RATE	TOTAL ACC. RATE
ADT < 5000						
ENTIRE MI	2.4	2.9	60.5	96.6	236.5	299.4
WITHIN PL	0.6	0.6	42.0	62.8	219.1	261.7
BENEFIT	1.8	2.3	18.5	33.8	17.4	37.7
5000 >ADT < 10000						
ENTIRE MI	2.6	3.1	74.5	123.3	193.3	270.4
WITHIN PL	2.1	2.6	59.8	94.1	186.5	246.8
BENEFIT	0.5	0.5	14.7	29.2	6.8	23.6
ADT > 10000						
ENTIRE MI	2.5	3.0	101.9	168.7	222.8	327.2
WITHIN PL	2.1	2.1	58.8	94.6	217.8	278.7
BENEFIT	0.4	0.9	43.1	74.1	5.0	48.5

8.2.2. ACCIDENT COSTS

The literature contains many articles on techniques for developing accident costs. One of the most recent such studies by Miller et.al. for the Federal Highway Administration [35] evaluated various approaches to accident cost estimation. The principal shortcoming of this study is its failure to express accident costs in a form that can be directly used in benefit-cost calculations. Costs are expressed on a per victim and per-vehicle basis rather than on a per accident basis, and are presented in terms of the Maximum Abbreviated Injury Scale (MAIS). However, benefit cost analysis often are based on accident data, which typically consists of numbers of accidents per year at various accident locations, with injury severities coded on the A-B-C scale (incapacitating, non incapacitating and possible injury respectively) rather than the MAIS (0, no injury; 1 to 5, least to most severe non fatal injury; 6, fatality). Hence, costs such as those presented by Miller et.al. [35] could not be directly applied to our data. Based on the values presented by Miller [35], the accident costs were calculated by using methods previously developed in a study for FHWA [36, 37].

The direct, indirect, and total costs used to determine accident costs were taken from the study by Miller et.al. [35]. Since these costs are given in 1980 dollars, the costs were updated by applying cost indices to the direct and indirect costs. For updating the accident costs to 1988, the Consumer Price Index (CPI) for all items (equal to 246.8 in 1980 and 360.3 in 1988) and the Index of Average Hourly Earning (IAHE) (equal to 127.3 in 1980 and

179.8 in 1988) were used. The update factors are 1.46 and 1.4 respectively. These updated costs (1988 dollars) by MAIS categories are given in Table 32.

A method was devised for relating the percentage distribution of MAIS severities to that of A-B-C severities. This was done by using the National Crash Severity Study (NCSS) and the National Accident Sampling System (NASS) data on injury severities cross classified by the MAIS and A-B-C scales. Tables 33 and 34 give the percentage distribution by the two scales for injuries in fatal accident and injuries in non-fatal injury accidents respectively. The data in Tables 33 and 34 were used in developing Figures 21 and 22. These figures were used to relate MAIS severities to A-B-C severities. For each MAIS category, the percentage of A, B, and C severities were obtained. The percentage for A, B, and C severities for Michigan data are given in Table 35. Net direct, indirect and total cost per injury were calculated for fatal and injury accidents. The updated values (1988 dollars) for net direct, indirect and total costs per injury are given in Table 36, for A, B, and C injuries.

8.2.2.1. COST FOR NONFATAL INJURY ACCIDENT

The indirect cost per injury accidents was estimated by multiplying the indirect costs of A, B, and C injuries from Table 36 by the corresponding number of injuries per injury accident from Table 37. The net direct cost per injury accident was calculated by summing the net direct costs of A, B, and C injuries from Table 36,

TABLE 32

COSTS BY (MAIS) CATEGORIES (1988 DOLLARS)

	COST PER VICTIM (MAIS Categories)						
TYPE OF cost	0 (PDO)[a] ($)	1	2	3	4	5	6 (FATALITY) ($)
DIRECT[b]	1045	2337	5025	11810	26962	202478	26709
INDIRECT[c]	184	962	1625	3093	45427	171441	1010297
TOTAL	1229	3299	6650	14903	72389	373919	1037006

a. Costs per vehicle in reported property-damage-only (PDO) accidents.

b. Direct costs include property damage, medical, legal, and funeral costs.

c. Indirect costs include administrative costs, human capital costs (lost productivity) for injuries, and for a fatality, human capital costs adjusted for individuals' willingness-to-pay to reduce their risk of death or injury.

TABLE 33

INJURIES IN FATAL ACCIDENTS, PERCENTAGE CROSS-CLASSIFIED BY A-B-C AND MAIS SEVERITIES, BASED ON NCSS SAMPLE

	A-B-C SCALE			
MAIS	C (%)	B (%)	A (%)	TOTAL (%)
0	0.30	0.30	0.00	0.60
1	5.86	17.90	14.99	38.75
2	0.75	5.86	13.51	20.12
3	0.60	3.90	19.21	23.71
4	0.30	1.05	9.16	10.51
5	0.00	0.15	5.86	6.01
6	0.00	0.00	0.30	0.30
TOTAL	7.81	29.16	63.03	100.00

TABLE 34

INJURIES IN INJURY ACCIDENTS, PERCENTAGES CROSS-CLASSIFIED BY A-B-C AND MAIS SEVERITIES, BASED ON NASS SAMPLE

	A-B-C SCALE			
MAIS	C (%)	B (%)	A (%)	TOTAL (%)
0	2.84	0.46	0.07	3.37
1	32.45	30.38	6.08	68.91
2	2.97	7.36	6.67	17.00
3	0.82	2.94	4.70	8.46
4	0.04	0.36	1.25	1.65
5	0.00	0.16	0.42	0.58
6	0.00	0.00	0.03	0.03
TOTAL	39.12	41.66	19.22	100.00

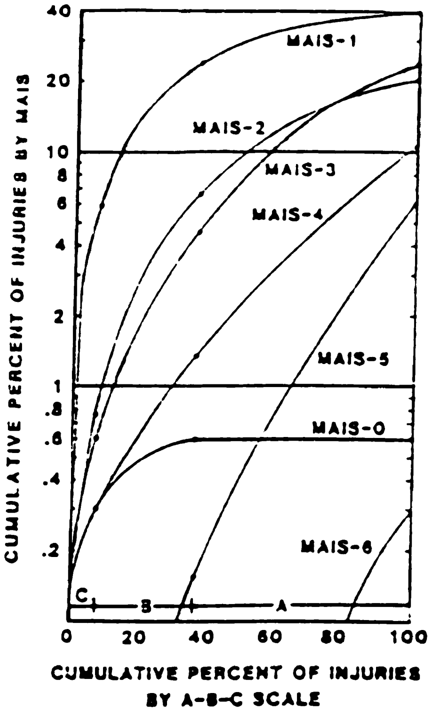


FIGURE 21. CUMULATIVE PERCENT OF INJURIES BY MAIS VERSUS CUMULATIVE PERCENT BY A-B-C SCALE, INJURIES IN FATAL ACCIDENTS, NCSS SAMPLE.

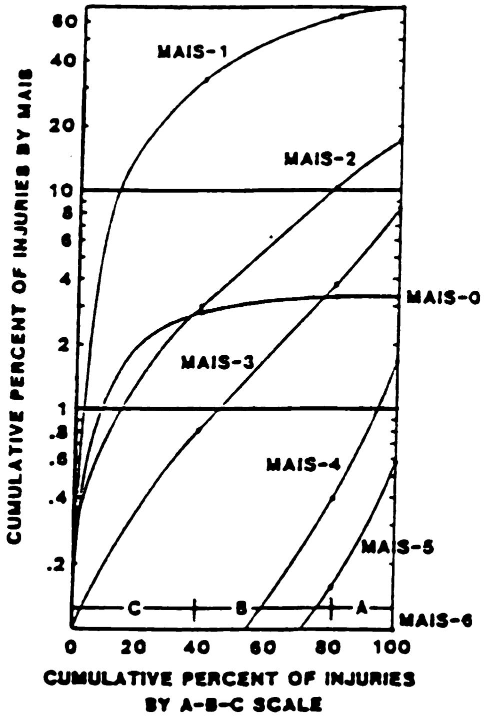


FIGURE 22. CUMULATIVE PERCENT OF INJURIES BY MAIS VERSUS CUMULATIVE PERCENT BY A-B-C SCALE, INJURIES IN INJURY ACCIDENTS, NASS SAMPLE.

TABLE 35

WEIGHTS FOR CONVERTING MAIS COSTS TO A-B-C COSTS PER INJURY

A-B-C CATEGORY AND ACCIDENT SEVERITY	MAIS PERCENTAGE (WEIGHTS)							
	0	1	2	3	4	5	6	TOTAL
FATAL ACCIDENT								
A	0.00	9.75	10.62	16.38	8.29	5.62	0.30	50.96
B	0.18	18.04	7.70	6.09	1.74	0.39	0.00	34.14
C	0.42	10.96	1.80	1.24	0.48	0.00	0.00	14.90
INJURY ACCIDENT								
A	0.05	5.11	5.94	4.31	1.19	0.40	0.03	17.03
B	0.40	28.04	7.71	3.21	0.41	0.18	0.00	39.95
C	2.92	35.76	3.35	0.94	0.05	0.00	0.00	43.02

TABLE 36

NET COST OF A, B, AND C INJURIES IN FATAL AND INJURY ACCIDENTS (1988 DOLLARS)

ACCIDENT SEVERITY AND TYPE OF COST	COST PER INJURY A($)	B($)	C($)
FATAL			
DIRECT[a]	29364	6282	2685
INDIRECT	33764	5700	2617
TOTAL[a]	63128	14982	5302
INJURY			
DIRECT[a]	9903	3231	1419
INDIRECT	10619	2476	1048
TOTAL[a]	20522	5707	2467

a. Net of direct property damage costs

TABLE 37

FATALITIES AND INJURIES PER ACCIDENT, FIVE STATES (36)

ACCIDENT SEVERITY AND AREA	NUMBER PER ACCIDENT FATALITIES	A INJURIES	B INJURIES	C INJURIES
FATAL				
RURAL	1.1516	0.5315	0.3173	0.1396
URBAN	1.0862	0.3528	0.3015	0.1298
ALL	1.1272	0.4648	0.3114	0.1359
INJURY				
RURAL	-	0.3457	0.5770	0.6027
URBAN	-	0.1883	0.5990	0.6575
ALL	-	0.2516	0.5902	0.6355

Note: Alabama, Montana, North Carolina, North Dakota, and Texas are combined.

times the corresponding numbers of A, B and C injuries per injury accident from Table 37. The direct cost per injury accident was calculated by summing the net direct cost and property damage per injury accident. The total cost per nonfatal injury accident is equal to the sum of the direct cost and indirect cost. The updated costs (1988 dollars) of non fatal injury accident are given in Table 39.

8.2.2.2. COST PER FATAL INJURY ACCIDENT

The indirect cost per fatal accident was obtained by multiplying the indirect cost per fatality in Table 32, and the indirect cost of A, B, and C injuries in Table 36, by the number of fatalities and A, B, and C injuries per fatal accident in Table 37. The direct cost per fatal accident was estimated as the sum of the net direct costs per fatality and per A, B, and C injury in Table 36, times the corresponding average numbers of fatalities and A, B, and C injuries per fatal accident from Table 37. The total cost per fatal accident is equal to the sum of the direct and indirect costs. The updated costs (1988 dollars) of fatal accidents are given in Table 39.

Direct, indirect and total costs per fatal, injury, and PDO accident in rural and urban areas are summarized in Table 39. Accident proportions by severity from Table 38, were used to obtain the average cost per rural accident. These accident costs were used to calculate the accident benefits for a passing lane(s).

TABLE 38

ACCIDENT PROPORTIONS BY SEVERITY, FIVE STATES COMBINED

AREA	ACCIDENT SEVERITY FATAL	INJURY	PDO
RURAL	0.0160	0.3497	0.6343
URBAN	0.0045	0.2458	0.7497

Note: Alabama, Montana, North Carolina, North Dakota, and Texas are combined (37).

TABLE 39

ACCIDENT COSTS BY AREA AND SEVERITY (1988 Dollars)

AREA AND TYPE OF COST	ACCIDENT COST BY SEVERITY FATAL($)	INJURY($)	PDO($)	AVERAGE($)
RURAL				
DIRECT	50654	9542	1600	5424
INDIRECT	1183580	5731	282	21356
TOTAL	1234234	15273	1882	26780
URBAN				
DIRECT	44071	8403	1872	3768
INDIRECT	1111355	4172	330	6364
TOTAL	1155426	12575	2202	10132

8.2.3. ACCIDENT COST SAVINGS

The accident cost saving provided by passing lane(s) were computed with the following equation.

ACS = (AC) (365) (ARF) (ADT) 10^{-8} -----------2

where:

ACS = Annual accident cost saving provided by a one mile long passing lane (dollars per year per mile)

AC = Average cost of accidents by severity (values taken from Table 39)

ARF = Average reduction in accident by severities for different ADT values (per 100 MVM)

ADT = Average Daily Traffic (vehicles per day)

The average reduction in accidents (per mile) by severity for different ADT values were calculated and are given in Table 40. Equation 2 was used to compute the safety benefits of a passing lane on rural two-lane highways in Michigan. In equation 2 the values of the average cost of an accident were taken as the total rural accident cost for fatal, injury and PDO accidents from Table 39. The accident cost benefits for different ADT were calculated by considering only direct costs as well as by considering both the direct and indirect cost of an accident. The computed values for a few values of ADT are given in Table 40. These values were plotted for different ADT levels in Figure 23 for case one, taking only direct costs of an accident, and extrapolated for lower ADT levels. Similarly, the values were plotted in Figure 24 for case two, taking

TABLE 40

AVERAGE ACCIDENT BENEFIT (ACC./MI AND $/MILE) DUE TO PASSING LANE

ADT (1988)	AVERAGE ACCIDENT BENEFIT ACC/MI AND $/MI						TOTAL ACC.
	FATAL ACC.		INJURY ACC.		PDO ACC.		
	ACC/MI	$/MI (1)	ACC/MI	$/MI (2)	ACC/MI	$/MI (3)	BENEFIT ($/MI) (1)+(2)+(3)
CONSIDERING DIRECT COST ONLY							
10820	0.016	810	1.70	16221	0.197	315	17346
14070	0.021	1064	2.21	21088	0.257	411	22563
12770	0.019	962	2.01	19179	0.233	373	20514
10280	0.015	760	1.62	15458	0.188	301	16519
CONSIDERING DIRECT AND INDIRECT COSTS							
10820	0.016	19748	1.70	25964	0.197	371	46083
14070	0.021	25919	2.21	33753	0.257	484	60156
12770	0.019	23450	2.01	30699	0.233	439	54588
10280	0.015	18514	1.62	24742	0.188	354	43610

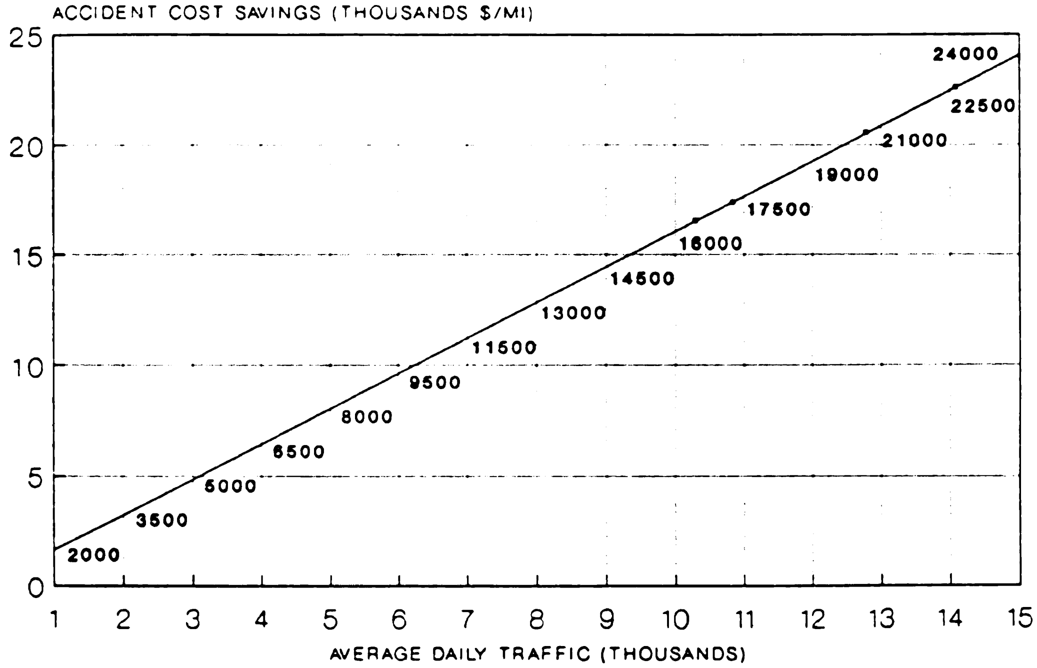


FIGURE 23. TOTAL ACCIDENT COST SAVING ($/MI) FOR DIFFERENT ADT (TAKING ACCIDENT DIRECT COST ONLY)

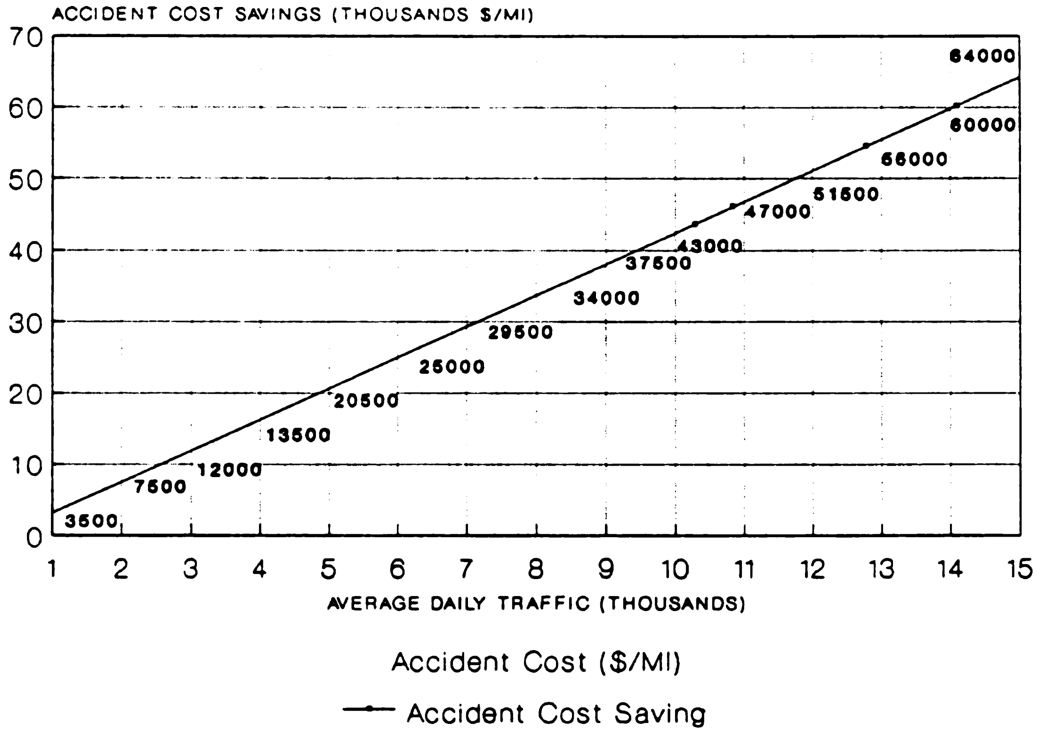


FIGURE 24. TOTAL ACCIDENT COST SAVING ($/MI) FOR DIFFERENT ADT (TAKING BOTH DIRECT AND INDIRECT COST OF ACCIDENT)

both direct and indirect costs of an accident, and extrapolated for lower ADT levels. For this study only the direct cost of an accident was considered in calculating total benefit as suggested by AASHTO (32) for this type of projects.

8.4. BENEFIT-COST ANALYSIS

The delay benefits in terms of seconds per mile were computed for different traffic and roadway conditions as discussed in the previous chapter. The annual delay cost saving provided by passing lane(s) were computed by using equation 1 as discussed before in this chapter. These values are given in Tables 41, 42, 43, 44, 45 and 46 for different percentage of trucks and traffic volumes, for terrain change @ 1-mile and @ 1/2-mile and for one passing lane and two passing lanes within the simulated roadway. These values are given only for the 50 percent no-passing zone case. The delay benefits were also computed for 75 and 25 percent no-passing zones. These values were plotted to get the delay benefits for lower ADT by extrapolation. The annual accident benefits for different ADT groups were added to these delay benefits to get the total benefit resulting from a 1.0 mile long passing lane. These values for different traffic volumes and geometric conditions are given in Appendix C.

