Warrants for Passing Lanes

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A two-lane road in rolling and hilly topography may not provide sufficient passing zone length between crests of vertical curves. The use of passing lanes can increase the passing opportunities, alleviating safety and operational problems on two-lane highways in a cost-effective manner. The simulation model TWOPAS was calibrated for different traffic and roadway conditions in Michigan. The calibrated model was used to study the operational benefits of providing passing lanes on two-lane highways. Two parameters, delay reduction and percentage vehicles in platoon, were selected for three configurations of road profiles. Simulation runs were made for different traffic volumes and truck percentages. The magnitude of the accident reduction potential of passing lanes was obtained. The total delay benefits were calculated by using a unit value of time established by AASHTO. The total benefit per year for different truck percentages and roadway conditions and the cost of construction for a passing lane were plotted against different average daily traffic values. The traffic volumes at which the benefits equal the costs of passing lanes for different traffic and roadway conditions were obtained.

There are more than 3 million mi of two-lane rural highways in the United States, composing 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. 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.

The design of two-lane, two-way roads has some serious safety and operational problems, 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 delay, a reduced level of service, and an increase in passing attempts, 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 alleviate safety and operational problems.

Accidents and traffic characteristics with and without passing lanes were analyzed to determine the possible benefits of passing relief lanes under various traffic conditions.

The main objectives of the study were

1. To select and calibrate a model to study the behavior of traffic, including the passing maneuver, on two-lane highways in Michigan;
2. To develop information on travel time savings due to passing lanes for different traffic composition and roadway geometry and driver characteristics;
3. To obtain and analyze accident data for two-lane, two-way Michigan highways with and without passing lanes to determine the potential benefits in terms of fewer accidents; and
4. To evaluate passing relief lanes on the basis of benefit-cost analyses for different combinations of traffic composition and geometrics.

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The passing maneuver is a complex phenomenon and cannot 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 of the passing maneuver on two-lane, two-way highways were reviewed, and a simulation model called TWOPAS was selected for use in this study. The advantages and disadvantages of different simulation models and the selection criteria for this model are given in the final project report.

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 were compared with the field values at different locations along the simulated roadway. It was found that the TWOPAS model could be calibrated to accurately depict 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 sections of rural two-lane roads in Michigan without passing lanes to estimate 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 costs of the motorist delay and accidents were used to develop warrants for passing relief lane construction.

TWOPAS MODEL

TWOPAS is a microscopic computer model of traffic operations on two-lane, two-way highways. The capability to simulate passing and climbing lanes was validated from field data by Harwood and St. John (*1*). Good agreement was found between model results and field data for traffic platooning and traffic speeds upstream and downstream of passing lanes.

The TWOPAS model simulates traffic operations on two-lane highways by reviewing the position, speed, and acceleration of each vehicle on a simulated roadway at 1-sec intervals and advancing the vehicle along the roadway. The model takes into account the effects on traffic operations of road geometrics, traffic control, driver preferences, vehicle size and performance characteristics, and 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 addition and lane drop transition areas and lane changing within the passing or climbing lane section. Spot data, space data, vehicle interaction data, and overall travel data are accumulated and processed, and various statistical summaries are printed. The model also gives output at different locations and subsections along the simulated roadway (*2*).

SIMULATION MODEL CALIBRATION

Field Data Collection

Two sections with passing lanes, one on US-37 in Lake County and one 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 1 and 2. These sites were selected mainly because they are on the main routes leading toward Traverse City, a widely used recreational area in Michigan.

Special data recording machines (VC-1900), recommended by FHWA, were used to record traffic volume, speed, headway, and vehicle mix. An important feature of these machines is the ability to classify the vehicles in 13 categories on the basis of total number and spacing of axles on a vehicle. Three sets of machines were installed at a location 0.5 mi upstream of the passing lane, and two sets of machines were installed at two locations, 0.5 and 1.5 mi downstream of the passing lane. The setup of machines is shown in Figures 1 and 2 for both the sites. The upstream machines collected speed, headway, and vehicle classification separately, and the downstream machines collected speed and headway data. Data were collected on Friday for 6 hr from noon to 6:00 p.m. in one direction and on Sunday for the same 6 hr in the other direction. The same machine setup, timings, and days of the week were used for both locations.