The construction and maintenance cost for a one mile long passing lane including right of way cost were obtained from the Michigan Department of Transportation (MDOT). The construction cost was taken as $270,000 per mile for a passing lane in hilly terrain

TABLE 41

DELAY BENEFITS FOR TERRAIN CHANGE @ 1 MILE, 6% GRADE AND 50% NO-PASSING ZONES

AVERAGE DAILY TRAFFIC	DELAY BENEFIT PER YEAR								
	TRUCK-5%			TRUCK-10%			TRUCK-20%		
	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR
WITH ONE PASSING LANE									
10000	6.5	3.0	10950	3.8	1.7	6205	0.7	0.3	1168
14000	10.2	6.5	23871	6.2	4.0	14600	4.7	3.0	10950
18000	9.0	7.4	27010	13.6	11.2	40880	7.5	6.2	22630
20000	5.1	4.7	17155	3.9	3.6	13140	7.5	6.9	25185
WITH TWO PASSING LANES									
10000	19.3	8.8	32120	13.0	6.0	21900	19.2	8.8	32120
14000	16.0	10.3	37595	20.7	13.3	48545	10.7	6.9	25185
18000	12.4	10.2	37230	17.5	14.4	52560	11.4	9.4	34310
20000	12.1	10.5	40515	10.5	9.6	35040	17.4	15.9	58035

TABLE 42

DELAY BENEFITS FOR TERRAIN CHANGE @ 1/2 MILE, 6% GRADE & 50% NO-PASSING ZONES

AVERAGE DAILY TRAFFIC	DELAY BENEFIT PER YEAR								
	TRUCK-5%			TRUCK-10%			TRUCK-20%		
	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR
WITH ONE PASSING LANE									
10000	21.1	9.7	35405	19.8	9.1	33215	17.8	8.1	29565
14000	21.0	13.5	49275	21.7	13.9	50735	16.1	10.3	37595
18000	22.9	18.9	68985	19.8	16.3	59495	13.0	10.7	39055
20000	22.4	20.5	74825	25.2	23.1	84315	15.4	14.1	51465
WITH TWO PASSING LANES									
10000	34.1	15.6	56940	26.7	12.2	44530	34.0	15.6	56940
14000	35.8	22.9	83585	35.9	23.0	83950	32.5	20.8	75920
18000	33.7	27.8	101470	33.9	27.9	101835	27.1	22.3	81395
20000	31.9	29.2	106580	41.3	37.8	137970	30.1	27.6	100740

TABLE 43

DELAY BENEFITS FOR TERRAIN CHANGE @ 1-MILE, 4% GRADE AND 50% NO-PASSING ZONES

	DELAY BENEFIT PER YEAR								
AVERAGE	TRUCK-5%			TRUCK-10%			TRUCK-20%		
DAILY TRAFFIC	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/hr	$/YEAR	SEC/VEH	$/hr	$/Year
WITH ONE PASSING LANE									
10000	22.3	10.2	37230	20.5	9.4	34310	15.5	7.1	25915
14000	22.0	14.1	51465	23.2	14.9	54385	13.1	8.4	30660
18000	23.5	19.4	70810	24.3	20.0	73000	13.6	11.2	40880
20000	22.2	20.3	74095	25.0	22.9	83585	14.2	13.0	47450
WITH TWO PASSING LANES									
10000	35.1	16.0	58400	31.1	14.2	51830	28.4	13.0	47450
14000	38.1	24.2	89060	36.3	23.3	85045	19.0	12.2	44530
18000	36.8	30.3	110595	34.1	28.1	102565	19.2	15.8	57670
20000	35.4	32.4	118260	36.2	33.1	120815	24.6	22.5	82125

TABLE 44

DELAY BENEFITS FOR TERRAIN CHANGE @ 1/2 MILE, 4% GRADE & 50% NO-PASSING ZONES

	DELAY BENEFIT PER YEAR								
AVERAGE	TRUCK-5%			TRUCK-10%			TRUCK-20%		
DAILY TRAFFIC	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR	SEC/VEH	$/HR	$/YEAR
WITH ONE PASSING LANE									
10000	25.3	11.6	42340	26.0	11.9	43435	24.7	11.3	41245
14000	25.7	16.5	60225	27.1	17.4	63510	24.1	15.4	56210
18000	28.6	23.6	86140	23.2	19.1	69715	20.3	16.7	60955
20000	31.8	29.1	106215	29.6	27.1	98915	26.0	23.8	86870
WITH TWO PASSING LANES									
10000	36.1	16.5	60225	39.7	18.2	66430	33.4	15.3	55845
14000	40.9	26.2	95630	38.2	24.5	89425	37.0	23.7	86505
18000	39.7	32.7	119355	38.2	31.5	114975	35.4	29.2	106580
20000	44.2	40.5	147825	40.2	36.8	134320	37.1	34.0	124100

TABLE 45

DELAY BENEFITS FOR TERRAIN CHANGE @ 1 MILE, 2% GRADE AND 50% NO-PASSING ZONES

AVERAGE DAILY TRAFFIC	DELAY BENEFIT PER YEAR TRUCK-5% SEC/VEH	$/HR	$/YEAR	TRUCK-10% SEC/VEH	$/hr	$/YEAR	TRUCK-20% SEC/VEH	$/hr	$/Year
WITH ONE PASSING LANE									
10000	23.1	10.6	38690	25.4	11.6	42340	21.8	10.0	36500
14000	25.1	16.1	58765	27.5	17.6	64240	21.8	14.0	51100
18000	27.5	22.7	82855	30.6	25.2	91980	24.1	19.9	72635
WITH TWO PASSING LANES									
10000	36.2	16.6	60590	35.5	16.2	59130	35.3	16.2	59130
14000	37.5	24.0	87600	40.6	26.0	94900	37.7	24.2	88330
18000	39.0	32.1	117165	40.0	33.0	120450	34.9	28.8	105120

TABLE 46

DELAY BENEFITS FOR TERRAIN CHANGE @ 1/2 MILE, 2% GRADE & 50% NO-PASSING ZONES

	DELAY BENEFIT PER YEAR								
AVERAGE	TRUCK-5%			TRUCK-10%			TRUCK-20%		
DAILY TRAFFIC	SEC/VEH	$/HR	$/YEAR	VEH/SEC	$/hr	$/YEAR	VEH/SEC	$/hr	$/YEAR
WITH ONE PASSING LANE									
10000	28.7	13.1	47815	26.3	12.0	43800	27.0	12.4	45260
14000	27.0	17.3	63145	28.9	18.5	67525	27.0	17.3	63145
18000	30.0	24.7	90155	27.0	22.2	81030	29.1	24.0	87600
WITH TWO PASSING LANES									
10000	40.7	18.6	67890	39.0	17.9	65335	36.0	16.5	60225
14000	42.1	27.0	98550	41.0	26.3	95995	39.2	25.1	91615
18000	43.8	36.1	131765	41.1	33.9	123735	37.9	31.2	113880

(6 percent grade), \$150,000 per mile for a passing lane in moderately hilly terrain (4 percent grade) and plain terrain (2 percent grade). The annual maintenance cost was taken as \$2000 per mile. The following equation was used to calculate Equivalent Uniform Annual Cost of construction and maintenace.

$$EUAC = I \, (CRi_n) + K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where: EUAC = Equivalent Uniform Annual Cost (\$)

I = Initial Construction Cost (\$)

i = Interest Rate (%)

n = Estimated Service Life of the Road (Yr)

K = Net Uniform Annual Cost of Maintenance (\$/Yr)

CRi_n = Capital Recovery Factor for n years at discount rate i

$$CRi_n = \; i \, (1 + i)^n / \, (1 + i)^n - 1$$

The interest rate of 8-12 percent is common for economic studies of public projects and a 10 percent discount rate is used for most federal projects [32]. For this study the discount rate was taken as 10 percent. The life of the road was taken as 15 years. For n = 15 years and i = 10 the value of the capital recovery factor was calculated as 0.1315. Equivalent uniform annual cost (EUAC) were calculated for one passing lane of length 1.0 mile and also for two passing lanes each of length 1.0 mile. The following values were obtained.

For one passing lane and:

Grade 2 and 4 percent I - $150,000 K - $2000 EUAC - $22,000

Grade 6 percent I - $270,000 K - $2000 EUAC - $37,500

For two passing lanes and:

Grade 2 and 4 percent I - $300,000 K - $4000 EUAC - $43,500

Grade 6 Percent I - $540,000 K - $4000 EUAC - $75,000

To illustrate the benefit-cost analysis, the total benefit per year for different truck percentages and roadway conditions were plotted against different ADT values. The construction cost for one passing lane and for two passing lanes for different terrains were also plotted on the respective graphs. The total benefits and cost for a road with 50 percent no-passing zones with one passing lane and two passing lanes with different traffic and road conditions were plotted and are given in the next chapter. Similar graphs were plotted for different traffic and roadway conditions for 75 and 25 percent no-passing zone conditions and are given in Appendix D. These graphs were used to determine the warrants for passing lanes for different traffic and roadway conditions. A similar graph was plotted considering direct and indirect costs of an accident for 10 percent trucks and one passing lane with 4 percent grade and terrain change @ 1-mile. This graph is also given in the next chapter.

CHAPTER 9

9.0 RESULTS AND INTERPRETATION

9.1. SENSITIVITY ANALYSIS RESULTS

Graphs were prepared to illustrate the total cost savings for all combinations of the variables tested. This was done to illustrate in total cost savings.

Figure 25 shows the total cost savings for a road section with 50 percent no passing zones, 10 percent trucks and a 4 percent grade. The top two lines are the benefits for 2 passing lanes, and the bottom two lines are for one passing lane. The frequency of vertical curves (1 mile and 1/2 mile spacing) do not effect the cost savings significantly for these set of conditions. As expected, the cost savings for each alternative increase with increased volume.

Figure 26 shows the sensitivity of total cost savings to the grade for the same combination of variables used in Figure 25. Cost savings are slightly higher when there is a 2 percent grade, while the benefits for a 6 percent grade are much lower than either the 2 percent or 4 percent case. For example, at a volume of 15000 ADT, the benefits are 72000, 59000 and 23000 respectively for 2, 4 and 6 percent grades and one passing lane. The benefits show a similar pattern for 2, 4 and 6 percent grades with two passing lanes.

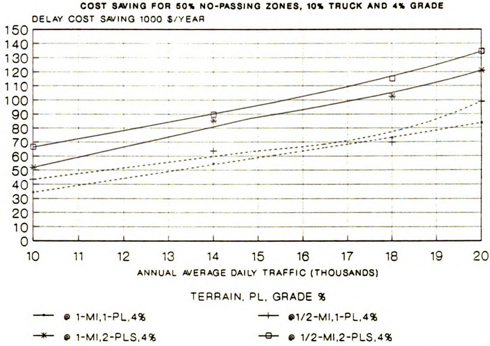


FIGURE 25. SENSITIVITY OF TERRAIN CHANGE WITH 50 PERCENT NO-PASSING ZONES, 10% TRUCKS AND 4% GRADE

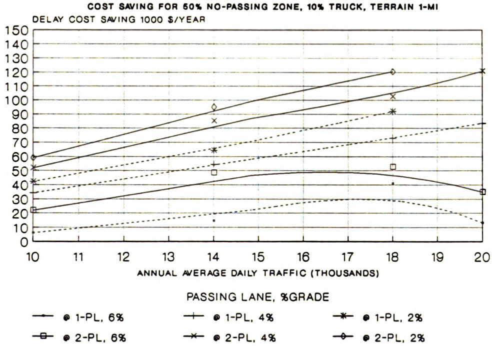


FIGURE 26. SENSITIVITY OF PERCENTAGE GRADE WITH 50 PERCENT NO-PASSING ZONES, 10% TRUCKS AND TERRAIN CHANGE @ MI

Figure 27 shows the sensitivity of the total cost savings to percentage no-passing zones for 10 percent trucks and a 4 percent grade with one passing lane. The top three lines are the benefits for vertical curve spacing at 1/2 mile and the bottom three lines are for 1 mile spacing. The percentage of no-passing zones does not effect the cost savings significantly for either case of vertical curve spacings.

Figure 28 shows the sensitivity of the total cost saving to the truck percentage for the same combination of the variables used in Figure 25. For a vertical curve spacing of 1/2 mile, the difference in total cost savings for 5, 10 and 20 percent trucks are not significant at lower volumes, but they vary considerably at higher volumes. For a vertical curve spacing of 1 mile the total cost saving is much lower for 20 percent trucks than either 5 or 10 percent.

It is clear from these figures that when there are steep grades in the undulating pattern modeled in this study, passing lanes do not provide a significant reduction in delay. The truck speeds on the downhill side of the vertical curves equal that of automobiles, and no passing is accomplished in this segment of the passing lane. The total cost saving is relatively insensitive to the percentage of no-passing zones for these geometric conditions. This phenomenon is even more pronounced with a higher percentage of trucks.

9.2. VOLUME WARRANTS FOR PASSING LANE(S)

Graphs were plotted for total benefit due to passing lanes for different traffic and roadway conditions for one passing lane and

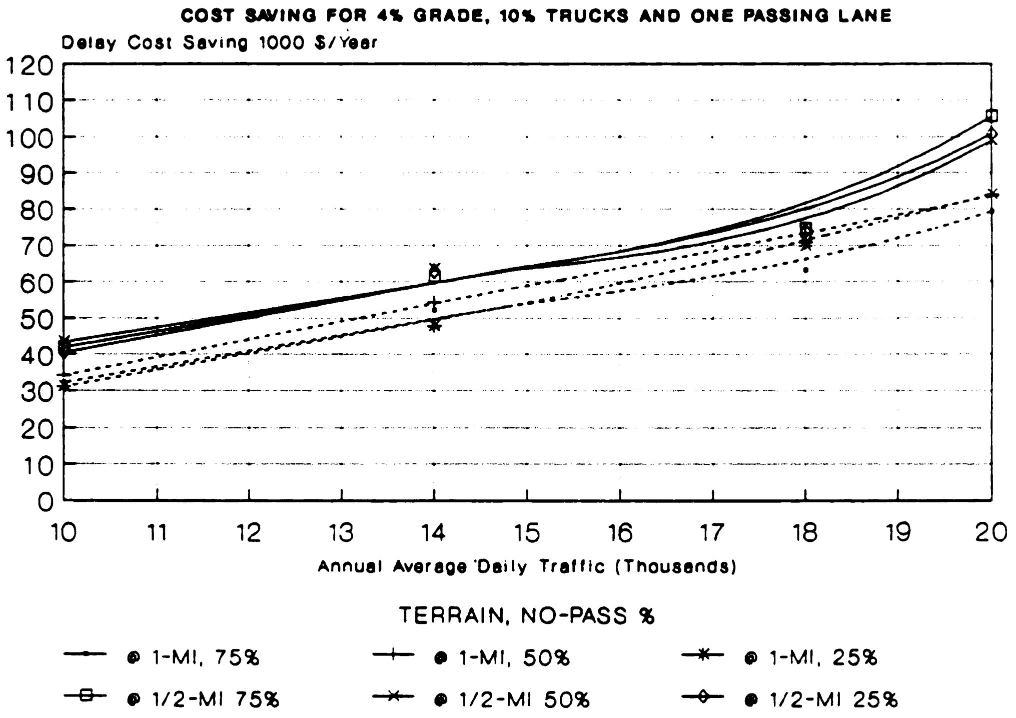


FIGURE 27. SENSITIVITY OF NO-PASSING ZONES WITH 4 PERCENT GRADE, 10 PERCENT TRUCKS AND ONE PASSING LANE

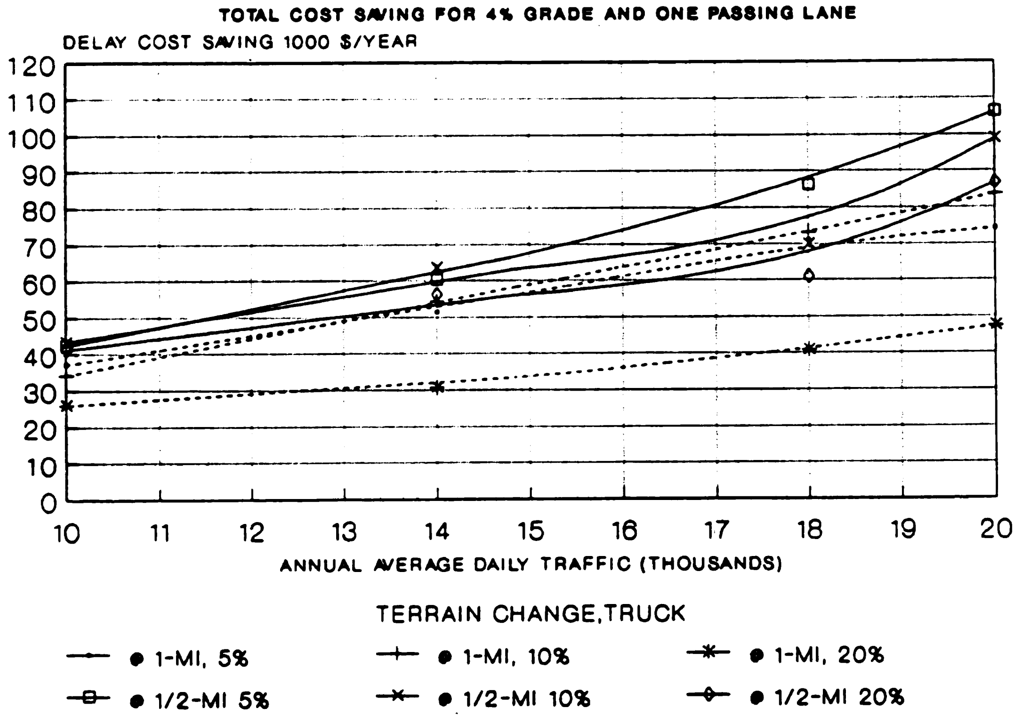


FIGURE 28. SENSITIVITY OF PERCENTAGE TRUCKS WITH 60 PERCENT NO-PASSING ZONES, 4 PERCENT GRADE AND ONE PASSING LANE

for two-passing lane configurations. These plots show that there is no significant difference in total benefits with percentage no-passing zones as discussed before. The 50 percent no-passing zones case for different truck percentages and roadway conditions were considered for further discussion. The plot for 75 an 25 percentage no-passing zones are given in Appendix C.

For 6 percent grade the values of total benefits were plotted for 5, 10 and 20 percent trucks for 1 mile and 1/2 mile terrain change and the values are given in Figures 29 and 30, for one passing lane and two passing lanes respectively. Figure 29 shows that it is economical to provide one passing lane for 5, 10 and 20 percent trucks if the volume is at least 1400, 1500 and 1650 vph respectively, for 1 mile spacing between the curves. Figure 30 shows that it is economical to provide two passing lanes for 5, 10 and 20 percent trucks if the volume is at least 1500 vph, for 1 mile spacing between the curves. These volumes are quite high and the reason may be that the truck speed on the downhill side of the vertical curves are quite high and no passing is accomplished in this segment of the passing lane. For the 1/2 mile terrain change case it is economical to provide one passing lane for 5, 10 and 20 percent trucks if the volume is at least 800 vph. For the 1/2 mile terrain change case it is economical to provide two passing lanes if the volume is at least 800 vph for 5 and 20 percent trucks. For 10 percent trucks it is not economical to provide two passing lanes until the volume is at least 950 vph.

For 4 percent grade the values of total benefits were plotted for 5, 10 and 20 percent trucks for 1 mile and 1/2 mile terrain

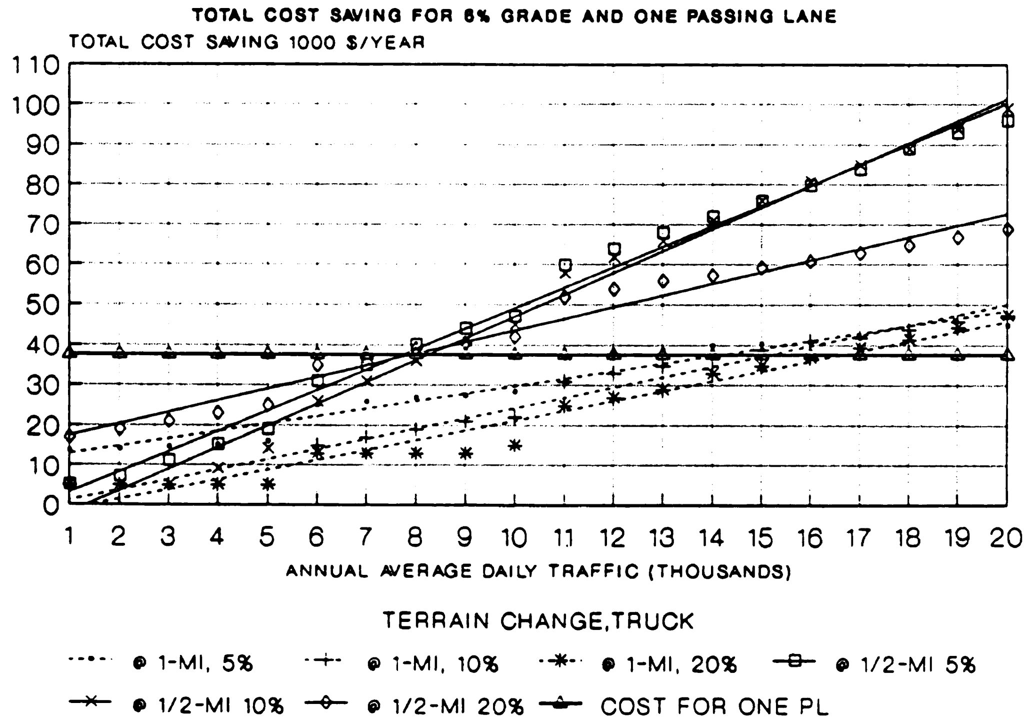


FIGURE 29. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND ONE PASSING LANE

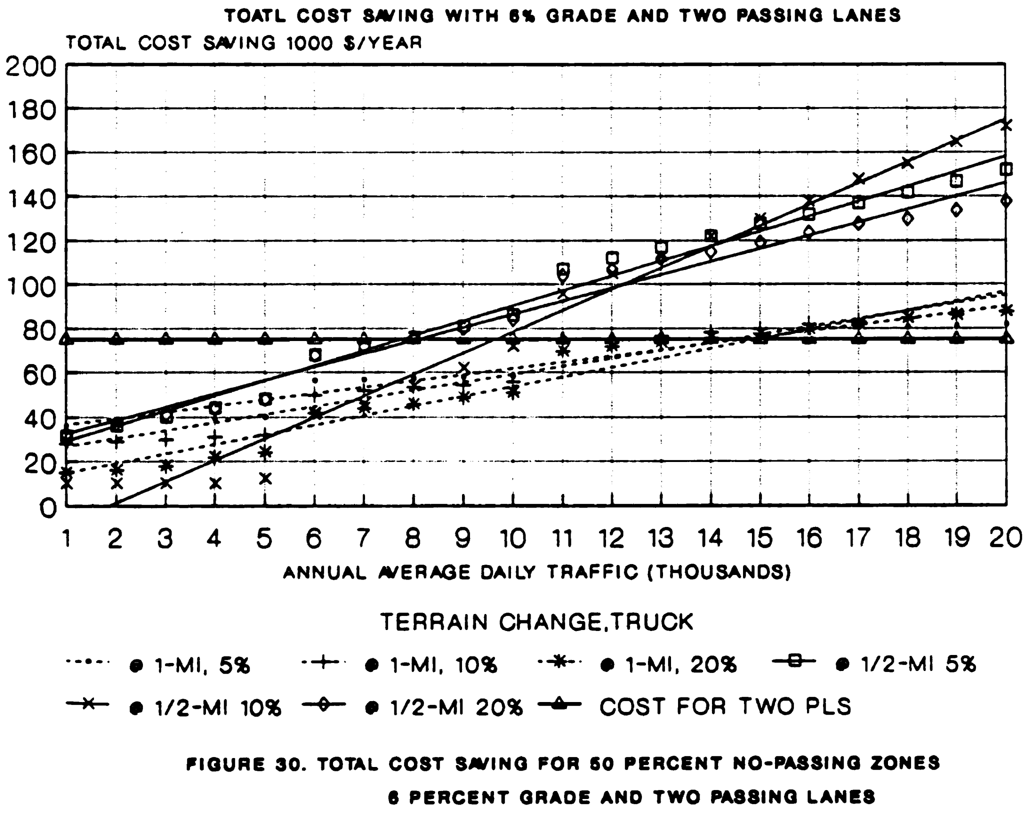


FIGURE 30. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND TWO PASSING LANES

changes and the values are shown in Figures 31 and 32 for one passing lane and two passing lanes respectively. Figure 31 shows that it is economical to provide one passing lane for the 1 mile terrain change case if the volume is at least 400, 500 and 450 vph for 5, 10 and 20 percent trucks respectively. For the 1/2 mile terrain change case it is economical to provide one passing lane if the volume is at least 500, 400 and 350 vph for 5, 10 and 20 percent trucks respectively. Figure 32 shows that it is economical to provide two passing lanes for the 1 mile terrain change case if the volume is at least 400 vph for 5 percent trucks and 500 vph for 10 and 20 percent trucks. For the 1/2 mile terrain change case it is economical to provide two passing lanes if the volume is at least 400 vph for 10 percent trucks and 500 vph for 5 and 20 percent trucks.

For 2 percent grade the value of total benefits were plotted for a 1 mile and 1/2 mile terrain change for 5, 10 and 20 percent trucks and the values are given in Figures 33 and 34 for one passing lane and two passing lanes respectively. Figures 33 shows that it is economical to provide one passing lane if the volume is at least 500 vph for 5, 10 and 20 percent trucks for 1 mile terrain change and if the volume is at least 350 vph for 10 percent trucks and 400 vph for 5 and 20 percent trucks for 1/2 mile terrain change. Figure 34 shows that it is economical to provide two passing lanes if the volume is at least 400 vph for 20 percent trucks and 500 vph for 5 and 10 percent trucks for 1 mile terrain change and if the volume is at least 450 vph for 5, 10 and 20 percent trucks for terrain change at every 1/2 mile.

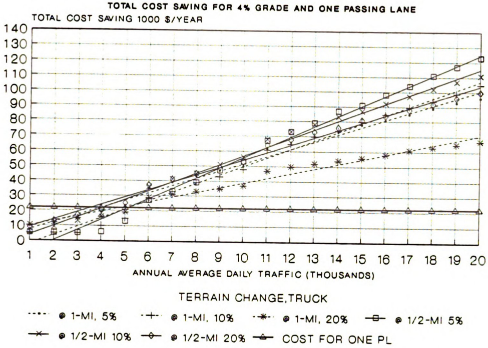


FIGURE 31. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND ONE PASSING LANE

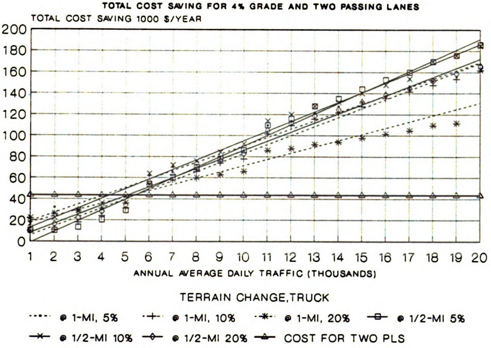


FIGURE 32. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND TWO PASSING LANES

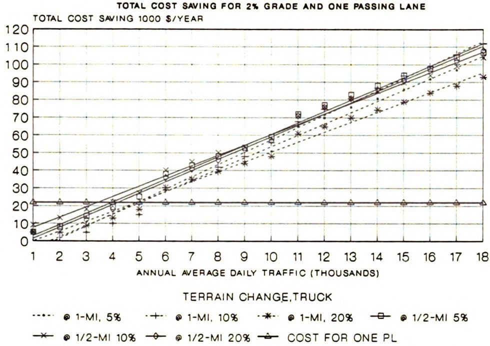


FIGURE 33. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
2 PERCENT GRADE AND ONE PASSING LANE

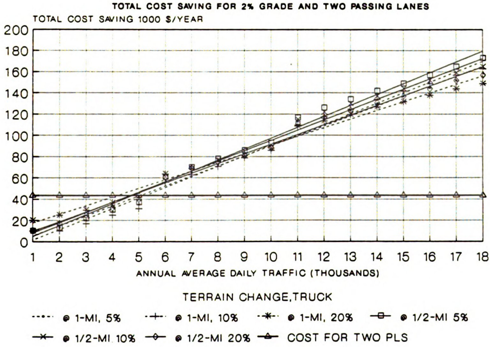


FIGURE 34. TOTAL COST SAVING FOR 50 PERCENT NO-PASSING ZONES
2 PERCENT GRADE AND TWO PASSING LANES

The traffic volumes warranting passing lane(s) for different traffic and roadway conditions are given in Table 47. These values show that for 2 percent grade, it is economical to provide passing lane(s) if the volume is approximately 500 vph for the one mile spacing and 400 vph for the 1/2 mile spacing for 5, 10 and 20 percent trucks. For 4 percent grade, it is economical to provide one passing lane if the volume is approximately 500 vph and two passing lanes if the volume is approximately 400 vph for 5, 10 and 20 percent trucks for 1 mile as well as for 1/2 mile terrain change. It is economical to provide passing lane(s) for the terrain change every 1 mile and grade 6 percent if the volume is approximately 1500 vph for 5, 10 1nd 20 percent trucks. It is economical to provide passing lane(s) for a terrain change every 1/2 mile and grade 6 percent if the volume is approximately 800 vph for 5, 10 and 20 percent trucks.

These values show that there is no significant variation in total cost saving with percent no-passing zones. For mild grades (2 to 4 percent) terrain change does not significantly affect the value of total cost savings for different percent trucks and the warrants for passing lane(s) varies from 350 vph to 500 vph. For steep grades, the terrain change affects the values of total cost savings for different percent of trucks and warrants for passing lane(s) are quite high. It varies from 800 to 950 vph for terrain change every 1/2 mile and varies from 1400 to 1650 vph for terrain change every 1 mile. Figure 35 shows a typical case considering both direct and indirect costs of an accident. The passing lane is warranted at a lower volume if indirect accident costs are considered.

TABLE 47

WARRANTS FOR PASSING LANE(S) FOR DIFFERENT TRAFFIC VOLUMES TRUCK PERCENTAGE AND GRADES

PASSING LANE(S)	GRADE 6% TRUCK PERCENTAGE			GRADE 4% TRUCK PERCENTAGE			GRADE 2% TRUCK PERCENTAGE		
	5	10	20	5	10	20	5	10	20
FOR NO-PASSING ZONES-75%									
FOR TERRAIN CHANGE @ 1 MILE									
ONE	1500	1500	1900	400	500	500			
TWO	1400	1500	1400	300	500	500			
FOR TERRAIN CHANGE @ 1/2 MILE									
ONE	700	800	700	500	500	300			
TWO	850	900	800	550	500	400			
FOR NO-PASSING ZONES-50%									
FOR TERRAIN CHANGE @ 1 MILE									
ONE	1400	1500	1650	400	500	450	500	500	500
TWO	1500	1500	1500	400	500	500	500	500	400
FOR TERRAIN CHANGE @ 1/2 MILE									
ONE	800	800	800	500	400	350	400	350	400
TWO	800	950	800	500	400	500	450	450	450
FOR NO-PASSING ZONES-25%									
FOR TERRAIN CHANGE @ 1 MILE									
ONE	1600	1400	1750	500	600	600			
TWO	1300	1300	1300	450	500	400			
FOR TERRAIN CHANGE @ 1/2 MILE									
ONE	800	800	800	300	500	500			
TWO	900	900	800	500	500	500			

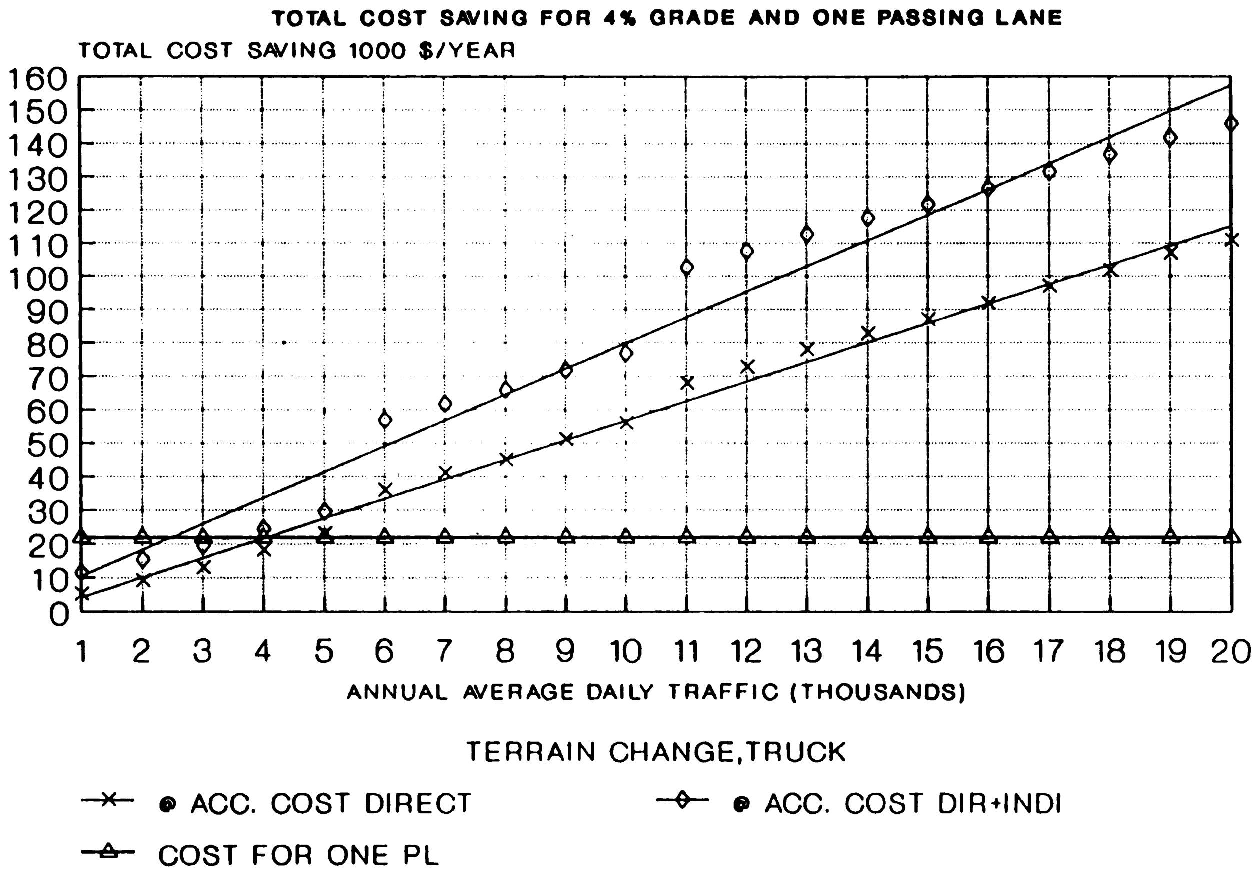


FIGURE 35. TOTAL COST SAVING FOR 4 % GRADE AND ONE PASSING LANE CONSIDERING DIRECT AND INDIRECT COST OF AN ACCIDENT

9.3. INPUT PARAMETERS USED

The major input parameters required to calibrate and use these programs to determine costs and benefits are:

- Traffic volume and the directional distribution:

  To calibrate the model the directional distribution was taken as obtained in the field. In the analysis traffic volume used were 1000, 1400, 1800 and 2000 vph. The directional distribution was taken as 50/50.

- The fraction of different type of vehicles:

  These values were obtained in the field. The vehicle characteristics were taken as suggested in the user's manual. In the analyses, the percentage of trucks were taken as 5, 10 and 20.

- The distribution of desired speed at which the drivers are willing to drive in a particular traffic and roadway environment. These values were obtained by calibrating the simulation model for Michigan two-lane two-way rural highways and the driver types as suggested in NCHRP report 3-28 A (28). These same values were used in the analysis.

- The grades were taken as 2, 4 and 6 percent in the analysis.

- The no-passing zones were considered as 25, 50 and 75 percent in the analysis.

- The roadway profile was taken as an undulating type with a change in grades at every 1 mile and every 1/2 mile with one and two passing lane(s).

  The unit value of travel time ($1.07) was obtained by updating the cost of travel time from $0.48 given by FHWA (32).

- The direct and indirect accident cost were determined based on Michigan accident data and national data on the cost of accidents.
- The construction and maintenance cost of a passing lane in different terrain were obtained from the Michigan Department of Transportation.
- The discount rate of 10 percent was recommended by the Michigan Department of Transportation. The value of EUAC was calculated for both 5 and 10 percent in the sensitivity analysis.

9.4. CASE STUDIES

The previous results were all based on a roadway with an assumed uniform spacing of vertical curves and no-passing zones. Since actual highways seldom approach such uniformity, a non-uniform configuration was modelled to see if the warrants developed in the preceeding analysis are applicable to field conditions present in Michigan.

Three different configurations of road profiles were used as examples. In the first configuration two passing lanes (one in each direction) were provided. In the second configuration, one passing lane was provided in direction 1 only and in the third configuration, one passing lane was provided in direction 2 only. The roadway profile and these configurations are shown in Figures 36 and 37.

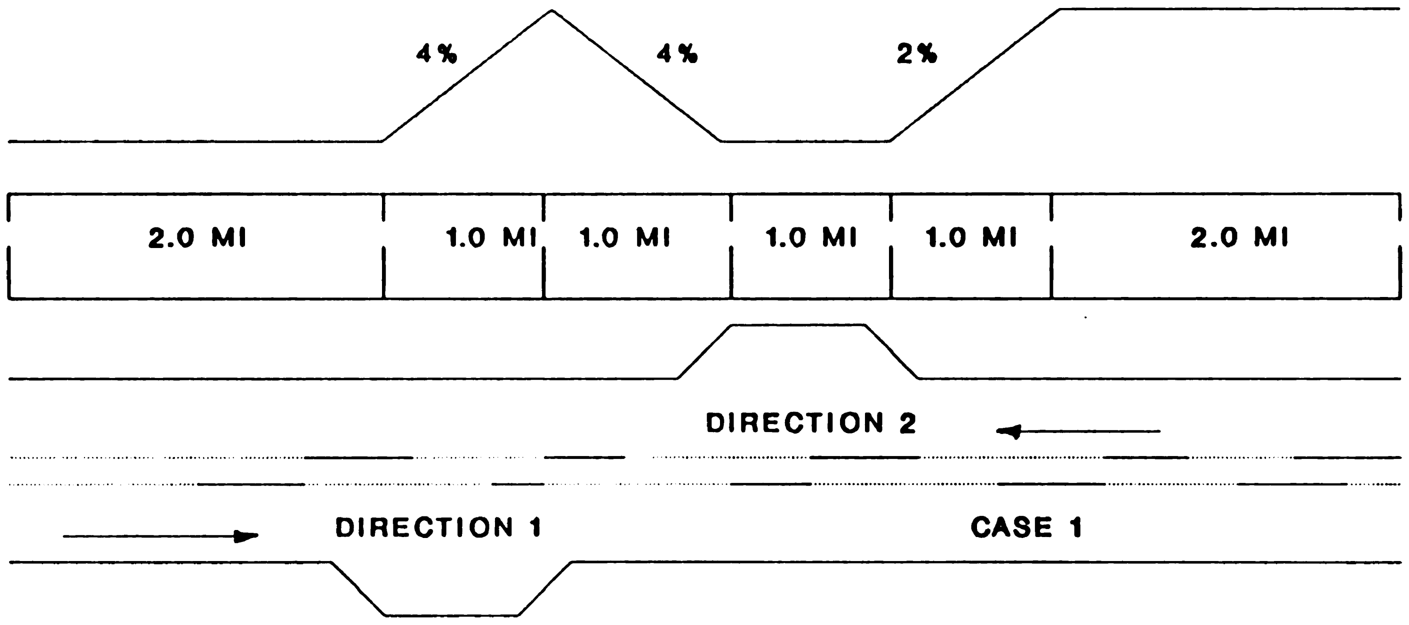


FIGURE 36. LAYOUT OF THE ROADWAY FOR A TYPICAL CASE STUDY WITH TWO PASSING LANES ONE IN EACH DIRECTION

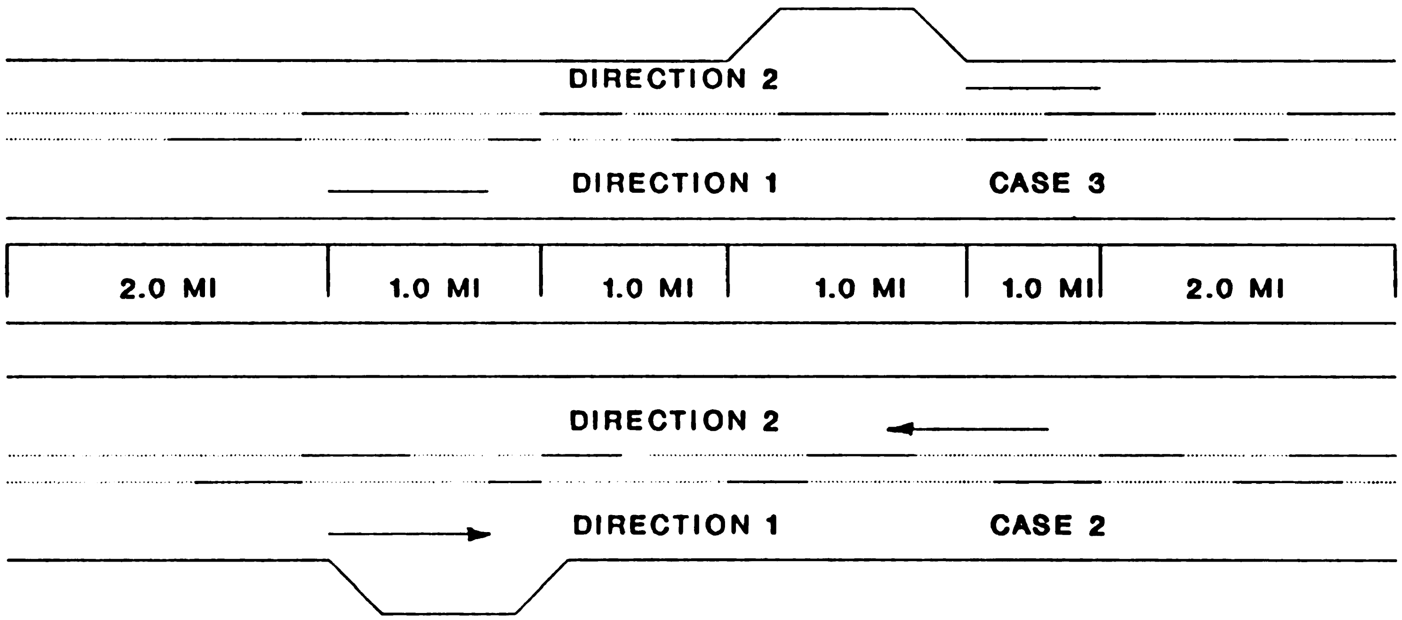


FIGURE 37. LAYOUT OF THE ROADWAY FOR A TYPICAL CASE STUDY WITH ONE PASSING LANE IN EACH DIRECTION

Runs were made for these three configurations for different traffic volumes. The runs were made with 10 percent trucks and 2 percent grade. A second set of runs was made with 10 percent truck and 4 percent grade. The values of delay benefits (sec/veh) for these cases are given in Tables 48 and 49 for 4 and 2 percent grades respectively.