Speed data were collected in 5-mph intervals and were plotted to get the speed distribution of the vehicles in the field. Mean desired speed and standard deviation of desired speed were obtained from these graphs. Vehicles having a headway of less than 5 sec were counted separately to get the percentage of vehicles in platoon.

For the simulation run, trucks were divided into three categories. The trucks classified by the machine as 5, 6, and 7 were taken as high-performance trucks; trucks classified as 8, 9, and 10 were taken as medium-performance trucks; and trucks classified as 11, 12, and 13 were taken as low-performance trucks. The model accepts three types of trucks and one type of bus. This machine does not distinguish rec-

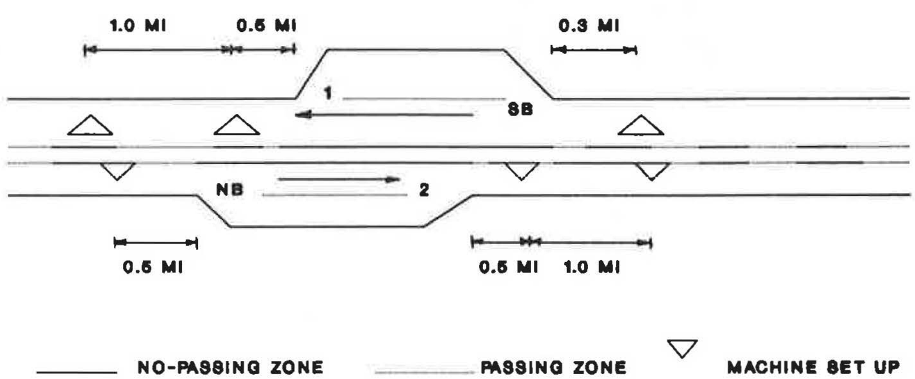

FIGURE 1 Machine setup for data collection at Lake County site.

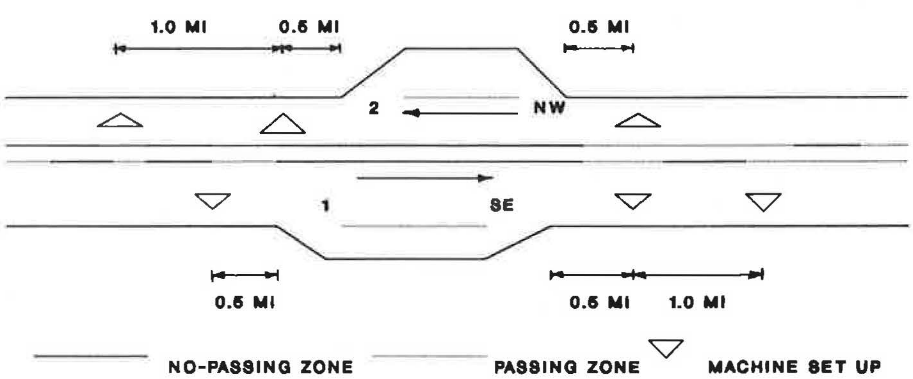

FIGURE 2 Machine setup for data collection at Clare County site.

reational 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 cars/pickups were used to calibrate the model.

Geometric data were collected by using the Michigan Automated Recording System (MARS) vehicle, which 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. 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.

Input Data Required

To run the simulation model, the following input data are required. Most of these data were collected in the field as discussed; a few values were taken directly from the TWOPAS user's guide (*2*) as default values.

- Entering traffic data,
- Geometric data,
- Traffic control data,
- Vehicle characteristics, and
- Driver characteristics.

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 weight/net horsepower ratio, weight/projected frontal area, a factor correcting horsepower to local elevation, and a factor correcting aerodynamic drag to local elevation to determine performance capabilities of trucks and buses. The performance capabilities of cars were considered in terms of maximum acceleration using maximum available horsepower and limitations on sustained use of maximum horsepower. These values were taken from the manual as default values for calibration of the model.

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 under given roadway conditions and indirectly represents the driver characteristics. Figure 3 shows a mean desired speed of 58.0 mph and standard deviation of 6.0 mph for the Clare County site. The model takes 10 types of drivers defined in terms of risk-taking characteristics and car-following sensitivity factors. In car-following models, driver response in a traffic stream can be explained in terms of sensitivity and stimuli. The response represents acceleration (or deceleration) of the following vehicle, and stimuli represent the relative velocity of the lead and following vehicle. The factor that relates response and stimuli in a car-following model is defined as the car-following sensitivity factor. The values recommended in NCHRP Project Report 3-28 A (*3*) were used in this study. 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.