The delay benefits were calculated for two different unit values of travel time, one based on average trips and one based on work trips. According to the 1980 census data, the average annual family income in Michigan is $27000. This converts to an average hourly family income of $13.00, considering 2080 working hours in a year. For average trip the value of travel time per traveler hour was taken as $0.36, which is 2.8 percent of the average hourly family income of $13.00. For work trip the value of time per traveler hour was taken as $0.88, which is 6.4 percent of the average hourly family income. The average delay benefits in terms of dollars per hour and dollars per year were calculated by using equation-1 for these two values of travel time. These values for 10 percent trucks are given in Tables 48 and 49 for 4 and 2 percent grades respectively. These values were plotted and extrapolated for different ADT values. Total benefits were calculated by adding delay and accident benefits.

Equivalent uniform annual cost (EUAC) for construction and maintenance for different cases were calculated for 5 and 10 percent discount rates. The life of the road was taken as 15 years. For $n = 15$ years and $i = 5$ and 10 percent the values of capital recovery factor were calculated as 0.0964 and 0.1315 respectively. EUAC

TABLE 48

COST BENEFIT DUE TO PASSING LANE(S) FOR TYPICAL CASES WITH GRADE 4% AND TRUCK 10%

VOLUME VEH/HR BOTH DIR	ADT	DELAY BENEFIT SEC/VEH	DELAY BENEFITS FOR AVERAGE TRIPS $/HR	$/YEAR	DELAY BENEFITS FOR WORK TRIPS $/HR	$/YEAR
WITH TWO PASSING LANES ONE IN EACH DIRECTION (CASE 1)						
500	5000	28.88	2.2	8030	5.1	18615
800	8000	32.76	4.0	14600	9.2	33580
1000	10000	37.84	5.8	21170	13.4	48910
WITH ONE PASSING LANE IN DIRECTION 1 (CASE 2)						
500	5000	17.29	1.3	4745	3.0	10950
800	8000	17.56	2.2	8030	5.1	18615
1000	10000	17.91	2.8	10220	6.5	23725
WITH ONE PASSING LANE IN DIRECTION 2 (CASE 3)						
500	5000	14.38	1.1	4015	2.5	9125
800	8000	19.06	2.3	8395	5.3	19345
1000	10000	23.40	3.6	13140	8.3	30295

TABLE 49

DELAY BENEFIT DUE TO PASSING LANE(S) FOR TYPICAL CASES WITH GRADE 2% AND TRUCK 10%

VOLUME VEH/HR BOTH DIR	ADT	DELAY BENEFIT SEC/VEH	DELAY BENEFITS FOR AVERAGE TRIPS		DELAY BENEFITS FOR WORK TRIPS	
			$/HR	$/YEAR	$/HR	$/YEAR
WITH TWO PASSING LANES ONE IN EACH DIRECTION (CASE 1)						
500	5000	32.56	2.5	9125	5.8	21170
800	8000	32.37	4.0	14600	9.2	33580
1000	10000	35.88	5.5	20075	12.7	46355
WITH ONE PASSING LANE IN DIRECTION 1 (CASE 2)						
500	5000	18.81	1.4	5110	3.3	12045
800	8000	17.94	2.2	8030	5.1	18615
1000	10000	16.50	2.5	9125	5.9	21535
WITH ONE PASSING LANE IN DIRECTION 2 (CASE 3)						
500	5000	15.07	1.2	4380	2.7	9855
800	8000	16.15	2.0	7300	4.6	16790
1000	10000	18.51	2.9	10585	6.6	24090

values for a 10 percent discount rate were given previously. The following values of EUAC were obtained for a 5 percent discount rate.

For one passing lane and:

Grade 2 and 4 percent I - $150,000 K - $2000 EUAC - $16,500

For two passing lanes:

Grade 2 and 4 percent I - $300,000 K - $4000 EUAC - $33,000

The values of total benefits for average trips and EUAC for 5 and 10 percent discount rates were plotted for 10 percent trucks and for 4 and 2 percent grades in Figures 38 and 39 respectively. The values of total benefits for work trips and EUAC for 5 and 10 percent discount rates were plotted for 10 percent trucks and 4 and 2 percent grades in Figures 40 and 41 respectively.

Figures 38 and 39 show the benefit and cost values for average trips on a typical roadway with 2 to 4 percent grades and 10 percent trucks in traffic mix. For case 1, having two passing lanes (one in each direction) and with grades 4 and 2 percent, the volume warrant varies from 650 to 900 vph for 5 to 10 percent discount rates. For case 2 and case 3, having one passing lane only and warrant also varies from 650 to 900 vph for 5 to 10 percent discount rates.

Figures 40 and 41 show the benefit and cost values for work trips on a typical roadway with 2 and 4 percent grade and 10 percent trucks in traffic mix. For case 1, having two passing lanes and with grades 2 and 4 percent, the volume warrant varies from 450 to 600 vph for 5 to 10 percent discount rates. Foe case 2 and case 3,

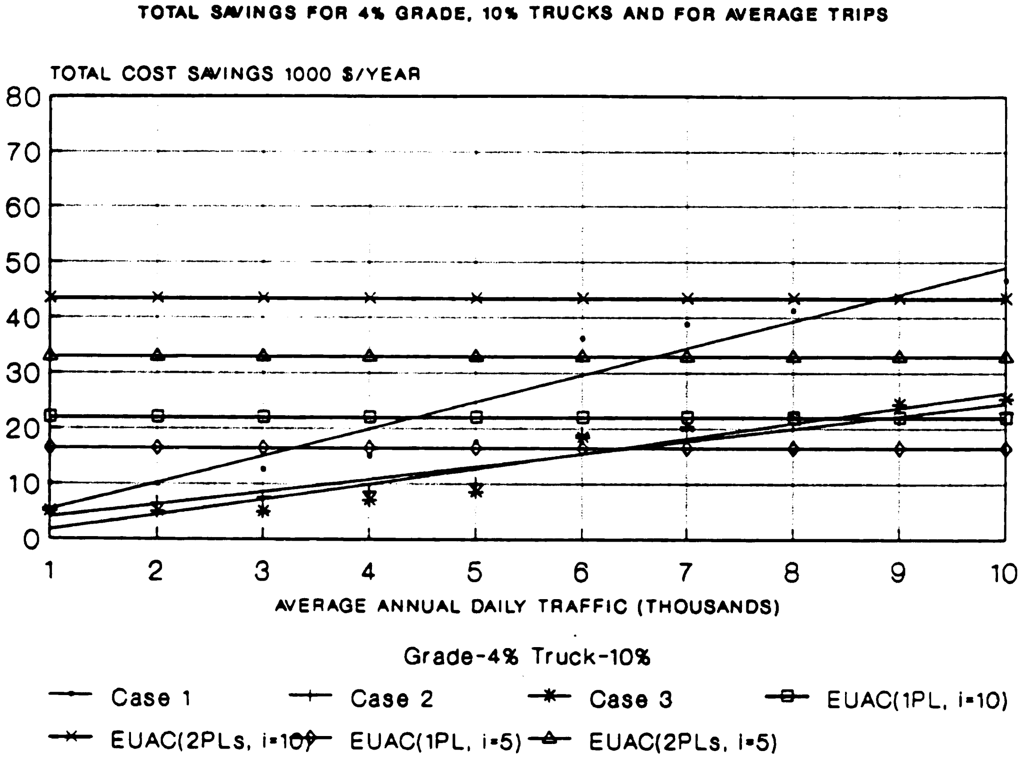


FIGURE 38. TOTAL SAVINGS FOR 4% GRADE, 10% TRUCKS AND FOR AVERAGE TRIPS ON A TYPICAL ROAD PROFILE - A CASE STUDY

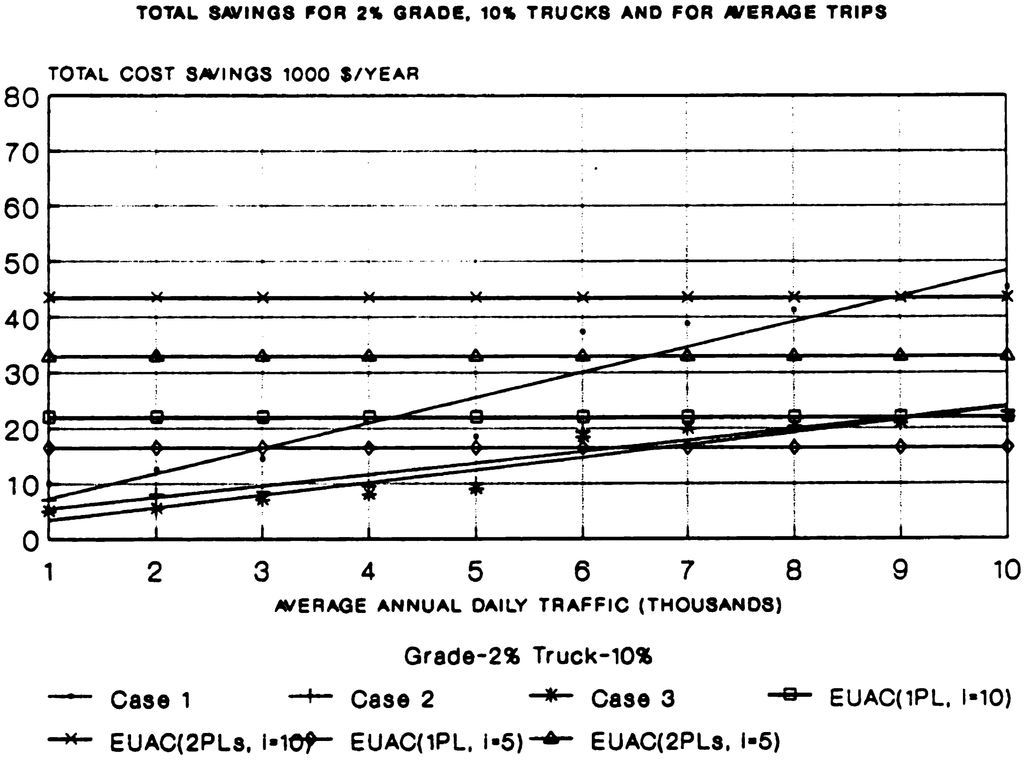


FIGURE 39. TOTAL SAVINGS FOR 2% GRADE, 10% TRUCKS AND FOR AVERAGE TRIPS ON A TYPICAL ROAD PROFILE - A CASE STUDY

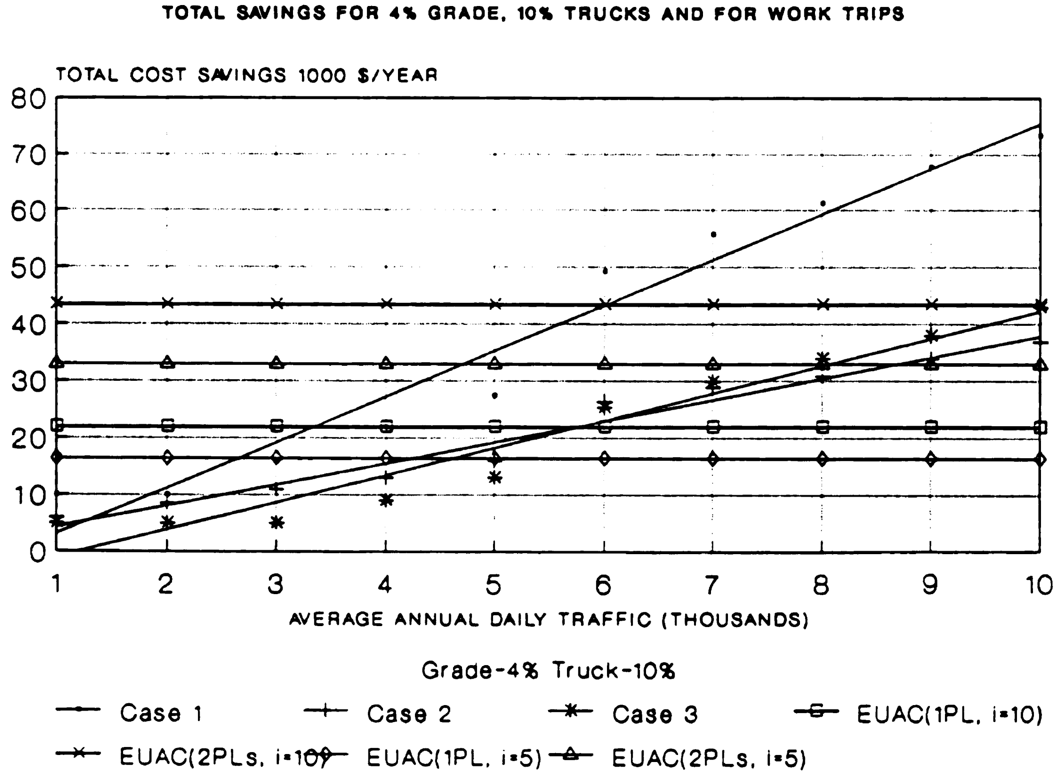

TOTAL SAVINGS FOR 4% GRADE, 10% TRUCKS AND FOR WORK TRIPS

FIGURE 40. VOLUME WARRANTS FOR 4% GRADE, 10% TRUCKS AND FOR WORK TRIPS ON A TYPICAL ROAD PROFILE - A CASE STUDY

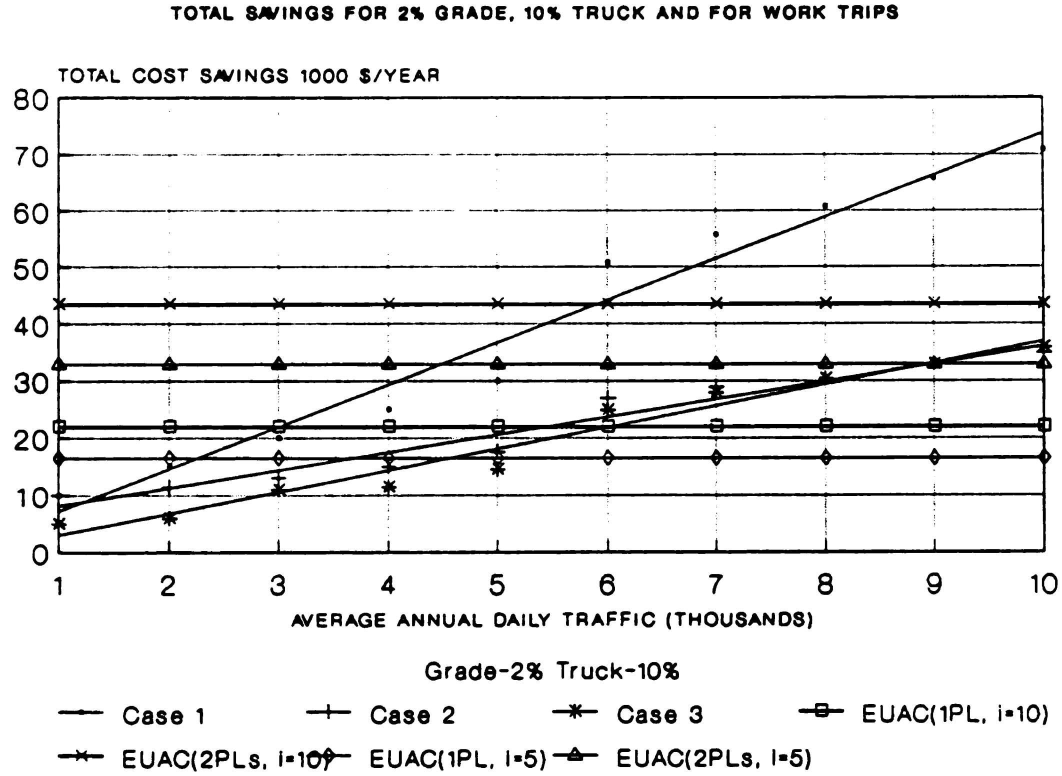

TOTAL SAVINGS FOR 2% GRADE, 10% TRUCK AND FOR WORK TRIPS

FIGURE 41. VOLUME WARRANTS FOR 2% GRADE, 10% TRUCKS AND FOR WORK TRIPS ON A TYPICAL ROAD PROFILE - A CASE STUDY

having one passing lane only and grade 4 and 2 percent, the volume warrant varies from 400 to 600 vph for 5 to 10 percent discount rates.

These volume warrants are equal for 4 and 2 percent grades for all the cases for each trip type and discount rate. The reason may be that the delay benefits are not significant for these mild grades and a low percent of trucks either with one passing lane or with two passing lanes and only varies with the unit value of travel time depending on the type of trips. The volume warrants for one passing lane and for two passing lanes are equal because the delay benefits are quite small and the main contribution to the total benefits is due to a reduction in accidents per mile. For two passing lanes, the accident benefits are double those for one passing lane.

This analysis indicates that for a roadway having mild grades the delay benefits in terms of time saving for an isolated passing lane may be insignificant. However, the value of the savings will vary significantly with the type of trip or unit value of travel time. Thus if a series of passing lanes was provided on a single route, the cummulative time savings may increase the value of time saving by a factor as high as 17. The value of the discount rate selected to calculate EUAC affects the benefit cost analysis significantly. The analyst must select the unit value of travel time and discount rate cautiously in determining warrants of passing relief lane, specially where the grades are quite mild and the delay benefits are low.

CHAPTER 10

SUMMARY AND CONCLUSIONS

The two-lane road in rolling and hilly topography may not provide sufficient passing zone length between crests of vertical curves and highway segments with sight distance below the minimum passing sight distance can result in excessive delay and unsafe driving. Providing passing relief lanes on two-lane highways with significant traffic volume and different traffic composition is desirable.

A review of mathematical models indicated that a majority of these models described only a particular aspect of traffic flow. The complex phenomenon of passing maneuver can be understood by using an appropriate simulation model. After reviewing different simulation models developed for two-lane highways, the TWOPAS model was selected as the most suitable model to study the traffic behavior on two-lane highways. The model gives output values before, after and within the passing lane at different locations and for different specified sections of the simulated roadway.

The TWOPAS model was calibrated for Michigan roadway conditions and driver behavior. The percentage vehicles in platoon was used to compare the simulated and field values at different locations along the simulated roadway. It was found that the model behaves well and simulated values are close to the field values. The distribution of desired speed of the drivers for Michigan roadway and traffic conditions was found after calibrating the simulation model and was used for further study.

Two configurations, one with one passing lane and the other with two passing lanes within a simulated roadway length of 8 miles were considered. Simulation runs were made for these two configurations for different roadway and traffic conditions. It was found that the reduction in delay affects traffic up to 3 miles downstream of the passing lane for both cases. The delay benefit is significantly higher when there is a low percentage of trucks (5, 10) compared to a high percentage of trucks (20). The reduction in delay is significantly higher for moderately hilly and plain terrain than it is for steep grades.

Safety benefits in terms of reduction in accident rates were calculated by comparing the accident rates within passing lanes and average accident rates for all rural two lane highways in Michigan. It was found that there are significant safety benefits due to passing lanes.

The length of the passing lane was taken as 1.0 mile as suggested in the literature. The delay benefits were calculated for different traffic volumes, percent grades and truck percentages. The traffic volumes at which benefits exceed costs for a passing lane are given in Table 47 for different traffic and roadway conditions. These volumes range from 350 vph for roads with a 2 percent grade and 50 percent no-passing zones to 1900 vph for roads with a 6 percent grade and 75 percent no-passing zones.

The economic analysis procedure used is that recommended by the U.S. Department of Transportation[32]. Alternative treatment of the cost of delay and the cost of accidents could be used to find similer warrants.

The model and procedure for determining the volume at which a passing lane(s) is economically justified can be applied to any segment of two-lane road in Michigan. The factors considered in the economic analysis (direct and indirect cost of accidents, maintenance cost and construction cost, discount rate and unit value of travel time) can be input by the user to reflect agency policy and location specific costs. The unit value of travel time and discount rate have a major impact on the results of this type of analysis and should be carefully selected.

APPENDIX A

FEATURES OF THE SIMULATION MODEL "TWOPAS"

APPENDIX A

TABLE A1

FEATURES OF THE SIMULATION MODEL "TWOPAS"(31)

FEATURES	CHARACTERIZATION IN SIMULATION MODEL	APLLICATION IN SIMULATION MODEL
GEOMETRICS		
GRADES	Linear functions of position in user-specified sections.	Directly affect the maximum acceleration and speed maintenance capabilities of cars, RV's, and trucks.
		Indirectly (through other user input) provide crawl speeds for trucks on steep sustained downgrades.
		Indriectly (through other user input) influence the passing sight distances.
HORIZONTAL CURVES	Radius, superelevation and degrees of alignment change.	Directly - may reduce speeds desired by vehicles in curve and its approach if radius and superelevation are sufficiently small.
		Directly - will reduce passing opportunity acceptances in approach to curvature to the right.
		Indirectly - may reduce passing sight distance (through other user input).
LANE WIDTH, SHOULDER WIDTH, AND PAVEMENT QUALITY	Indirectly through user-specified distribution of desired speeds.	Directly - vehicles will attempt to travel at their desired speeds and, when free in most alignments, will exhibit the distribution associated with free speeds.

TABLE A1(Cont'd.)