The model gives output values at specified locations along the simulation roadway length. These locations were the same locations at which the machines were installed to collect field data, so different output values could be compared with the field values to calibrate the simulation model.

Model Calibration

To calibrate the model, the values of selected parameters given by the simulation model were compared with the field values. The model output includes the percentage of vehicles in platoon, percentage of vehicles at or above the desired speed, average delay at a particular location, and delay for a specified section of simulated roadway. According to the *Highway Capacity Manual* (*4*), level of service on two-lane, two-way highways can be defined in terms of the percentage of vehicles in platoon. The percentage of vehicles in platoon at different locations was obtained to calibrate the model. As mentioned, these locations were 0.5 mi upstream and 0.5 and

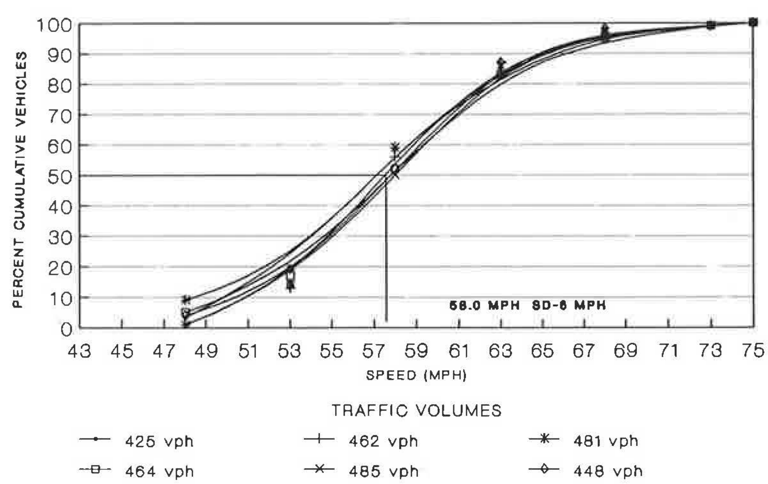

FIGURE 3 Speed distribution for Clare County site (southeast-bound traffic) showing mean desired speed and standard deviation of desired speed.

1.5 mi downstream of the passing lanes. Speed and headway data were collected at these three locations for all four passing lanes.

Simulation runs were made using hourly volumes and traffic mix collected in the field for both directions of flow and for different distributions of desired speeds. Average desired speeds were taken as 88 ft/sec, 92.4 ft/sec, and 95.4 ft/sec, and the standard deviation was taken as 8.58 ft/sec, 10.98 ft/sec, and 12.0 ft/sec for different runs for the Lake County roadway and traffic conditions. Subsequent runs were made using different values of the car-following sensitivity factor with a desired speed of 92.4 ft/sec and a standard deviation of 8.58 ft/sec for Lake County. The values of the sensitivity factor were raised until the model results best fit the field data. A value of 0.5 gave the best results. The simulation and field values of the percentage vehicles in platoon at different locations are given in Table 1. 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 for the Lake County site. The simulation and field values for the percentage of vehicles in platoon at different locations are given in Table 2.

To calibrate the model, the percentage of vehicles in platoon was taken as the main variable to compare the field values with the simulation values. The field values of percentage of vehicles in platoon were plotted against the values obtained by simulation for both sites, as shown in Figure 4. The field values are close to the simulation values, which indicates that 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.

TABLE 1 PERCENTAGE OF PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES (LAKE COUNTY SITE)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED FT/SEC	MPH	HEADWAY < 5 SEC (BY SIMULATION) AT BEG. OF ROAD DIR 1	DIR 2	AVG. BOTH	AT END OF ROAD DIR 1	DIR 2	AVG. BOTH	AVERAGE** DIR 1	DIR 2	HEADWAY < 5 SEC (FIELD VALUES) DIR-1 AT LOCATIONS* 1	2	DIR-2 AT LOCATIONS* 1	2	AVERAGE** 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	57	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 2 PERCENTAGE OF PLATOONING AT DIFFERENT LOCATIONS FOR DIFFERENT TRAFFIC VOLUMES (CLARE COUNTY SITE)