PASSING SIGHT DISTANCE	Separately in each direction as linear functions of position in user-specified sections.	Directly - oncoming vehicles are "seen" and affect the passing and pass abort decisions only if within the locally defined passing sight distance. Directly - the downstream end of a passing zone is "seen" and affects pass/abort decisions only if it is within sight.
PASSING AND CLIMBING LANES	Specific locations of lane addition and lane drop. Specified geometrics of lane addition and lane drop.	Directly - initial lane choice of each entering vehicle based on: traffic ahead, vehicle category, state (free vehicle, platoon leader, platoon member), performance capability, desired speed, and effect of lane favored by local geometrics and markings. Subsequent lane choices described below under Driver Characteristics and Performances.
TRAFFIC CONTROL		
PASSING AND NO-PASSING ZONES ON A CONVENTIONAL TWO-LANE HIGHWAY	Specified locations of zones by direction of travel.	Directly - drivers do not start passes in no-passing zones. They attemp to avoid initiating a pass that will extent into the no-passing zone if that boundary is in sight. Directly - when the driver is not committed to complete a pass, the pass will be aborted if the pass indicates that the end of the zone will be overrun. When driver is committed to complete a pass, the driver will attempt to avoid or minimize overrunning the end of the passing zone. Directly - impeded vehicles are motivated to examine pass opportunities when passing zone is first entered.

TABLE A1 (Cont'd.)

PASSING AND NO-PASSING ZONES IN THE OPPOSING DIRECTION TO A PASSING OR CLIMBING LANE	Specified by location and direction.	Directly - drivers observe the same costriants as above. They see opposing vehicles in either oncoming lane as potential conflicts.
SPEED LIMIT	Indirectly - through the user-specified distribution of desired speed.	See lane width, etc.
VEHICLE CHARACTERISTICS		
ACCELERATION AND SPEED CAPABILITIES.	Individual capabilities assignable to 13 vehicle types (four trucks, four RV's and five cars/light trucks).	Directly - maximum acceleration and speed capability depends on vehicle type and local grade. Directly - maximum acceleration and speed capability is always a potentially limiting constraint. Directly - drivers have an approximate concept of vehicle capability and use it as part of the projection of passing maneuvers and their outcomes. Directly - lack of a threshold acceleration or speed capability eliminates interest in passing.
LENGTHS	Assignable for each of 13 vehicle types.	Directly - vehicles "follow" the rear of an impeder. Directly - in passing an impeder, the passing vehicle must "clear," taking its own length into account.

TABLE A1(Cont'd.)

DRIVER CHARACTERISTICS AND PREFERENCES		
DESIRED SPEEDS	Assigned stochastically from a truncated normal distribution with user-specified mean and standard deviation.	Directly - each vehicle attempts to travel at its desired speed. It is also the basis for determining reduced speeds that may be preferred in horizontal curves and (for trucks) on downgrades. Directly - the desired speed is increased for vehicles during passing maneuvers. Directly - the difference between desired speed and impeder speed is one factor that helps determine how an impeded vehicle will "follow" and consider whether to pass.
PREFERRED ACCELERATION LEVELS	Incorporated in program logic.	Directly - unless otherwise restrained, vehicles use accelerations that are partly dependent on the difference between their current and desired speeds. Directly - If current speed exceeds desired speed, the deceleration used is dependent on the traffic situation.
SUSTAINED USE OF MAXIMUM POWER PERFORMANCE	Behavior of cars and RV's is controlled by input and program logic.	Directly - vehicles will use maximum power performance if required in a pass or for acceleration toward a desired speed. However, for sustained periods, cars and RV's will use only a fraction (usually 70%) of maximum power, if user so designates.
EXAMINATION OF PASSING POSSIBILITIES (VEHICLE IN DIRECTION OF TRAVEL WITH ONLY ONE LANE)	Program logic plus user-specified probability.	Directly - Impeded vehicles examine passing possibilities and become motivated to pass only when they have first overtaken an impeder, entered a passing zone, cleared oncoming vehicles, and possess adequate vehicle performance capability to pass.

TABLE A1(Cont'd.)

ACCEPTANCE/ REJECTION OF PASSING OPPORTUNITIES (VEHICLE IN DIRECTION OF TRAVEL WITH ONLY ONE LANE)	Built-in tables of acceptance probabilities are dependent on leader speed, type, and measure of constraint (i.e., sight distance or oncoming vehicle in sight) position in platoon, horizontal curvature, and location within passing zone.	Directly - passing opportunities are rejected if: projected time safety margin too small, truck already passing impeder, two other leaders already passing impeder, leader aborting pass of same impeder, follower(s) in pass(es) that may produce conflict, pass maneuver time projected to be too long, or insufficient gap in front of impeder. Otherwise, acceptance based on stochastic decision and probability tables.
EXTEND PASS IN PROGRESS TO ADDITIONAL IMPEDER (VEHICLE IN DIRECTION OF TRAVEL WITH ONLY ONE LANE)	Incorporated in program logic.	Directly - dependent on distance to next impeder, projected time to complete pass, gap in front of next impeder, and stochastic decision based on projected time safety margin.
BEHAVIOR WHILE BEING PASSED (VEHICLE IN DIRECTION OF TRAVEL WITH ONE LANE)	Incorporated in Program Logic.	Unless otherwise more constrained, a vehicle being passed will use only limited acceleration.
BEHAVIOR IN PASSING AND CLIMBING LANE SECTIONS	Incorporated in Program Logic.	There are no arbitrary assignment of preferred lanes. Drivers use foresight and attempt to avoid being trapped behind an impeding vehicle in the right lane or being trapped in the closed lane at a lane drop. Drivers are increasingly motivated to move to the right lane of two unidirectional lanes when they will not be delayed in the near term by right lane

TABLE A1(Cont'd.)

		vehicles, when their acceleration capability is small or negative and their speed is slow, and when they are impeding other vehicles. Trucks are slightly biased to move to the right lane. RV's have a lesser bias and cars have none.
ENTERING TRAFFIC		
FLOW RATES	Program logic creates entering traffic stream in response to user-specified flow rate.	Flow rate in entering traffic stream is near user-specified value.
VEHICLE MIX	Program logic responds to user-specified proportion of individual vehicle types by direction.	Vehicle mix in entering traffic stream in near user-specified distribution.
PLATOONING IN ENTERING TRAFFIC STREAM	Program logic responds to user-specified percentage of traffic platooned by direction, and the upstream alignment in which platoons formed.	Percentage of traffic platooned in entering traffic stream is near user-specified value, which platoon leaders chosen logically on the basis of vehicle performance, driver desired speed, and user-specified upstream alignment.
IMMEDIATE UPSTREAM ALIGNMENT	User-specified maximum entrance speeds by direction for each vehicle type.	User-specified maximums are imposed at entrances when they are a limiting constraint.

APPENDIX B

DATA FILES FOR SIMULATION RUN TO CALIBRATE THE MODEL

TABLE B1

DATA FILE FOR SIMULATION RUN TO CALIBRATE THE MODEL (LAKE COUNTY)

```
   1BASE CONDITION - ROLLING TERRAIN FOR LAKE COUNTY SITE
    RUN NO. 1 USING 473/270 AS THE FLOW RATE AND NEW PS/SL CARDS
1 3600   1       5.0       60.0       1.0       5.0       -1.
2             27456.        8.        10.      800.     2000.       0.2
3   473.   65.      1  270.   50.     1
41.0023 .0184 .0069 .0023 0.0   0.0   0.0   0.0   0.0   0.0   0.0    .675  .294
52.008  .0488 .0122 .0162 0.0   0.0   0.0   0.0   0.0   0.0   0.0    .622  .292
6   92.4  8.58  -1.5  -2.2    0..6293 1.6293  .81   .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
9   1985      1     5     3     4    50      0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                     266.       620.      65.        1.0     .957
VC  2                     196.       420.      65.        1.0     .957
VC  3                     128.       284.      65.        1.0     .957
VC  4                      72.       158.      30.        1.0     .957
VC  5                     8.22       78.7      36.
VC  6                     8.64       89.7      28.
VC  7                     8.75       96.0      21.
VC  8                     8.76       97.5      32.
VC  9                    9.277     109.14      13.
VC 10                    9.766     114.89      14.
VC 11                   10.089     118.69      16.
VC 12                   10.429     122.69      17.
VC 13                   11.201     131.78      18.
CV       9         1     3376.      3784.    0.091        1.5
CV       9         2     4062.      5679.    0.093        1.0
CV       9         3     5330.      5142.    0.087        1.1
CV       9         4     6597.      2900.    0.090       -2.0
CV       9         5     9237.      2565.    0.097       -2.2
CV       9         6     9765.      5165.    0.078        1.1
CV       9         7    10504.      5521.    0.081        1.0
CV       9         8    23810.      7957.    0.091       -0.7
CV       9         9    26766.      5495.    0.084       -1.0
ST  1    5    5    1     3218.       800.     800.      4274.
ST  1    5    5    2     5200.       800.     800.      6700.
ST  1    5    5    3     8800.       800.     800.      9700.
ST  1    5    5    4    19058.       800.     800.     19902.
ST  1    5    5    5    23100.       800.     800.     23400.
ST  2    5    5    1    23500.       800.     800.     23300.
ST  2    5    5    2    14306.       800.     800.     13144.
ST  2    5    5    3     9750.       800.     800.      8650.
ST  2    5    5    4     6900.       800.     800.      5500.
ST  2    5    5    5     4960.      1000.    1000.      2900.
RN                   93742469. 99230755.  1120379. 41724931. 81500573.
```

TABLE B1(Con'd)

GD	1	30			0.	0.	0.	7525.
GD	2	30			7525.	1.54	1.54	7978.
GD	3	30			7978.	0.21	0.21	8022.
GD	4	30			8022.	0.	0.	8603.
GD	5	30			8603.	0.21	0.21	8698.
GD	6	30			8698.	0.84	0.84	9273.
GD	7	30			9273.	-2.34	-2.34	9818.
GD	8	30			9818.	0.	0.	11349.
GD	9	30			11349.	-0.61	-0.61	11463.
GD	10	30			11463.	2.21	2.21	12277.
GD	11	30			12277.	0.12	0.12	12299.
GD	12	30			12299.	0.	0.	13461.
GD	13	30			13461.	1.52	1.52	13669.
GD	14	30			13669.	-2.33	-2.33	14837.
GD	15	30			14837.	1.15	1.15	15256.
GD	16	30			15256.	0.	0.	16734.
GD	17	30			16734.	1.15	1.15	16927.
GD	18	30			16927.	-2.00	-2.00	17358.
GD	19	30			17358.	-1.28	-1.28	17421.
GD	20	30			17421.	0.	0.	17949.
GD	21	30			17949.	-1.28	-1.28	18041.
GD	22	30			18041.	-2.41	-2.41	18213.
GD	23	30			18213.	0.	0.	19005.
GD	24	30			19005.	-2.38	-2.38	19484.
GD	25	30			19484.	1.03	1.03	19962.
GD	26	30			19962.	-0.98	-0.98	20219.
GD	27	30			20219.	0.	0.	23018.
GD	28	30			23018.	-0.75	-0.75	23076.
GD	29	30			23076.	1.30	1.30	23546.
GD	30	30			23546.	0.	0.	27456.
PS	1	14	14	1	0.	1.		
PS	1	14	14	2	3218.	-1.		
PS	1	14	14	3	4274.	1.		
PS	1	14	14	4	5200.	-1.		
PS	1	14	14	5	6700.	1.		
PS	1	14	14	6	8800.	-1.		
PS	1	14	14	7	9700.	1.		
PS	1	14	14	8	12299.	2.	2.	
PS	1	14	14	9	18266.	0.		
PS	1	14	14	10	19058.	-1.		
PS	1	14	14	11	19902.	0.		
PS	1	14	14	12	20906.	1.		
PS	1	14	14	13	23100.	-1.		
PS	1	14	14	14	23400.	1.		
PS	2	14	14	1	27456.	1.		
PS	2	14	14	2	23500.	-1.		
PS	2	14	14	3	23300.	1.		

TABLE B1(Con'd)

```
PS  2   14   14    4    20906.       2.         2.
PS  2   14   14    5    14886.       0.
PS  2   14   14    6    14306.      -1.
PS  2   14   14    7    13144.       0.
PS  2   14   14    8    12299.       1.
PS  2   14   14    9     9750.      -1.
PS  2   14   14   10     8650.       1.
PS  2   14   14   11     6900.      -1.
PS  2   14   14   12     5500.       1.
PS  2   14   14   13     4960.      -1.
PS  2   14   14   14     2901.       1.
SL       1    1    0      500.         500 FT UPSTREAM OF MP 0.0 (SB)
SL       2    1    1     1000.         MP 0.0 BEG OF TEST ROAD
SL       3    1    0    10715.         MP 1.84 FIRST STATION UPST 0.3 MI
SL       4    1    2    12299.         MP 2.14 BEG OF PASSING LANE
SL       5    1    2    17632.         MP 3.15
SL       6    1    0    18266.         MP 3.27 END OF PASSING LANE
SL       7    1    3    20906.         MP 3.77 0.5 MI DOWNST OF PASS LANE
SL       8    1    0    26186.         MP 4.77 - 1.5 MI DOWNST OF PASS LANE
SL       1    2    0    26956.         770 FT UPSTREAM OF MP 4.77 (NB)
SL       2    2    1    26186.         MP 4.77 (NB)
SL       3    2    0    23546.         MP 4.27 - 0.5 MI UPST OF PASS LANE
SL       4    2    2    20906.         MP 3.77 BEG OF PASSING LANE
SL       5    2    2    15678.         MP 2.78
SL       6    2    0    14886.         MP 2.63 END OF PASSING LANE
SL       7    2    3    12246.         MP 2.13 - 0.5 MI DOWNST OF PASS LANE
SL       8    2    0     6066.         MP 1.13 - 1.5 MI DOWNST OF PASS LANE
SL       9    2    0     1000.         MP 0.0 END OF TEST ROAD
SL      10    2    0      500.         500 FT DOWNSTREAM OF MP 0.0 (NB)
 -1
```

TABLE B2

DATA FILE FOR SIMULATION RUN TO CALIBRATE THE MODEL (CLARE COUNTY)

```
    1BASE CONDITION - ROLLING TERRAIN - CLARE COUNTY SITE
    RUN NO. 1 USING 415/226 AS THE FLOW RATE AND NEW PS/SL CARDS
1 3600   1       5.0       60.0       1.0       5.0       -1.
2             28400.        9.        11.      800.     2000.       0.2
3  415.   59.      1  226.   32.     1
41.003  .02   .01   .007  0.0   0.0   0.0   0.0   0.0   0.0   0.0   .712  .248
52.018 .062  .013   .007  0.0   0.0   0.0   0.0   0.0   0.0   0.0   .610  .290
6   92.4  8.58  -1.0  -2.2    0..6293 1.6293   .81   .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
9   1985     1     5     3     4    50     0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                      266.      620.       65.       1.0      .957
VC  2                      196.      420.       65.       1.0      .957
VC  3                      128.      284.       65.       1.0      .957
VC  4                       72.      158.       30.       1.0      .957
VC  5                      8.22      78.7       36.
VC  6                      8.64      89.7       28.
VC  7                      8.75      96.0       21.
VC  8                      8.76      97.5       32.
VC  9                     9.277    109.14       13.
VC 10                     9.766    114.89       14.
VC 11                    10.089    118.69       16.
VC 12                    10.429    122.69       17.
VC 13                    11.201    131.78       18.
CV       3         1      9342.      904.     0.075       6.3
CV       3         2     10768.     2689.     0.040       2.1
CV       3         3     22278.     5872.     0.025       1.0
ST  1    3    3    1      9000.      800.      800.     9800.
ST  1    3    3    2     10200.      800.      800.    11200.
ST  1    3    3    3     22000.      800.      800.    23000.
ST  2    3    3    1     26500.      800.      800.    25500.
ST  2    3    3    2     11200.      800.      800.    10200.
ST  2    3    3    3      9800.      800.      800.     9000.
RN                    93742469. 99230755.  1120379. 41724931. 81500573.
GD  1   22                   0.        0.        0.     1792.
GD  2   22                1792.      0.24      0.24     1869.
GD  3   22                1869.     -0.58     -0.58     2056.
GD  4   22                2056.        0.        0.     7072.
GD  5   22                7072.     -0.46     -0.46     7685.
GD  6   22                7685.      0.40      0.40     8035.
GD  7   22                8035.     -1.05     -1.05     8828.
GD  8   22                8828.      1.42      1.42     9132.
GD  9   22                9132.      1.05      1.05     9400.
GD 10   22                9400.     -2.46     -2.46     9659.
GD 11   22                9659.        0.        0.    14464.
GD 12   22               14464.      0.20      0.20    14485.
GD 13   22               14485.     -0.81     -0.81    14570.
GD 14   22               14570.        0.        0.    18425.
GD 15   22               18425.     -1.56     -1.56    18636.
```

TABLE B2(Con'd.)

```
GD 16   22                  18636.       0.         0.     22331.
GD 17   22                  22331.    -0.17      -0.17     22395.
GD 18   22                  22395.    -1.10      -1.10     22806.
GD 19   22                  22806.       0.         0.     23810.
GD 20   22                  23810.    -1.10      -1.10     24089.
GD 21   22                  24089.    -0.15      -0.15     24127.
GD 22   22                  24127.       0.         0.     28400.
PS  1   10    10     1          0.       1.
PS  1   10    10     2       9000.      -1.
PS  1   10    10     3       9800.       1.
PS  1   10    10     4      10200.      -1.
PS  1   10    10     5      11200.       1.
PS  1   10    10     6      11560.       2.         2.
PS  1   10    10     7      16154.      -1.
PS  1   10    10     8      18688.       1.
PS  1   10    10     9      22000.      -1.
PS  1   10    10    10      23000.       1.
PS  2   10    10     1      28400.       1.
PS  2   10    10     2      26500.      -1.
PS  2   10    10     3      25500.       1.
PS  2   10    10     4      18688.       2.         2.
PS  2   10    10     5      12986.      -1.
PS  2   10    10     6      11560.       1.
PS  2   10    10     7      11200.      -1.
PS  2   10    10     8      10200.       1.
PS  2   10    10     9       9800.      -1.
PS  2   10    10    10       9000.       1.
SL       1     1     0        500.        500 FT UPSTREAM OF MP 0.0 (SE)
SL       2     1     1       1000.        MP 0.0 BEG OF THE ROAD
SL       3     1     0       8920.        MP 1.50 FIRST STATION UPST 0.5 MI
SL       4     1     2      11560.        MP 2.0  BEG OF PASSING LANE 1
SL       5     1     2      13883.        MP 2.44 MIDDLE OF PASSING LANE 1
SL       6     1     0      16154.        MP 2.87 END OF PASSING LANE 1
SL       7     1     3      18794.        MP 3.37 0.5 MI DOWNST OF PL 1
SL       8     1     4      21434.        MP 3.87 1.0 MI DOWNST OF PL 1
SL       9     1     0      26714.        MP 4.87 2.0 MI DOWNST OF PL 1
SL       1     2     0      27900.        1186 FT UPST OF MP 4.87
SL       2     2     1      26714.        MP 4.87 (NE)
SL       3     2     0      21328.        MP 3.85 STATION 0.5 MI UPST PL2
SL       4     2     2      18688.        MP 3.35 BEG OF PASSING LANE 2
SL       5     2     2      15784.        MP 2.8 MIDDLE OF PL 2
SL       6     2     0      12986.        MP 2.27 END OF PASSING LANE 2
SL       7     2     3      10346.        MP 1.77 - 0.5 MI DOWNST OF PL 2
SL       8     2     4       7706.        MP 1.27 - 1.0 MI DOWNST OF PL 2
SL       9     2     0       5066.        MP 0.77 - 1.5 MI DOWNST OF PL 2
SL      10     2     0       1000.        MP 0.0  END OF THE ROAD
SL      11     2     0        500.        500 FT DOWNSTREAM OF MP 0.0 (NE)
 -1
```

TABLE B3

DATA FILE FOR SIMULATION RUNS FOR ONE-PL, GRADE-4% AND TERRAIN CHANGE @ 1-MILE

```
  1BASE COND - ROLLING EVERY 1-MILE WITH ONE-PL GRADE-4% NO-PASS-50%
     RUN NO. 1 USING 500/500 AS THE FLOW RATE AND TRUCK-5% FILE-LAKEE
1 3600   1       5.0      30.0       1.0       5.0        -1.
2             44240.        11.       5.       800.     2000.       0.2
3   500.   50.     1  500.   50.     1
41.0055 .0285 .008  .008  0.0   0.0   0.0   0.0   0.0   0.0   0.0    .65   .30
52.0055 .0285 .008  .008  0.0   0.0   0.0   0.0   0.0   0.0   0.0    .65   .30
6   92.4  8.58 -1.0  -2.2     0..6293 1.6293   .81    .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.
9    1985    1     5     3     4    50     0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                     266.      620.       65.        1.0      .957
VC  2                     196.      420.       65.        1.0      .957
VC  3                     128.      284.       65.        1.0      .957
VC  4                      72.      158.       30.        1.0      .957
VC  5                     8.22      78.7       36.
VC  6                     8.64      89.7       28.
VC  7                     8.75      96.0       21.
VC  8                     8.76      97.5       32.
VC  9                    9.277    109.14       13.
VC 10                    9.766    114.89       14.
VC 11                   10.089    118.69       16.
VC 12                   10.429    122.69       17.
VC 13                   11.201    131.78       18.
ST  1    6    7    1     4655.      600.      600.      7905.
ST  1    6    7    2     9935.      600.      600.     13185.
ST  1    6    7    3    15215.      600.      600.     18465.
ST  1    6    7    4    25775.      600.      600.     29025.
ST  1    6    7    5    31055.      600.      600.     34305.
ST  1    6    7    6    36335.      600.      600.     39585.
ST  2    6    7    1    39585.      600.      600.     36335.
ST  2    6    7    2    34205.      600.      600.     31055.
ST  2    6    7    3    29025.      600.      600.     25775.
ST  2    6    7    4    23745.      600.      600.     20495.
ST  2    6    7    5    18465.      600.      600.     15215.
ST  2    6    7    6    13185.      600.      600.      9935.
ST  2    6    7    7     7905.      600.      600.      4655.
RN                   93742469. 99230755.  1120379. 41724931. 81500573.
GD  1   16                  0.        0.        0.      3640.
GD  2   16               3640.       4.0       4.0      6280.
GD  3   16               6280.      -4.0      -4.0      8920.
GD  4   16               8920.       4.0       4.0     11560.
```

TABLE B3(Con'd.)