VOLUME DIR1/DIR2 (VPH)	DESIRED SPEED FT/SEC	MPH	PERCENTAGE VEHICLES IN PLATOON (HEADWAY <5 SECONDS) (SIMULATION VALUES) AT BEG. OF ROAD DIR 1	DIR 2	AVG. BOTH	AT END OF ROAD DIR 1	DIR 2	AVG. BOTH	AVERAGE DIR 1	DIR 2	(FIELD VALUES) DIR1 AT LOCATIONS* 1	2	3	DIR2 AT LOCATIONS* 1	2	3	AVERAGE 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

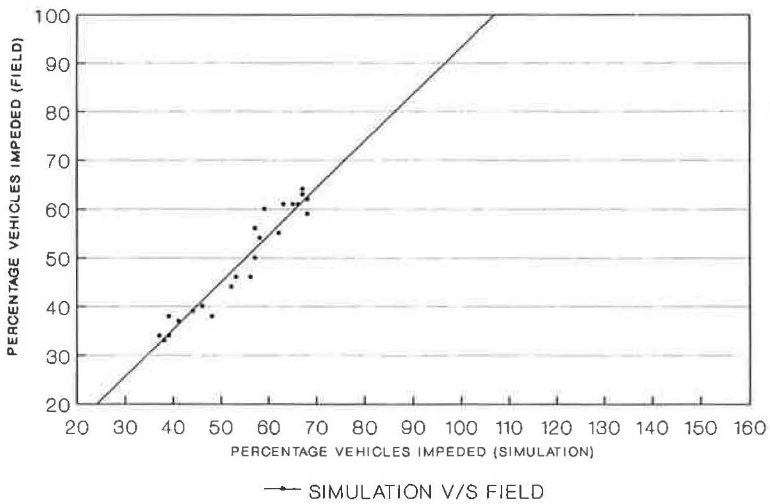

FIGURE 4 Percentage of vehicles impeded for speed of 92.4 ft/sec (simulation versus field values).

Although this calibration did not produce a true orthogonal line, the slope of the line matches the field data. The precise location of the line can be modified by changing the percentage of vehicles in platoon specified at the entry location.

Accident Data Required

Accident data were used 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 5 years, 1983 to 1987. To compare the accident rates and severity of the accidents within the passing lane and the rest of the road, all the accident data on two-lane highways in Michigan were segregated on the basis of average daily traffic (ADT) levels: less than 5,000, between 5,000 and 10,000, and greater than 10,000. These accident rates by severity on two-lane rural highways in Michigan (with and without passing lanes) are given in Table 3.

CASE STUDIES

The calibrated model was used to study the operational benefits gained by providing a passing lane on two-lane highways. According to the *Highway Capacity Manual* (*4*), the main

TABLE 3 ACCIDENT RATES BY SEVERITY ON TWO-LANE RURAL HIGHWAYS IN MICHIGAN WITH AND WITHOUT PASSING LANES

	WITHOUT PASSING LANES				WITH PASSING LANES			
YEAR	INJURY ACC. RATE	FATAL ACC. RATE	P.D.O. ACC. RATE	TOTAL ACC. RATE	INJURY ACC. RATE	FATAL ACC. RATE	P.D.O. ACC. RATE	TOTAL ACC. RATE
FOR ADT 1-5000								
1983	61.0	2.2	203.1	266.3	49.1	0.0	183.8	232.9
1984	61.8	2.3	221.9	286.0	59.4	0.0	172.4	231.9
1985	60.4	2.3	242.6	305.3	40.6	0.0	283.0	323.7
1986	60.0	2.5	255.6	318.1	46.3	3.0	206.8	256.0
1987	59.5	2.5	259.5	321.5	14.6	0.0	249.4	264.1
FOR ADT 5001-10000								
1983	72.5	2.1	169.1	243.7	63.8	2.5	181.2	246.3
1984	75.7	2.6	172.9	251.2	49.3	0.0	170.5	192.4
1985	79.0	2.6	210.0	291.6	80.9	0.0	183.9	263.3
1986	72.0	2.9	210.1	285.0	45.8	0.0	228.2	272.0
1987	73.1	2.6	204.5	280.2	59.1	0.0	168.6	260.0
FOR ADT 10001-15000								
1983	103.8	1.5	199.6	304.9	27.5	10.5	203.8	241.5
1984	109.4	2.8	217.5	329.7	39.8	0.0	183.0	222.8
1985	97.7	3.0	228.9	329.6	70.5	0.0	157.5	228.0
1986	99.9	2.2	245.4	347.5	63.3	0.0	328.0	391.3
1987	98.9	3.0	223.0	324.9	93.0	0.0	216.5	309.5

NOTE: Rates = Accidents Per 100 Million Vehicle Miles parameters defining 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 of passing lanes. Three configurations of road profiles were used for this study. 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 5 and 6.