GD	5	16			11560.	-4.0	-4.0	14200.
GD	6	16			14200.	4.0	4.0	16840.
GD	7	16			16840.	-4.0	-4.0	19480.
GD	8	16			19480.	4.0	4.0	22120.
GD	9	16			22120.	-4.0	-4.0	24760.
GD	10	16			24760.	4.0	4.0	27400.
GD	11	16			27400.	-4.0	-4.0	30040.
GD	12	16			30040.	4.0	4.0	32680.
GD	13	16			32680.	-4.0	-4.0	35320.
GD	14	16			35320.	4.0	4.0	37960.
GD	15	16			37960.	-4.0	-4.0	40600.
GD	16	16			40600.	0.	0.	44240.
PS	1	15	17	1	0.	1.		
PS	1	15	17	2	4655.	-1.		
PS	1	15	17	3	7905.	1.		
PS	1	15	17	4	9935.	-1.		
PS	1	15	17	5	13185.	1.		
PS	1	15	17	6	15215.	-1.		
PS	1	15	17	7	18465.	1.		
PS	1	15	17	8	19480.	2.	2.	
PS	1	15	17	9	24760.	1.		
PS	1	15	17	10	25775.	-1.		
PS	1	15	17	11	29025.	1.		
PS	1	15	17	12	31055.	-1.		
PS	1	15	17	13	34305.	1.		
PS	1	15	17	14	36335.	-1.		
PS	1	15	17	15	39585.	1.		
PS	2	15	17	1	44240.	1.		
PS	2	15	17	2	39585.	-1.		
PS	2	15	17	3	36335.	1.		
PS	2	15	17	4	34305.	-1.		
PS	2	15	17	5	31055.	1.		
PS	2	15	17	6	29025.	-1.		
PS	2	15	17	7	25775.	1.		
PS	2	15	17	8	24760.	0.		
PS	2	15	17	9	23745.	-1.		
PS	2	15	17	10	20495.	0.		
PS	2	15	17	11	19480.	1.		
PS	2	15	17	12	18465.	-1.		
PS	2	15	17	13	15215.	1.		
PS	2	15	17	14	13185.	-1.		
PS	2	15	17	15	9935.	1.		
PS	2	15	17	16	7905.	-1.		
PS	2	15	17	17	4655.	1.		

TABLE B3(Con'd)

```
SL     1   1   0     500.        500 FT UPSTREAM OF MP 0.0 (D1)
SL     2   1   1    1000.        MP 0.0 BEG OF ROAD
SL     3   1   0   18424.        MP 3.3 0.2 MI UPST OF PL
SL     4   1   2   19480.        MP 3.5 BEG OF PL
SL     5   1   2   22120.        MP 4.0 MIDDLE OF PL
SL     6   1   3   24760.        MP 4.5 END OF PL
SL     7   1   3   25816.        MP 4.7 0.2 MI DNST OF PL
SL     8   1   4   30040.        MP 5.5 1.0 MI DNST OF PL
SL     9   1   5   35320.        MP 6.5 2.0 MI DNST OF PL
SL    10   1   0   40600.        MP 7.5 3.0 MI DNST OF PL
SL    11   1   0   43240.        MP 8.0 END OF THE ROAD
SL     1   2   0   43740.        500 FT UPST OF MP 8.00 (D2)
SL     2   2   1   43240.        MP 8.00 (D2)
SL     3   2   1   22120.        MP 4.0 MIDDLE OF THE ROAD
SL     4   2   0    1000.        MP 0.0 (D2)
SL     5   2   0     500.        500 FT DNST OF MP 0.0 (D2)
  -1
```

TABLE B4

DATA FILE FOR SIMULATION RUNS FOR ONE-PL, GRADE-4%, TERRAIN CHANGE @ 1/2-MILE

```
 1BASE COND - ROLLING EVERY 1/2 MILE WITH ONE-PL GRADE-4% NO-PASS-50%
  RUN NO. 1 USING 500/500 AS THE FLOW RATE AND TRUCK-5% FILE-LAKEL
1 3600   1       5.0      30.0       1.0       5.0       -1.
2            44240.       11.        5.      800.      2000.       0.2
3   500.   50.     1  500.   50.     1
41.0055 .0285 .008  .008 0.0   0.0   0.0   0.0   0.0   0.0   0.0   .650  .30
52.0055 .0285 .008  .008 0.0   0.0   0.0   0.0   0.0   0.0   0.0   .650  .30
6   92.4  8.58  -1.0  -2.2   0..6293 1.6293  .81   .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
9   1985     1     5     3     4    50    0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                    266.      620.       65.       1.0      .957
VC  2                    196.      420.       65.       1.0      .957
VC  3                    128.      284.       65.       1.0      .957
VC  4                     72.      158.       30.       1.0      .957
VC  5                    8.22      78.7       36.
VC  6                    8.64      89.7       28.
VC  7                    8.75      96.0       21.
VC  8                    8.76      97.5       32.
VC  9                   9.277    109.14       13.
VC 10                   9.766    114.89       14.
VC 11                  10.089    118.69       16.
VC 12                  10.429    122.69       17.
VC 13                  11.201    131.78       18.
ST  1   12   14    1     4160.      600.      600.     5760.
ST  1   12   14    2     6800.      600.      600.     8400.
ST  1   12   14    3     9440.      600.      600.    11040.
ST  1   12   14    4    12080.      600.      600.    13680.
ST  1   12   14    5    14720.      600.      600.    16320.
ST  1   12   14    6    17360.      600.      600.    18960.
ST  1   12   14    7    25280.      600.      600.    26880.
ST  1   12   14    8    27920.      600.      600.    29520.
ST  1   12   14    9    30560.      600.      600.    32160.
ST  1   12   14   10    33200.      600.      600.    34800.
ST  1   12   14   11    35840.      600.      600.    37440.
ST  1   12   14   12    38480.      600.      600.    40080.
ST  2   12   14    1    40080.      600.      600.    38480.
ST  2   12   14    2    37440.      600.      600.    35840.
ST  2   12   14    3    34800.      600.      600.    33200.
ST  2   12   14    4    32160.      600.      600.    30560.
ST  2   12   14    5    29520.      600.      600.    27920.
ST  2   12   14    6    26880.      600.      600.    25280.
ST  2   12   14    7    24400.      600.      600.    22480.
```

TABLE B4(Con'd)

ST	2	12	14	8	21760.	600.	600.	19840.	
ST	2	12	14	9	18960.	600.	600.	17360.	
ST	2	12	14	10	16320.	600.	600.	14720.	
ST	2	12	14	11	13680.	600.	600.	12080.	
ST	2	12	14	12	11040.	600.	600.	9440.	
ST	2	12	14	13	8400.	600.	600.	6800.	
ST	2	12	14	14	5760.	600.	600.	4160.	
RN					93742469.	99230755.	1120379.	41724931.	81500573.
GD	1	30			0.	0.	0.	3640.	
GD	2	30			3640.	4.0	4.0	4960.	
GD	3	30			4960.	-4.0	-4.0	6280.	
GD	4	30			6280.	4.0	4.0	7600.	
GD	5	30			7600.	-4.0	-4.0	8920.	
GD	6	30			8920.	4.0	4.0	10240.	
GD	7	30			10240.	-4.0	-4.0	11560.	
GD	8	30			11560.	4.0	4.0	12880.	
GD	9	30			12880.	-4.0	-4.0	14200.	
GD	10	30			14200.	4.0	4.0	15520.	
GD	11	30			15520.	-4.0	-4.0	16840.	
GD	12	30			16840.	4.0	4.0	18160.	
GD	13	30			18160.	-4.0	-4.0	19480.	
GD	14	30			19480.	4.0	4.0	20800.	
GD	15	30			20800.	-4.0	-4.0	22120.	
GD	16	30			22120.	4.0	4.0	23440.	
GD	17	30			23440.	-4.0	-4.0	24760.	
GD	18	30			24760.	4.0	4.0	26080.	
GD	19	30			26080.	-4.0	-4.0	27400.	
GD	20	30			27400.	4.0	4.0	28720.	
GD	21	30			28720.	-4.0	-4.0	30040.	
GD	22	30			30040.	4.0	4.0	31360.	
GD	23	30			31360.	-4.0	-4.0	32680.	
GD	24	30			32680.	4.0	4.0	34000.	
GD	25	30			34000.	-4.0	-4.0	35320.	
GD	26	30			35320.	4.0	4.0	36640.	
GD	27	30			36640.	-4.0	-4.0	37960.	
GD	28	30			37960.	4.0	4.0	39280.	
GD	29	30			39280.	-4.0	-4.0	40600.	
GD	30	30			40600.	0.	0.	44240.	
PS	1	27	31	1	0.	1.			
PS	1	27	31	2	4160.	-1.			
PS	1	27	31	3	5760.	1.			
PS	1	27	31	4	6800.	-1.			
PS	1	27	31	5	8400.	1.			
PS	1	27	31	6	9440.	-1.			
PS	1	27	31	7	11040.	1.			
PS	1	27	31	8	12080.	-1.			
PS	1	27	31	9	13680.	1.			

TABLE B4(Con'd.)

PS	1	27	31	10	14720.	-1.	
PS	1	27	31	11	16320.	1.	
PS	1	27	31	12	17360.	-1.	
PS	1	27	31	13	18960.	1.	
PS	1	27	31	14	19480.	2.	2.
PS	1	27	31	15	24760.	1.	
PS	1	27	31	16	25280.	-1.	
PS	1	27	31	17	26880.	1.	
PS	1	27	31	18	27920.	-1.	
PS	1	27	31	19	29520.	1.	
PS	1	27	31	20	30560.	-1.	
PS	1	27	31	21	32160.	1.	
PS	1	27	31	22	33200.	-1.	
PS	1	27	31	23	34800.	1.	
PS	1	27	31	24	35840.	-1.	
PS	1	27	31	25	37440.	1.	
PS	1	27	31	26	38480.	-1.	
PS	1	27	31	27	40080.	1.	
PS	2	27	31	1	44240.	1.	
PS	2	27	31	2	40080.	-1.	
PS	2	27	31	3	38480.	1.	
PS	2	27	31	4	37440.	-1.	
PS	2	27	31	5	35840.	1.	
PS	2	27	31	6	34800.	-1.	
PS	2	27	31	7	33200.	1.	
PS	2	27	31	8	32160.	-1.	
PS	2	27	31	9	30560.	1.	
PS	2	27	31	10	29520.	-1.	
PS	2	27	31	11	27920.	1.	
PS	2	27	31	12	26880.	-1.	
PS	2	27	31	13	25280.	1.	
PS	2	27	31	14	24760.	0.	
PS	2	27	31	15	24400.	-1.	
PS	2	27	31	16	22480.	0.	
PS	2	27	31	17	21760.	-1.	
PS	2	27	31	18	19840.	0.	
PS	2	27	31	19	19480.	1.	
PS	2	27	31	20	18960.	-1.	

TABLE B4(Con'd.)

```
PS  2   27   31   21    17360.       1.
PS  2   27   31   22    16320.      -1.
PS  2   27   31   23    14720.       1.
PS  2   27   31   24    13680.      -1.
PS  2   27   31   25    12080.       1.
PS  2   27   31   26    11040.      -1.
PS  2   27   31   27     9440.       1.
PS  2   27   31   28     8400.      -1.
PS  2   27   31   29     6800.       1.
PS  2   27   31   30     5760.      -1.
PS  2   27   31   31     4160.       1.
SL       1    1    0      500.         500 FT UPSTREAM OF MP 0.0 (D1)
SL       2    1    1     1000.         MP 0.0 BEG OF ROAD
SL       3    1    0    18480.         MP 3.3 0.2 MI UPST OF PL
SL       4    1    2    19480.         MP 3.5 BEG OF PL
SL       5    1    2    22120.         MP 4.0 MIDDLE OF PL
SL       6    1    3    24760.         MP 4.5 END OF PL
SL       7    1    3    25816.         MP 4.7 0.2 MI DNST OF PL
SL       8    1    4    30040.         MP 5.5 1.0 MI DNST OF PL
SL       9    1    5    35320.         MP 6.5 2.0 MI DNST OF PL
SL      10    1    0    40600.         MP 7.5 3.0 MI DNST OF PL
SL      11    1    0    43240.         MP 8.0 END OF THE ROAD
SL       1    2    0    43740.         500 FT UPST OF MP 8.00 (D2)
SL       2    2    1    43240.         MP 8.00 (D2)
SL       3    2    1    22120.         MP 4.0 MIDDLE OF THE ROAD
SL       4    2    0     1000.         MP 0.0 (D2)
SL       5    2    0      500.         500 FT DNST OF MP 0.0 (D2)
  -1
```

TABLE B5

DATA FILE FOR SIMULATION RUNS FOR TWO-PLS, GRADE-4%, TERRAIN CHANGE @ 1-MILE

```
   1BASE COND - ROLLING EVERY-1 MILE WITH TWO-PL GRADE-4% NO-PASS-50%
    RUN NO. 1 USING 500/500 AS THE FLOW RATE AND TRUCK-5% FILE-LAKEO
1 3600  1      5.0     30.0      1.0      5.0      -1.
2           44240.      15.        5.     800.    2000.      0.2
3   500.  50.    1  500.  50.    1
41.0055 .0285 .008  .008 0.0  0.0  0.0  0.0  0.0  0.0  0.0  .650 .30
52.0055 .0285 .008  .008 0.0  0.0  0.0  0.0  0.0  0.0  0.0  .650 .30
6   92.4  8.58  -1.0  -2.2   0..6293 1.6293  .81  .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
9   1985     1     5     3     4    50     0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                  266.     620.      65.      1.0     .957
VC  2                  196.     420.      65.      1.0     .957
VC  3                  128.     284.      65.      1.0     .957
VC  4                   72.     158.      30.      1.0     .957
VC  5                  8.22     78.7      36.
VC  6                  8.64     89.7      28.
VC  7                  8.75     96.0      21.
VC  8                  8.76     97.5      32.
VC  9                 9.277   109.14      13.
VC 10                 9.766   114.89      14.
VC 11                10.089   118.69      16.
VC 12                10.429   122.69      17.
VC 13                11.201   131.78      18.
ST  1   6   8    1    2140.     600.     600.    5140.
ST  1   6   8    2    7420.     600.     600.   10420.
ST  1   6   8    3   17980.     600.     600.   20980.
ST  1   6   8    4   23260.     600.     600.   26260.
ST  1   6   8    5   33820.     600.     600.   36820.
ST  1   6   8    6   39100.     600.     600.   42100.
ST  2   6   8    1   42100.     600.     600.   39100.
ST  2   6   8    2   36820.     600.     600.   33820.
ST  2   6   8    3   31600.     600.     600.   28480.
ST  2   6   8    4   26260.     600.     600.   23260.
ST  2   6   8    5   20980.     600.     600.   17980.
ST  2   6   8    6   15760.     600.     600.   12640
ST  2   6   8    7   10420.     600.     600.    7420.
ST  2   6   8    8    5140.     600.     600.    2140.
RN                93742469. 99230755.  1120379. 41724931. 81500573.
GD  1  18                0.       0.       0.    1000.
GD  2  18             1000.      4.0      4.0    3640.
GD  3  18             3640.     -4.0     -4.0    6280.
GD  4  18             6280.      4.0      4.0    8920.
GD  5  18             8920.     -4.0     -4.0   11560.
```

TABLE B5(Con'd)

GD	6	18			11560.	4.0	4.0	14200.
GD	7	18			14200.	-4.0	-4.0	16840.
GD	8	18			16840.	4.0	4.0	19480.
GD	9	18			19480.	-4.0	-4.0	22120.
GD	10	18			22120.	4.0	4.0	24760.
GD	11	18			24760.	-4.0	-4.0	27400.
GD	12	18			27400.	4.0	4.0	30040.
GD	13	18			30040.	-4.0	-4.0	32680.
GD	14	18			32680.	4.0	4.0	35320.
GD	15	18			35320.	-4.0	-4.0	37960.
GD	16	18			37960.	4.0	4.0	40600.
GD	17	18			40600.	-4.0	-4.0	43240.
GD	18	18			43240.	0.	0.	44240.
PS	1	17	21	1	0.	1.		
PS	1	17	21	2	2140.	-1.		
PS	1	17	21	3	5140.	1.		
PS	1	17	21	4	7420.	-1.		
PS	1	17	21	5	10420.	1.		
PS	1	17	21	6	11560.	2.	2.	
PS	1	17	21	7	16840.	1.		
PS	1	17	21	8	17980.	-1.		
PS	1	17	21	9	20980.	1.		
PS	1	17	21	10	23260.	-1.		
PS	1	17	21	11	26260.	1.		
PS	1	17	21	12	27400.	2.	2.	
PS	1	17	21	13	32680.	1.		
PS	1	17	21	14	33820.	-1.		
PS	1	17	21	15	36820.	1.		
PS	1	17	21	16	39100.	-1.		
PS	1	17	21	17	42100.	1.		
PS	2	17	21	1	44240.	1.		
PS	2	17	21	2	42100.	-1.		
PS	2	17	21	3	39100.	1.		
PS	2	17	21	4	36820.	-1.		
PS	2	17	21	5	33820.	1.		
PS	2	17	21	6	32680.	0.		
PS	2	17	21	7	31600.	-1.		
PS	2	17	21	8	28480.	0.		
PS	2	17	21	9	27400.	1.		
PS	2	17	21	10	26260.	-1.		
PS	2	17	21	11	23260.	1.		
PS	2	17	21	12	20980.	-1.		
PS	2	17	21	13	17980.	1.		
PS	2	17	21	14	16840.	0.		
PS	2	17	21	15	15760.	-1.		

TABLE B5(Con'd.)

```
PS  2   17   21   16    12640.          0.
PS  2   17   21   17    11560.          1.
PS  2   17   21   18    10420.         -1.
PS  2   17   21   19     7420.          1.
PS  2   17   21   20     5140.         -1.
PS  2   17   21   21     2140.          1.
SL       1    1    0      500.          500 FT UPSTREAM OF MP 0.0 (D1)
SL       2    1    1     1000.          MP 0.0 BEG OF ROAD
SL       3    1    0     8920.          MP 1.5 0.5 MI UPST OF PL 1
SL       4    1    2    11560.          MP 2.0 BEG OF PL 1
SL       5    1    2    14200.          MP 2.5 MIDDLE OF PL 1
SL       6    1    3    16840.          MP 3.0 END OF PL 1
SL       7    1    3    19480.          MP 3.5 0.5 MI DNST OF PL
SL       8    1    4    22120.          MP 4.0 1.0 MI DNST OF PL
SL       9    1    0    24760.          MP 4.5 1.5 MI DNST OF PL
SL      10    1    5    27400.          MP 5.0 BEG OF PL 2
SL      11    1    5    30040.          MP 5.5 MIDDLE OF PL 2
SL      12    1    6    32680.          MP 6.0 END OF PL 2
SL      13    1    6    35320.          MP 6.5 0.5 MI DNST OF PL 2
SL      14    1    7    37960.          MP 7.0 1.0 MI DNST OF PL 2
SL      15    1    0    43240.          MP 8.0 2.0 MI DNST OF PL 2
SL       1    2    0    43740.          500 FT UPST OF MP 8.00 (D2)
SL       2    2    1    43240.          MP 8.00 (D2)
SL       3    2    1    22120.          MP 4.0 MIDDLE OF THE ROAD
SL       4    2    0     1000.          MP 0.0 (D2)
SL       5    2    0      500.          500 FT DNST OF MP 0.0 (D2)
  -1
```

TABLE B6

DATA FILE FOR SIMULATION RUNS FOR TWO-PLS, GRADE-4%, TERRAIN CHANGE @ 1/2 MI

```
   1BASE COND - ROLLING EVERY-1/2 MI WITH TWO-PL GRADE-4% NO-PASS-50%
    RUN NO. 1 USING 500/500 AS THE FLOW RATE AND TRUCK-5% FILE-LAKER
1 3600   1       5.0        30.0        1.0        5.0       -1.
2              44240.        15.         5.        800.      2000.        0.2
3  500.   50.      1  500.   50.      1
41.0055 .0285 .008  .008  0.0   0.0   0.0   0.0   0.0   0.0   0.0   .650  .30
52.0055 .0285 .008  .008  0.0   0.0   0.0   0.0   0.0   0.0   0.0   .650  .30
6   92.4  8.58  -1.0  -2.2    0..6293 1.6293   .81   .90
71  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
82  150.  150.  150.  150.  150.  150.  150.  150.  150.  150.  150. 150. 150.
9   1985     1     5     3     4    50     0
10   0.5  0.43  0.51  0.57  0.65  0.76  0.91  1.13  1.34  1.58  2.12
VC  1                      266.       620.       65.       1.0       .957
VC  2                      196.       420.       65.       1.0       .957
VC  3                      128.       284.       65.       1.0       .957
VC  4                       72.       158.       30.       1.0       .957
VC  5                      8.22       78.7       36.
VC  6                      8.64       89.7       28.
VC  7                      8.75       96.0       21.
VC  8                      8.76       97.5       32.
VC  9                     9.277     109.14       13.
VC 10                     9.766     114.89       14.
VC 11                    10.089     118.69       16.
VC 12                    10.429     122.69       17.
VC 13                    11.201     131.78       18.
ST  1    10    14    1    4080.       600.      600.     5840.
ST  1    10    14    2    6720.       600.      600.     8480.
ST  1    10    14    3    9360.       600.      600.    11120.
ST  1    10    14    4   17280.       600.      600.    19040.
ST  1    10    14    5   19920.       600.      600.    21680.
ST  1    10    14    6   22560.       600.      600.    24320.
ST  1    10    14    7   25200.       600.      600.    26960.
ST  1    10    14    8   33120.       600.      600.    34880.
ST  1    10    14    9   35760.       600.      600.    37520.
ST  1    10    14   10   38400.       600.      600.    40160.
ST  2    10    14    1   40160.       600.      600.    38400.
ST  2    10    14    2   37520.       600.      600.    35760.
ST  2    10    14    3   34880.       600.      600.    33120.
ST  2    10    14    4   32240.       600.      600.    30480.
ST  2    10    14    5   29600.       600.      600.    27840.
ST  2    10    14    6   26960.       600.      600.    25200.
ST  2    10    14    7   24320.       600.      600.    22560.
ST  2    10    14    8   21680.       600.      600.    19920.
ST  2    10    14    9   19040.       600.      600.    17280.
ST  2    10    14   10   16400.       600.      600.    14640.
```

TABLE B6(Con'd.)

ST	2	10	14	11	13760.	600.	600.	12000.	
ST	2	10	14	12	11120.	600.	600.	9360.	
ST	2	10	14	13	8480.	600.	600.	6720.	
ST	2	10	14	14	5840.	600.	600.	4080.	
RN					93742469.	99230755.	1120379.	41724931.	81500573.
GD	1	30			0.	0.	0.	3640.	
GD	2	30			3640.	4.0	4.0	4960.	
GD	3	30			4960.	-4.0	-4.0	6280.	
GD	4	30			6280.	4.0	4.0	7600.	
GD	5	30			7600.	-4.0	-4.0	8920.	
GD	6	30			8920.	4.0	4.0	10240.	
GD	7	30			10240.	-4.0	-4.0	11560.	
GD	8	30			11560.	4.0	4.0	12880.	
GD	9	30			12880.	-4.0	-4.0	14200.	
GD	10	30			14200.	4.0	4.0	15520.	
GD	11	30			15520.	-4.0	-4.0	16840.	
GD	12	30			16840.	4.0	4.0	18160.	
GD	13	30			18160.	-4.0	-4.0	19480.	
GD	14	30			19480.	4.0	4.0	20800.	
GD	15	30			20800.	-4.0	-4.0	22120.	
GD	16	30			22120.	4.0	4.0	23440.	
GD	17	30			23440.	-4.0	-4.0	24760.	
GD	18	30			24760.	4.0	4.0	26080.	
GD	19	30			26080.	-4.0	-4.0	27400.	
GD	20	30			27400.	4.0	4.0	28720.	
GD	21	30			28720.	-4.0	-4.0	30040.	
GD	22	30			30040.	4.0	4.0	31360.	
GD	23	30			31360.	-4.0	-4.0	32680.	
GD	24	30			32680.	4.0	4.0	34000.	
GD	25	30			34000.	-4.0	-4.0	35320.	
GD	26	30			35320.	4.0	4.0	36640.	
GD	27	30			36640.	-4.0	-4.0	37960.	
GD	28	30			37960.	4.0	4.0	39280.	
GD	29	30			39280.	-4.0	-4.0	40600.	
GD	30	30			40600.	0.	0.	44240.	
PS	1	25	33	1	0.	1.			
PS	1	25	33	2	4080.	-1.			
PS	1	25	33	3	5840.	1.			
PS	1	25	33	4	6720.	-1.			
PS	1	25	33	5	8480.	1.			
PS	1	25	33	6	9360.	-1.			
PS	1	25	33	7	11120.	1.			
PS	1	25	33	8	11560.	2.	2.		
PS	1	25	33	9	16840.	1.			
PS	1	25	33	10	17280.	-1.			

TABLE B6(Con'd.)

PS	1	25	33	11	19040.	1.	
PS	1	25	33	12	19920.	-1.	
PS	1	25	33	13	21680.	1.	
PS	1	25	33	14	22560.	-1.	
PS	1	25	33	15	24320.	1.	
PS	1	25	33	16	25200.	-1.	
PS	1	25	33	17	26960.	1.	
PS	1	25	33	18	27400.	2.	2.
PS	1	25	33	19	32680.	1.	
PS	1	25	33	20	33120.	-1.	
PS	1	25	33	21	34880.	1.	
PS	1	25	33	22	35760.	-1.	
PS	1	25	33	23	37520.	1.	
PS	1	25	33	24	38400.	-1.	
PS	1	25	33	25	40160.	1.	
PS	2	25	33	1	44240.	1.	
PS	2	25	33	2	40160.	-1.	
PS	2	25	33	3	38400.	1.	
PS	2	25	33	4	37520.	-1.	
PS	2	25	33	5	35760.	1.	
PS	2	25	33	6	34880.	-1.	
PS	2	25	33	7	33120.	1.	
PS	2	25	33	8	32680.	0.	
PS	2	25	33	9	32240.	-1.	
PS	2	25	33	10	30480.	0.	
PS	2	25	33	11	29600.	-1.	
PS	2	25	33	12	27840.	0.	
PS	2	25	33	13	27400.	1.	
PS	2	25	33	14	26960.	-1.	
PS	2	25	33	15	25200.	1.	
PS	2	25	33	16	24320.	-1.	
PS	2	25	33	17	22560.	1.	
PS	2	25	33	18	21680.	-1.	
PS	2	25	33	19	19920.	1.	
PS	2	25	33	20	19040.	-1.	
PS	2	25	33	21	17280.	1.	
PS	2	25	33	22	16840.	0.	
PS	2	25	33	23	16400.	-1.	
PS	2	25	33	24	14640.	0.	
PS	2	25	33	25	13760.	-1.	
PS	2	25	33	26	12000.	0.	
PS	2	25	33	27	11560.	1.	
PS	2	25	33	28	11120.	-1.	
PS	2	25	33	29	9360.	1.	
PS	2	25	33	30	8480.	-1.	

TABLE B6(Con'd.)

```
PS  2   25   33   31    6720.        1.
PS  2   25   33   32    5840.       -1.
PS  2   25   33   33    4080.        1.
SL       1    1    0     500.          500 FT UPSTREAM OF MP 0.0 (D1)
SL       2    1    1    1000.          MP 0.0 BEG OF ROAD
SL       3    1    1    8920.          MP 1.5 0.5 MI UPST OF PL 1
SL       4    1    2   11560.          MP 2.0 BEG OF PL 1
SL       5    1    2   14200.          MP 2.5 MIDDLE OF PL 1
SL       6    1    3   16840.          MP 3.0 END OF PL 1
SL       7    1    3   19480.          MP 3.5 0.5 MI DNST OF PL
SL       8    1    4   22120.          MP 4.0 1.0 MI DNST OF PL
SL       9    1    0   24760.          MP 4.5 1.5 MI DNST OF PL
SL      10    1    5   27400.          MP 5.0 BEG OF PL 2
SL      11    1    5   30040.          MP 5.5 MIDDLE OF PL 2
SL      12    1    6   32680.          MP 6.0 END OF PL 2
SL      13    1    6   35320.          MP 6.5 0.5 MI DNST OF PL 2
SL      14    1    7   37960.          MP 7.0 1.0 MI DNST OF PL 2
SL      15    1    0   43240.          MP 8.0 2.0 MI DNST OF PL 2
SL       1    2    0   43740.          500 FT UPST OF MP 8.00 (D2)
SL       2    2    1   43240.          MP 8.00 (D2)
SL       3    2    1   22120.          MP 4.0 MIDDLE OF THE ROAD
SL       4    2    0    1000.          MP 0.0 (D2)
SL       5    2    0     500.          500 FT DNST OF MP 0.0 (D2)
  -1
```

APPENDIX C

VALUES OF TOTAL BENEFITS FOR DIFFERENT TRAFFIC AND ROADWAY CONDITIONS

TABLE C1

DELAY AND TOTAL BENEFITS FOR ONE PL, GRADE-6% & NO-PASSING ZONE-50%

ADT		DELAY AND TOTAL BENEFITS FOR ONE PL ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TE. CH.	1-MI	1/2-MI	1-MI	1/2MI	1-MI	1/2-MI
1000	D	8500	0	0	0	0	12000
	T	13500	5000	5000	5000	5000	17000
2000	D	9000	2000	0	0	0	14000
	T	14000	7000	5000	5000	5000	19000
3000	D	9500	6000	0	0	0	16000
	T	14500	11000	5000	5000	5000	21000
4000	D	10000	10000	0	4000	0	18000
	T	15000	15000	5000	9000	5000	23000
5000	D	11000	14000	0	9000	0	20000
	T	16000	19000	5000	14000	5000	25000
6000	D	12000	18000	2000	13000	0	22000
	T	24900	30900	14900	25900	12900	34900
7000	D	13000	22000	4000	18000	0	23500
	T	25900	34900	16900	30900	12900	36400
8000	D	14000	27000	6000	23000	0	26000
	T	26900	39900	18900	35900	12900	38900
9000	D	14500	31000	8000	28000	0	27500
	T	27400	43900	20900	40900	12900	40400
10000	D	15500	34000	9000	32000	2000	29000
	T	28400	46900	21900	44900	14900	41900
11000	D	16000	39000	10000	37000	4000	31000
	T	36800	59800	30800	57800	24800	51800
12000	D	17000	43000	12000	41000	6000	33000
	T	37800	63800	32800	61800	26800	53800
13000	D	18000	47000	14000	45000	8000	35000
	T	38800	67800	34800	65800	28800	55800
14000	D	19000	51000	16000	50000	12000	36500
	T	39800	71800	36800	70800	32800	57300
15000	D	19500	55000	18000	55000	14000	38500
	T	40300	39800	38800	75800	34800	59300
16000	D	20000	59000	20000	60000	16000	40000
	T	40800	79800	40800	80800	36800	60800
17000	D	21000	63000	21000	64000	18500	42000
	T	41800	83800	41800	84800	39300	62800
18000	D	22000	68000	23000	68000	20500	44000
	T	42800	88800	43800	88800	41300	64800
19000	D	23000	72000	25000	73000	23500	46000
	T	43800	92800	45800	93800	44300	66800
20000	D	24000	75000	26000	78000	26500	48000
	T	44800	95800	46800	98800	47300	68800

TABLE C2

DELAY AND TOTAL BENEFITS FOR TWO PLS, GRADE-6% & NO-PASSING ZONE-50%

ADT		DELAY AND TOTAL BENEFITS FOR TWO PLS ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TER.CH.	1-MI	1/2-MI	1-MI	1/2-MI	1-MI	1/2-MI
1000	D	26000	21500	18000	0	5000	22000
	T	36000	31500	28000	10000	15000	32000
2000	D	27000	26000	19000	0	6000	27000
	T	37000	36000	29000	10000	16000	37000
3000	D	28000	30000	20000	0	8000	31000
	T	38000	40000	30000	10000	18000	41000
4000	D	29000	34000	21000	0	12000	34000
	T	39000	44000	31000	10000	22000	44000
5000	D	30000	38000	22000	2000	14000	38000
	T	40000	48000	32000	12000	24000	48000
6000	D	30500	42000	24000	15000	16000	42000
	T	56300	67800	49800	40800	41800	67800
7000	D	31000	46000	26000	20000	18000	46000
	T	56800	71800	51800	45800	43800	71800
8000	D	31500	50000	27500	28000	20000	50000
	T	57300	75800	53300	53800	45800	75800
9000	D	32000	55000	28500	36000	23000	54000
	T	57800	80800	54300	61800	48800	79800
10000	D	32500	60000	30000	46000	25000	58000
	T	58300	85800	55800	71800	50800	83800
11000	D	33500	65000	31500	54000	28000	62000
	T	75100	106600	73100	95600	69600	103600
12000	D	34500	70000	33000	63000	30000	65000
	T	76100	111600	74600	104600	71600	106600
13000	D	35500	75000	35000	71000	32000	70000
	T	77100	116600	76600	112600	73600	111600
14000	D	36500	80000	36500	80000	34000	73000
	T	78100	121600	78100	121600	75600	114600
15000	D	37500	86000	38000	88000	36000	77500
	T	79100	127600	79600	129600	77600	119100
16000	D	38000	90000	40000	96000	38000	82000
	T	79600	131600	81600	137600	79600	123600
17000	D	38500	95000	41500	106000	40000	86000
	T	80600	136600	83100	147600	81600	127600
18000	D	39000	100000	43000	113000	43000	88000
	T	81100	141600	84600	154600	84600	129600
19000	D	39500	105000	44500	123000	44500	92000
	T	81100	146600	86100	164600	86100	133600
20000	D	40000	110000	46000	130000	46000	96000
	T	81600	151600	87600	171600	87600	137600

TABLE C3

DELAY AND TOTAL BENEFITS FOR ONE PL, GRADE-4% & NO-PASSING ZONE-50%

ADT		DELAY AND TOTAL BENEFITS FOR ONE PL ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TER.CH.	1-MI	1/2-MI	1-MI	1/2-MI	1-MI	1/2-MI
1000	D	2000	0	0	0	5000	4000
	T	7000	5000	5000	5000	10000	9000
2000	D	6000	0	0	4000	7000	8000
	T	11000	5000	5000	9000	12000	13000
3000	D	10000	0	0	8000	10000	12000
	T	15000	5000	5000	13000	15000	17000
4000	D	14000	1000	5000	13000	11000	16000
	T	19000	6000	10000	18000	16000	21000
5000	D	18000	8000	10000	18000	14000	20000
	T	23000	13000	15000	23000	19000	25000
6000	D	22000	14000	15000	23000	16000	24000
	T	34900	26900	27900	35900	28900	36900
7000	D	26000	20000	20000	28000	18000	28000
	T	38900	32900	32900	40900	30900	40900
8000	D	30000	26000	26000	32000	20000	32000
	T	42900	38900	38900	44900	32900	44900
9000	D	34000	34000	30000	38000	22000	36000
	T	46900	46900	42900	50900	34900	48900
10000	D	37000	40000	35000	43000	24000	40000
	T	49900	52900	47900	55900	36900	52900
11000	D	41000	46000	40000	47000	26000	43000
	T	61800	66800	60800	67800	46800	63800
12000	D	45000	52000	44000	52000	29000	47000
	T	65800	72800	64800	72800	49800	67800
13000	D	49000	58000	49000	57000	31000	52000
	T	69800	78800	69800	77800	51800	72800
14000	D	52000	66000	53000	62000	33000	55000
	T	72800	86800	73800	82800	53800	75800
15000	D	57000	70000	59000	66000	35000	60000
	T	77800	90800	79800	86800	55800	80800
16000	D	60000	77000	64000	71000	37000	63000
	T	80800	97800	84800	91800	57800	83800
17000	D	64000	83000	69000	76000	40000	67000
	T	84800	103800	89800	96800	60800	87800
18000	D	68000	90000	73000	81000	42000	71000
	T	88800	110800	93800	101800	62800	91800
19000	D	72000	96000	78000	86000	44000	75000
	T	92800	116800	98800	106800	64800	95800
20000	D	75000	102000	84000	90000	46000	79000
	T	95800	122800	104800	110800	66800	99800

TABLE C4

DELAY AND TOTAL BENEFITS FOR TWO PLS, GRADE-4% & NO-PASSING ZONE-50%

ADT		DELAY AND TOTAL BENEFITS FOR TWO PLS ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TER.CH.	1-MI	1/2-MI	1-MI	1/2-MI	1-MI	1/2-MI
1000	D	8000	0	0	6000	12000	0
	T	18000	10000	10000	16000	22000	10000
2000	D	12000	0	1000	12000	16000	6000
	T	22000	10000	11000	22000	26000	16000
3000	D	19000	3000	8000	18000	19000	12000
	T	29000	13000	18000	28000	29000	22000
4000	D	26000	10000	14000	26000	21000	18000
	T	36000	20000	24000	36000	31000	28000
5000	D	32000	19000	21000	32000	26000	24000
	T	42000	29000	31000	42000	36000	34000
6000	D	36000	28000	28000	38000	28000	30000
	T	61800	53800	53800	63800	53800	55800
7000	D	44000	34000	37000	46000	32000	37000
	T	69800	59800	62800	71800	57800	62800
8000	D	50000	44000	40000	50000	34000	43000
	T	75800	69800	65800	75800	59800	68800
9000	D	54000	52000	48000	58000	37000	50000
	T	79800	77800	73800	83800	62800	75800
10000	D	60000	60000	52000	66000	40000	57000
	T	85800	85800	77800	91800	65800	82800
11000	D	68000	68000	60000	72000	44000	63000
	T	109600	109600	101600	113600	85600	104600
12000	D	72000	74000	68000	78000	46000	70000
	T	113600	115600	109600	119600	87600	111600
13000	D	80000	86000	74000	86000	50000	77000
	T	121600	127600	115600	127600	91600	118600
14000	D	86000	93000	80000	90000	52000	83000
	T	127600	134600	121600	131600	93600	124600
15000	D	90000	102000	86000	98000	56000	90000
	T	131600	143600	127600	139600	97600	131600
16000	D	96000	111000	94000	106000	60000	97000
	T	137600	152600	135600	147600	101600	138600
17000	D	102000	118000	100000	112000	63000	103000
	T	143600	159600	141600	153600	104600	144600
18000	D	110000	128000	106000	128000	68000	110000
	T	151600	169600	147600	169600	109600	151600
19000	D	114000	134000	112000	134000	70000	117000
	T	155600	175600	153600	175600	111600	158600
20000	D	120000	144000	120000	143000	72000	124000
	T	161600	185600	161600	184600	161600	165600

TABLE C5

DELAY AND TOTAL BENEFITS FOR ONE PL, GRADE-2% & NO-PASSING ZONE-50%

ADT		DELAY AND TOTAL BENEFITS FOR ONE PL ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TER.CH.	1-MI	1/2-MI	1-MI	1/2-MI	1-MI	1/2-MI
1000	D	0	0	0	4000	0	0
	T	5000	5000	5000	9000	5000	5000
2000	D	0	3000	0	8000	0	2000
	T	5000	8000	5000	13000	5000	7000
3000	D	0	9000	0	13000	3500	7000
	T	5000	14000	5000	18000	8500	3000
4000	D	5000	14000	5000	18000	8000	3000
	T	10000	19000	10000	23000	13000	18000
5000	D	10000	20000	10000	22000	13000	17000
	T	15000	25000	15000	27000	18000	22000
6000	D	16000	25000	16000	27000	17500	23000
	T	28900	37900	28900	39900	30400	35900
7000	D	21000	30000	22000	32000	22000	28000
	T	33900	42900	34900	44900	34900	40900
8000	D	27000	35000	29000	37000	26500	33000
	T	39900	47900	41900	49900	39400	45900
9000	D	32000	40000	35000	40000	31000	39000
	T	44900	52900	47900	52900	43900	51900
10000	D	38000	46000	43000	45000	35000	44000
	T	50900	58900	55900	57900	47900	56900
11000	D	44000	51000	47000	50000	40000	50000
	T	64800	71800	67800	70800	60800	70800
12000	D	49000	56000	54000	55000	44000	55000
	T	69800	76800	74800	75800	64800	75800
13000	D	55000	62000	60000	60000	49000	60000
	T	75800	82800	80800	80800	69800	80800
14000	D	60000	67000	66000	64000	53500	65000
	T	80800	87800	86800	84800	74300	85800
15000	D	65000	73000	73000	69000	58000	70000
	T	85800	93800	93800	89800	78800	90800
16000	D	71000	77000	78000	73000	63000	76000
	T	91800	97800	98800	93800	83800	96800
17000	D	76000	83000	85000	78000	67000	81000
	T	96800	103800	105800	98800	87800	101800
18000	D	83000	86000	91000	83000	72000	87000
	T	103800	106800	111800	103800	92800	107800