Runs were made for these three configurations for different traffic volumes and truck percentages. The runs were made for all three cases for volumes of 500, 800, and 1,000 vehicles per hour. The values of delay benefits for each case are given in sec/veh in Table 4.

BENEFIT-COST ANALYSIS

The benefits of a passing lane are reductions in delay and accidents. The road user cost savings associated with these benefits were evaluated over a range of traffic volumes and compared with the cost of constructing and maintaining passing lanes. The reduction in delay provided by a passing lane results in operational cost savings to the road users. Simulation runs were made for different volumes, truck percentages, and geometric conditions; the reduction in delay due to a passing lane was computed as the difference between the average delay in the two directions of flow. The reduction in delay was used to compute the time cost savings.

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 savings per trip. According to AASHTO (*5*), the time savings is divided into three categories and can be expressed as a function of time saved in a trip and type of trip.

1. Low time savings (0–5 min): For work trips and average trips, the values of time per traveler hour are suggested as \$0.48 (6.4 percent of average hourly family income) and \$0.21 (2.8 percent of average hourly family income), respectively.
2. Medium time savings (5–15 min): For work trips and average trips, the values of time per traveler hour are suggested as \$2.40 (32.2 percent of average hourly family income) and \$1.80 (24.4 percent of average hourly family income), respectively.

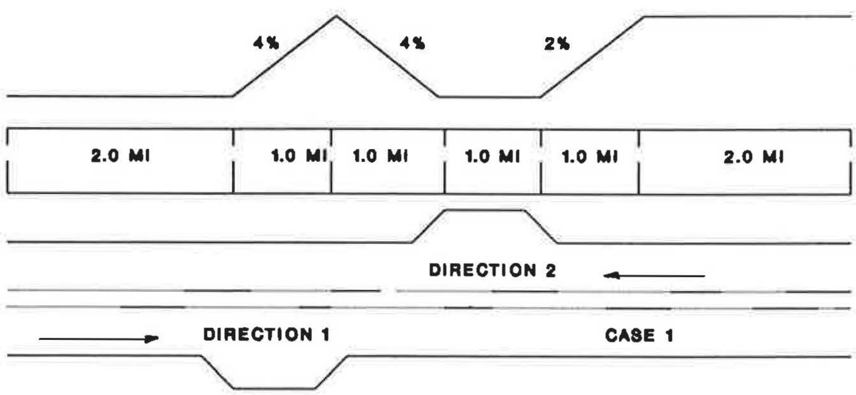

FIGURE 5 Layout of roadway for typical case study with two passing lanes, one in each direction.

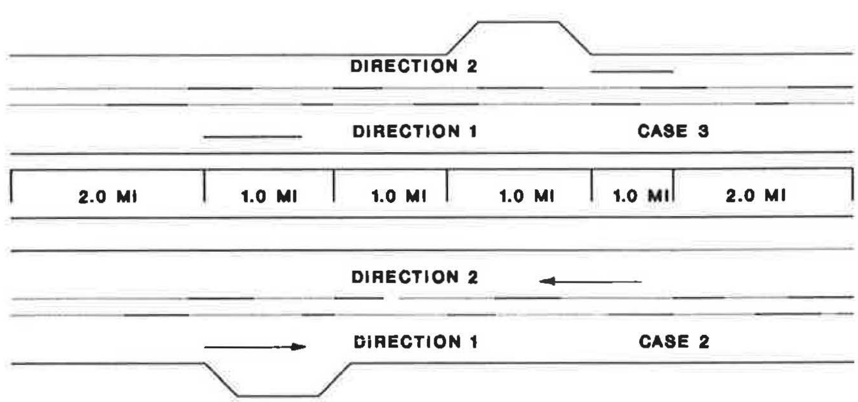

FIGURE 6 Layout of roadway for typical case study with one passing lane in each direction.