TABLE C6

DELAY AND TOTAL BENEFITS FOR TWO PLS, GRADE-2% & NO-PASSING ZONE-50%

ADT		DELAY (D) AND TOTAL (T) BENEFITS FOR TWO PLS ($/YEAR)					
		TRUCK-5%		TRUCK-10%		TRUCK-20%	
	TER.CH.	1-MI	1/2-MI	1-MI	1/2-MI	1-MI	1/2-MI
1000	D	0	0	0	0	10000	0
	T	10000	10000	10000	10000	20000	10000
2000	D	3000	3000	0	7000	15000	7000
	T	13000	13000	10000	17000	25000	17000
3000	D	10000	12000	7000	15000	20000	15000
	T	20000	22000	17000	25000	30000	25000
4000	D	18000	20000	15000	22000	27000	22000
	T	28000	30000	25000	32000	37000	32000
5000	D	25000	27000	21000	30000	32000	30000
	T	35000	37000	31000	40000	42000	40000
6000	D	32000	35000	30000	35000	38000	35000
	T	57800	60800	55800	60800	63800	60800
7000	D	39000	44000	37000	43000	43000	43000
	T	64800	69800	62800	68800	68800	68800
8000	D	46500	52000	45000	51000	50000	49000
	T	72300	77800	70800	76800	75800	74800
9000	D	53000	60000	53000	59000	55000	55000
	T	78800	85800	78800	84800	80800	80800
10000	D	60000	67000	60000	65000	62000	62000
	T	85800	92800	85800	90800	87800	87800
11000	D	68000	75000	68000	73000	67000	69000
	T	109600	116600	109600	114600	108600	110600
12000	D	74000	84000	76000	80000	72000	75000
	T	115600	125600	117600	121600	113600	116600
13000	D	82000	92000	83000	88000	78000	82000
	T	123600	133600	124600	129600	119600	123600
14000	D	88000	100000	92000	95000	85000	89000
	T	129600	141600	133600	136600	126600	130600
15000	D	95000	107000	100000	102000	90000	95000
	T	136600	148600	141600	143600	131600	136600
16000	D	103000	115000	107000	110000	96000	102000
	T	144600	156600	148600	151600	137600	143600
17000	D	110000	123000	115000	117000	102000	110000
	T	151600	164600	156600	158600	143600	151600
18000	D	117000	131000	121000	123000	107000	115000
	T	158600	172600	162600	164600	148600	156600

APPENDIX D

GRAPHS SHOWING VOLUME WARRANTS FOR PASSING LANE(S)

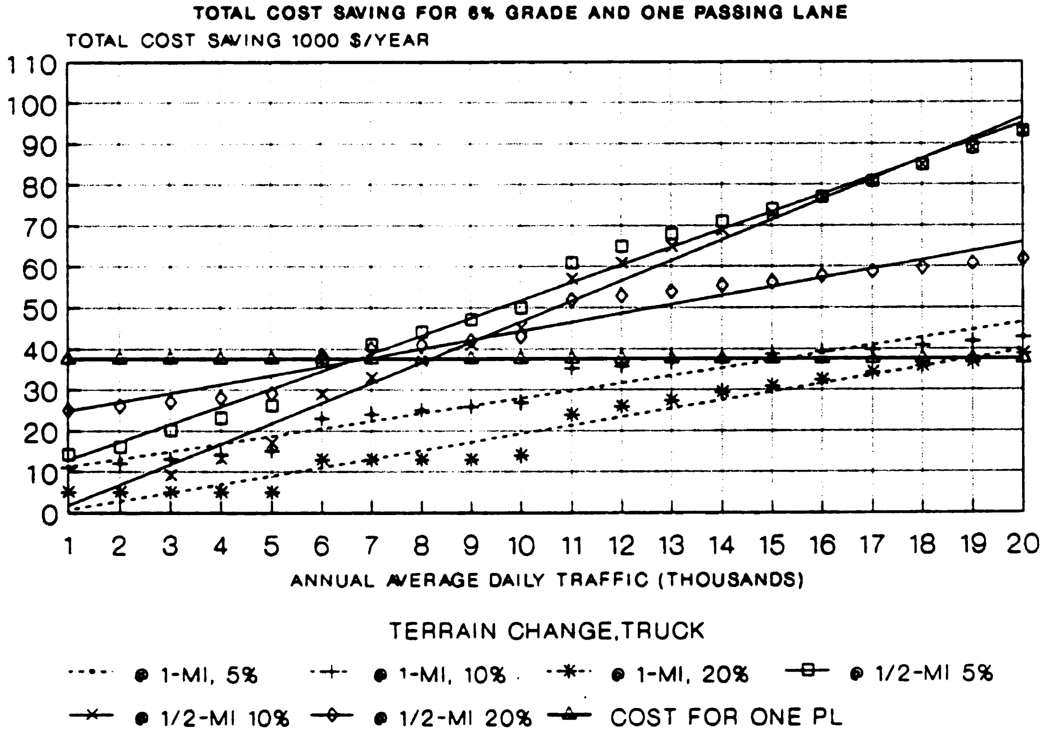


FIGURE D1. TOTAL COST SAVING FOR 75 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND ONE PASSING LANE

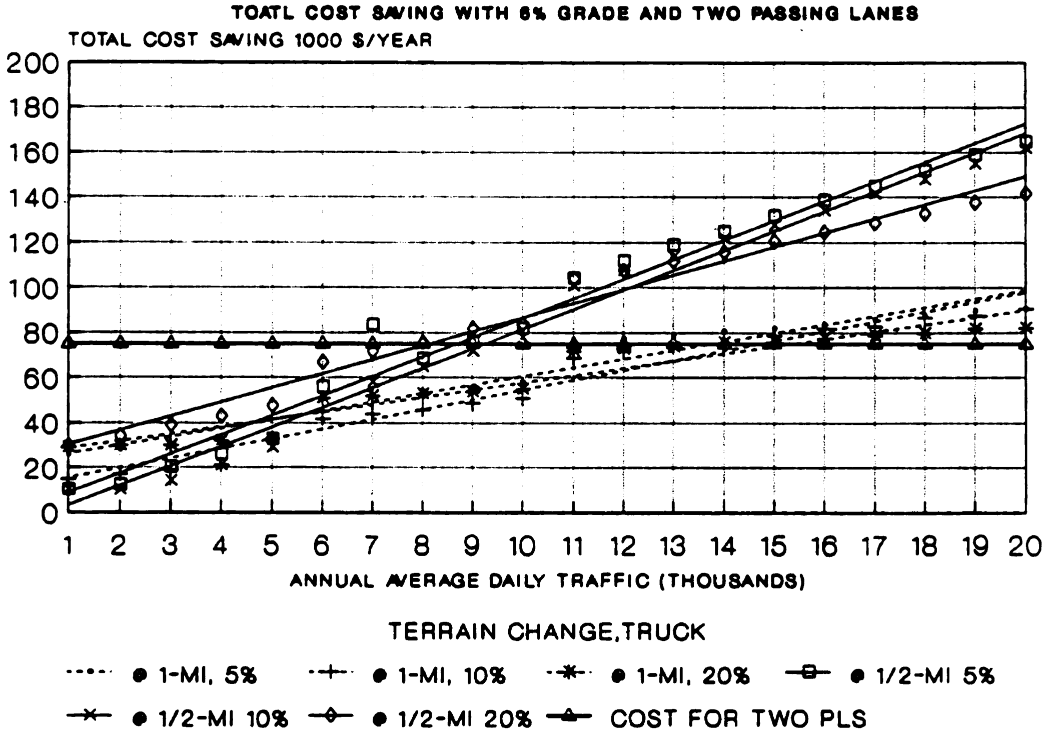


FIGURE D2. TOTAL COST SAVING FOR 75 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND TWO PASSING LANES

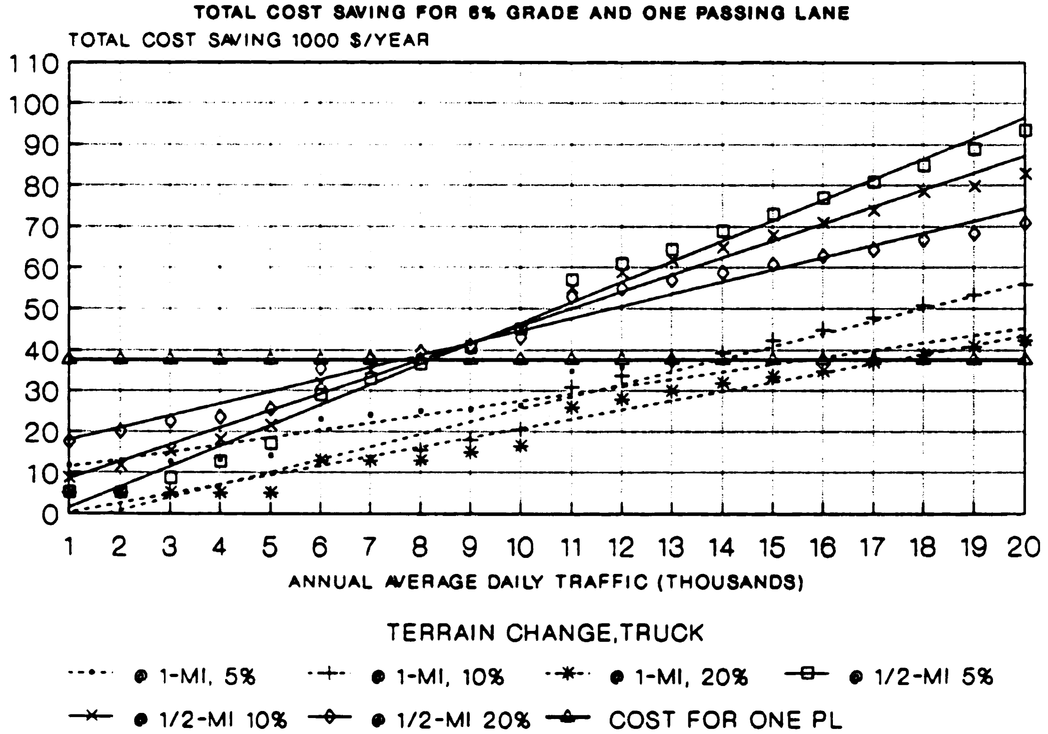


FIGURE D3. TOTAL COST SAVING FOR 25 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND ONE PASSING LANE

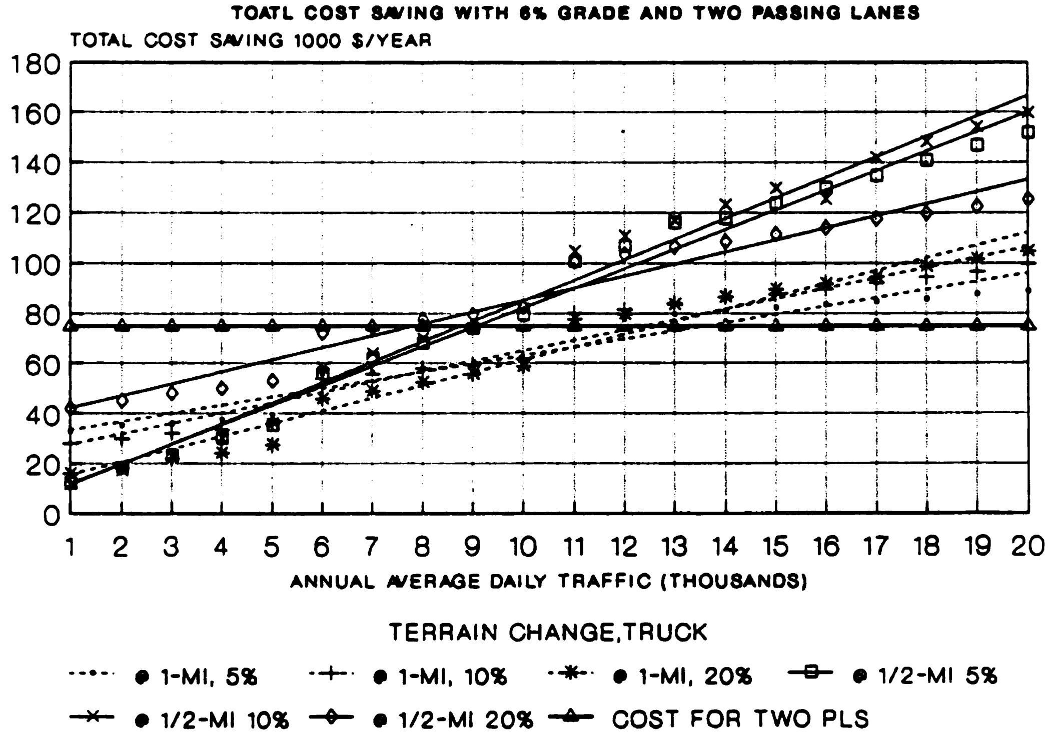


FIGURE D4. TOTAL COST SAVING FOR 25 PERCENT NO-PASSING ZONES
6 PERCENT GRADE AND TWO PASSING LANES

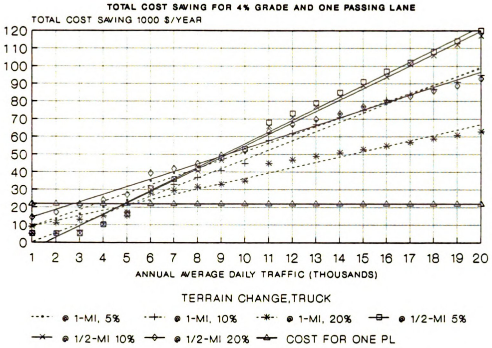


FIGURE D5. TOTAL COST SAVING FOR 75 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND ONE PASSING LANE

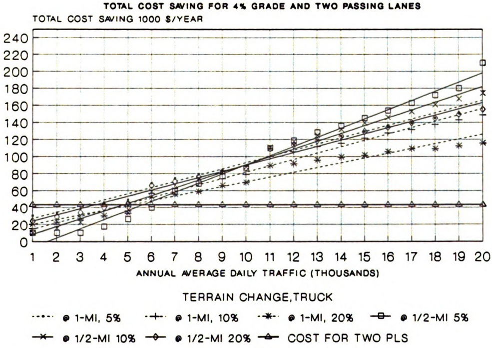


FIGURE D6. TOTAL COST SAVING FOR 75 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND TWO PASSING LANES

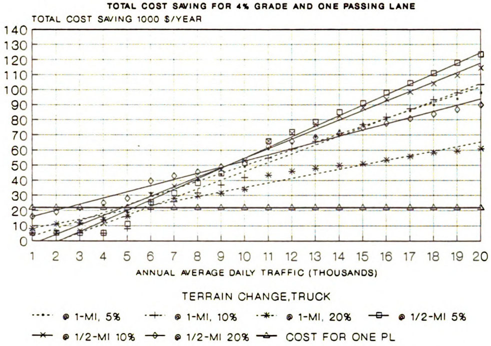


FIGURE D7. TOTAL COST SAVING FOR 25 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND ONE PASSING LANE

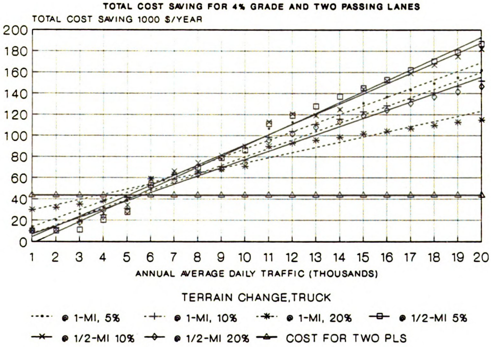


FIGURE D8. TOTAL COST SAVING FOR 25 PERCENT NO-PASSING ZONES
4 PERCENT GRADE AND TWO PASSING LANES

LIST OF REFERENCES

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1. Forbes, T.W., and Maston, T.M.," Driver Judgement on Passing on the Highways," Journal of Psychology, Vol.8, July 1939, pp 1-11.

2. Jones, H.V., and Heimestra, N.W.," Ability of Drivers to Make Criteria Passing Judgements," Highway Research Record 122, 1966, pp 89-92.

3. National Joint Committee on Uniform Traffic Control Devices for Streets Highways, U.S. Department of Transportation, Bureaue of Public Roads, Washington, D.C., 1970.

4. Heimbach, C.L., Hom, J.W., Khasnabis, S., and Chao, G.C.," A Study on No-Passing Zone Configurations on Rural Two-Lane Highways in North Carolina: Volume I, Highway Research Program, North Carolina University, Raleigh, March 1972.

5. Khasnabis, S.," Operational and Safety Problems of Trucks in No-Passing Zones on Two-Lane Rural Highways," TRR-1052.

6. Gordon, D.A., and Mast, M.T." Drivers Decisions in Overtaking and Passing," HRB, Highway Research Record 247, 1968, pp 42-50.

7. Matson, T.M., and Forbes, T.W.," Overtaking and Passing Requirements as Determined From a Moving Vehicle," HRB Proceedings, Vol. 18. 1938.

8. Prisk, C.W.," Passing Practices on Rural Highways," Proceedings, 21st Annual Meeting, Highway Research Board, Vol. 21, 1941, pp 366-378.

9. Crawford, A.," The Overtaking Driver," Ergonomics, Vol. 6, 1963, pp 153-170.

10. Farber, E., and Silver, C.A.," Behavior of Drivers Performing a Flying Pass," HRB, Highway Research Record 247, 1968, pp 51-56.

11. Farber, E., and Silver, C.A., and Landis, D.," Knowledge of Closing Rate Versus Knowledge of Driver Passing Behavior," HRB, Highway Research Record 247, 1968, pp 1-6.

12. Silver, C.A., and Farber, E.," Driver Judgement in Overtaking Situations," HRB, Highway Research Record 247, 1968, pp 57-62.

13. McDonald, Larry B.," A Model for Predicting Driver Work Load in the Freeway Environment: A Feasibility Study," A Dissertation, Texas A & M University, College Station, Texas, August 1973 (Unpublished).

14. Weaver, G.D., and Glennon, J.C.," Passing Performance Measurements Related to Sight Distance Design," Texas Transportation Institute, Texas A & M University, College Station, Research Report 134-6, 1971.

15. Stonex, K.A., Loutzenheiser, D.W., Haile, E.R., Jr.; and Norman, O.K.," Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length of No-Passing Zone," Highway Research Board Bulletin, No. 195, 1958, pp 1-13.

16. Richards, Stephen H., Graeme D. Weaver, R. Dale Huchingson, and Donald L. Woods," Passing and No-Passing Zones: signs, Markings, and Warrants-- Human Factors Laboratory Studies (TTI Report RF 3453-3) September 1978 (Unpublished).

17. Weaver, G.D, and Glennon, J.C.," The Passing Maneuver As It Relates to Passing Sight Distance Standards," Texas Transportation Institute A & M University, College Station, Texas, Research Report 134-1, August, 1969.

18. Hostetter, R.S., and Seguin, E.L.," The Effects of Sight Distance and Controlled Impedance on Passing Behavior," HRB, Highway Research Record 292, 1969, pp 64-78.

19. Fancher, P.S.," Sight Distance Problems Related to Large Trucks," TRR-1052.

20. Harwood, D.W., St. John, A.D., and Warren, D.L.," Operational and Safety Effectiveness of Passing Lanes on Two-Lane Highways," Transportation Research Record 1026, pp 31-39.

21. Harwood, D.W., Hoban, C.J., and Warren, D.L.," Effective Use of Passing Lanes on Two-Lane Hgihways," TRB 67th Annual Meeting, January, 11-14, 1988, Washington, D.C.

22. Casel, A., and Janoff, M.S.," A Simulation Model of Two-Lane Rural-Road," HRB, Hgihway Research Record 292, 1968, pp 1-16.

23. Heimbach, C.L., and Wu, Shie-Shin.," Simulation of Highway Traffic on Two-Lane Two-Way Rural Highways," Transportation Research Record 806, pp 21-28.

24. Heimbach, C.L., and Khasnabis, S.," Traffic Simulation as Highway Design Tool," Journal of the Transportation Engineering Division, ASCE, Vol. 103, No. TE 3, May 1977, pp 369-384.

25. Morales, J.M., and Paniati, J.F.," Two-Lane Traffic Simulation: A Field Evaluation of Roadsim," TRR-1100, pp 29-39.

26. St John, A.D., and Kobett, D.R.," Grade Effects on Traffic Flow Stability and Capacity, Midwest Research Institute, Kansas City, Missouri, Final Report on NCHRP Project 3-19, August, 1974.

27. Hoban, C.J., and McLean, J.R.," Progress with Rural Traffic Simulation, Australian Road Research Board, Vol. 11, Part 4, 1982.

28. Messer, C.J.," Two-Lane Two-Way Rural Highway Capacity," Final Report of NCHRP Project 3-28A, February, 1983.

29. Highway Capacity Manual, TRB Special Report-209, 1985.

30. Harwood, D.W., and St John, A.D.," Operational Effectiveness of Passing Lanes on Two-Lane Hgihways," Report No. FHWA/RD-86/196, Federal Highway Administration, 1986.

31. A User's Guide to TWOPAS - A Microscopic Computer Simulation Model of Traffic on Two-Lane, Two-Way Highways, U.S. Department of Transportation, FHWA, May 1986.

32. A Manual on User's Benefit Analysis of Highway and Bus-Transit Improvements 1977, American Association of State Highway and Transportation Officials, Washington, D.C.

33. U.S.A. Statistics in Brief 1989. A Statistical Abstract Supplement, U.S. Department of Commerce, Bureau of the Census.

34. Employment and Earnings, U.S. Department of Labor, Bureau of Labor Statistics, August 1989.

35. Miller, T.R., Reinert, K.A., and Whiting, B.E., " Alternative Approaches to Accident Cost Concepts: State of the Art," Report FHWA/RD-83/079. FHWA, U.S. Department of Transportation, 1984, pp. 1-4, 122-130.

36. McFarland, W.F., and Rollins, J.B.," Cost-Effectiveness Techniques for Highway Safety, Resource Allocation, " Report FHWA/RD-84/011, FHWA, U.S. Department of Transportation, 1985, pp. 1-6, 55-118.

37. Rollins, J.B., and McFarland, W.F.," Costs of Motor Vehicle Accidents and Injuries," Transportation Research Record 1068, 1986, pp. 1-7.