TABLE 4 COST BENEFIT DUE TO PASSING LANES FOR TYPICAL CASES

VOLUME VEH/HR BOTH DIRS	ADT	DELAY BENEFIT SEC/VEH (DT)	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

3. High time savings (over 15 min): For work trips and average trips, the value of time per traveler hour is suggested as $3.90 (52.3 percent of average hourly family income).

The delay benefits were calculated using the values of travel time for both average trips and work trips. According to 1980 Census data, the average annual family income in Michigan is $27,000. That gives the average hourly family income as $13.00, considering 2,080 working hours in a year. For average trips, the value of travel time per traveler hour was taken as $0.36, which is 2.8 percent of the average hourly income of $13.00. For work trips, the value of time per traveler hour was taken as $0.88, which is 6.4 percent of the average hourly income of $13.00. The average delay benefits were calculated by using Equation 1 in terms of dollars per hour and dollars per year. These values are given in Table 4.

Because the relationship between time savings and volume was not linear, a procedure for converting hourly benefits to annual benefits was required. Using Figure 2-4(a) of the *Highway Capacity Manual* (*4*), the relationship between daily benefits and peak-hour benefits was established as daily benefits equals hourly volumes times the benefits expected at that volume summed over the 24-hr period. The ratio of this sum to the benefits derived during the peak hour was approximately 10. Thus, the estimated daily benefits were taken to be equal to 10 times the peak-hour benefits.

Accident Cost Savings

An analysis of accidents on two-lane highways with and without passing lanes determined 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 two-lane road sections on rural highways throughout Michigan for 5 years, 1983 to 1987. The accident rates (by severity) were calculated, and the values are given in Table 3 for different ADT ranges.

To compare the accident rates within the passing lane and on the rest of the road, the mean accident rates for different ADT ranges were calculated for the sections with and without passing lanes. An average reduction in accidents was computed for each accident type for each ADT range. These values are given in Table 5, which indicates that passing lanes are effective in reducing accidents on two-lane highways.

Accident Costs

One of the most recent studies, by Miller et al. for FHWA (*6*), 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-

TABLE 5 AVERAGE ACCIDENT BENEFIT (PER MILLION VEHICLE-MILES) 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						
WITHOUT PL	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						
WITHOUT PL	2.6	3.1	74.5	123.3	193.3	270.4
WITHIN PL	0.5	0.5	59.8	94.1	186.5	246.8
BENEFIT	2.1	2.6	14.7	29.2	6.8	23.6
ADT > 10000						
WITHOUT PL	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

TABLE 6 ACCIDENT COSTS BY AREA AND SEVERITY (1988 DOLLARS)

	ACCIDENT COST BY SEVERITY			
AREA AND TYPE OF COST	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

cost calculations. Costs are expressed per victim and per vehicle rather than per accident, and are presented in terms of the Maximum Abbreviated Injury Scale (MAIS). However, benefit-cost analyses are often based on accident data, which typically consist of numbers of accidents per year at various accident locations, with injury severities coded on the ABC scale (incapacitating, non-incapacitating, and possible injury) rather than on the MAIS (0, no injury; 1 to 5, least to most severe nonfatal injury; 6, fatality). Hence, costs such as those presented by Miller et al. (*6*) could not be directly applied to this analysis. On the basis of the values presented by Miller et al. (*6*), the accident costs were calculated by using methods previously developed in a study for FHWA (*7,8*). This method gives direct, indirect, and total costs per fatal, injury, and property-damage-only (PDO) accident in rural and urban areas. These values were updated for 1988 dollars and are summarized in Table 6.

Accident Cost Savings Analysis

The accident cost savings provided by passing lanes were computed with the following equation:

$$ACS = (AC)(365)(ARF)(ADT)10^{-8} \quad (1)$$

where

ACS = annual accident cost savings provided by a 1-mi passing lane (dollars per year per mile),
AC = average cost of accidents by severity (values taken from Table 10), and
ARF = average reduction in accidents by severity for different ADT values (per 100 million vehicle-miles).

Equation 1 was used to compute the safety benefits of a passing lane on rural two-lane highways in Michigan. In Equation 1, 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 6. The accident cost benefits for different ADT values were calculated by considering direct costs of an accident.

Previously calculated delay benefit values were plotted and extrapolated for different ADT values. Total benefits were calculated by adding delay and accident benefits for different ADT values.

Equivalent uniform annual cost (EUAC) values were calculated for one passing lane 1 mi long and for two passing lanes each 1 mi long. Previous studies show that it may not be economical to provide passing lanes that are either too long or too short. Based on these studies, the length of passing lane was taken as 1.0 mi for this study. The life of the road was taken as $n = 15$ years. For $i = 5$ and 10, the values of the capital recovery factor were calculated as 0.0964 and 0.1315, respectively.

The values of total benefits for average trips and EUAC for 5 and 10 percent discount rates were plotted in Figure 7. The values of total benefits for work trips and EUAC for 5 and 10 percent discount rates were plotted in Figure 8.

Figures 7 and 8 show the benefit and cost values for average trips and work trips on a typical roadway. For example, using Figure 7, the warrants for a passing lane are met at a 4 percent grade, 10 percent trucks, and average trip type, as the user benefits are greater than construction costs for a passing lane for all ADT values greater than 6,500 for a discount rate of 5 percent. Similarly, for the same value of truck percentage, grade, and trip type, the benefits are greater than construction

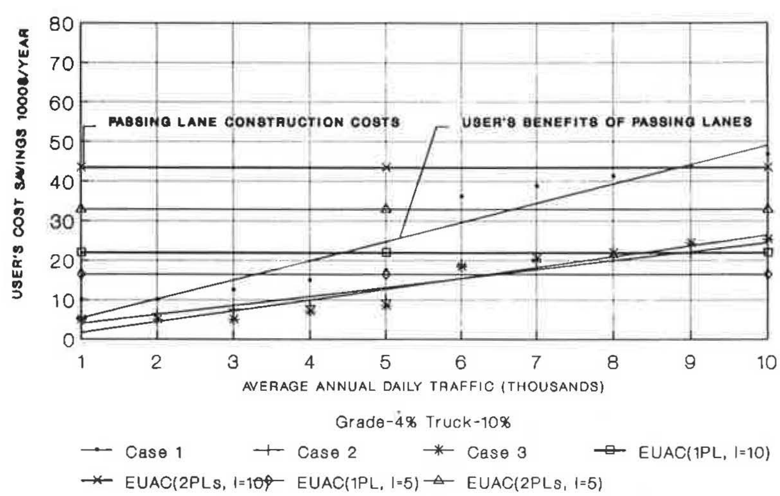

FIGURE 7 Comparison of cost and benefits for 4 percent grade, 10 percent trucks, and average trips on typical road profile.

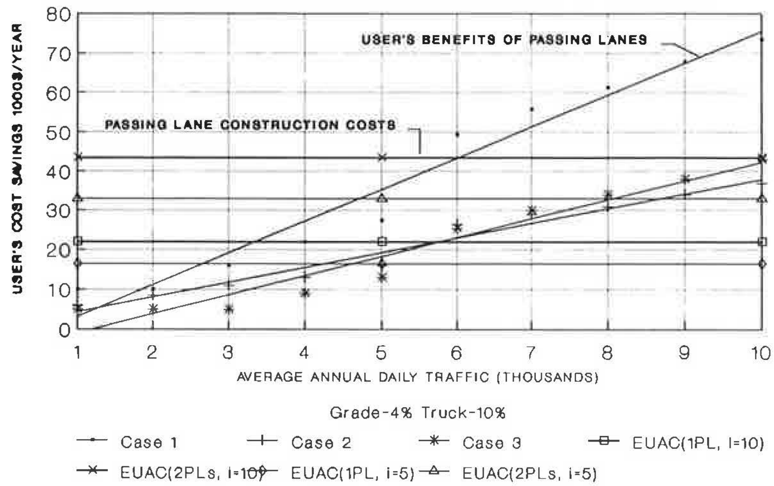

FIGURE 8 Comparison of cost and benefits for 4 percent grade, 10 percent trucks, and work trips on typical road profile.

cost for two passing lanes for ADT values greater than 9,000 for a 10 percent discount rate.

Figure 8 shows that for 4 percent grade, 10 percent trucks, and work trips, warrants for a passing lane are met at an ADT of 4,500 for a 5 percent discount rate. For the same value of truck percentage, grade, and trip type, the benefits are greater than the cost of two passing lanes at 6,000 ADT for a 10 percent discount rate. The values of ADT that warrant passing lanes were obtained for different grades, truck percentages, and percentage no-passing zones, and are documented in the final project report.

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

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