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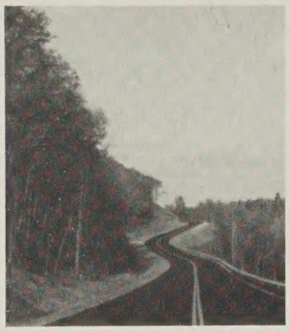

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COVER:
Route RS0176 near Bethel, Vermont

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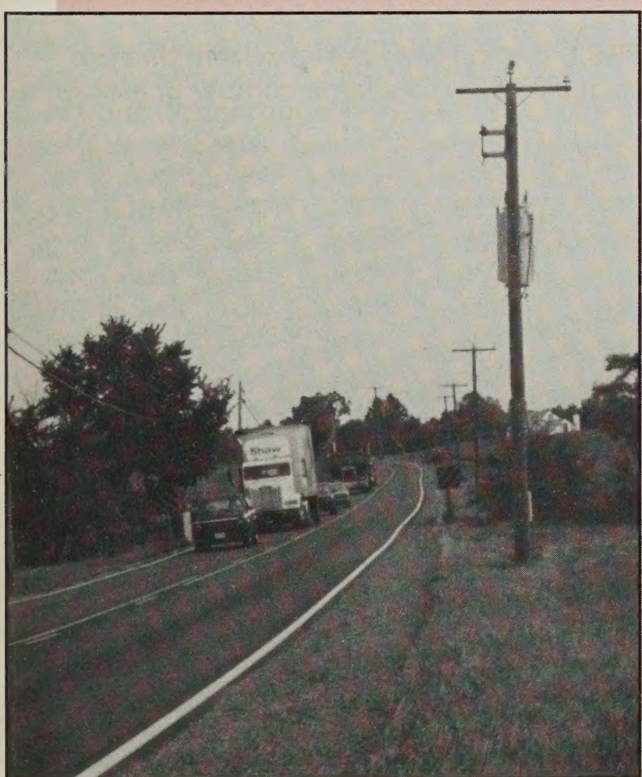
The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

An Investigation Of *Passing Accidents on Two-Lane, Two-Way Roads*

by Henrietta B. Alexander and Paul A. Pisano

Introduction

The passing maneuver on two-lane highways is one of the most demanding and hazardous operations performed by motorists. Its danger lies in the fact that a passing vehicle must occupy an opposing lane of traffic to complete the maneuver, and it is not uncommon for drivers at some point in time to want to pass a slower moving vehicle on a two-lane highway. Two-lane highways comprise the majority of the roadway mileage in the United States. On the Federal-aid Highway System alone, nearly 960,000 km (600,000 mi) are classified as two-lane rural highways, and an additional 193,000 km (120,000 mi) are classified as two-lane urban highways. *(1)*[1]



Waiting for an opportunity to pass on two-lane road.

A recent study undertaken by the Federal Highway Administration (FHWA) analyzed the issues surrounding passing on two-lane rural roads. The goals of this research were to:

- Determine if there is a safety problem in passing zones on two-lane, two-way highways.
- Determine the magnitude of the problem and associated risk.
- Identify causal and/or contributory factors to the problem.

Background

Since the 1920's, much has been written about passing problems on two-lane rural roads. *(2, 3, 4)* A critical issue that was identified in the past research is the difference between the American Association of State Highway and Transportation Officials (AASHTO) passing sight distance design criteria for two-lane roads found in the manual *A Policy on Geometric Design of Highway and Secondary Streets* and the marking criteria for no-passing zones on the same roads found in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD). (5, 6) These criteria are presented in tables 1 and 2, respectively.

In the field, passing zones are not specifically marked; instead, they exist where no-passing zones are not warranted. The warrants for no-passing zones are established by the MUTCD, and the MUTCD values are clearly different from the AASHTO values, which are used in the design of two-lane roads and not for traffic control. The net result was that two different sets of "minimum passing sight distances" were devel-

[1]Italic numbers in parentheses identify references on page 60.

Table 1.—AASHTO minimum passing sight distances for design of two-lane highways

Design Speed (mi/h)	Minimum Passing Sight Distance (ft)
20	800
30	1,100
40	1,500
50	1,800
60	2,100
65	2,300
70	2,500

Source: AASHTO Policy, 1990 Edition

Table 2.—MUTCD's minimum passing sight distances for marking no-passing zones

85 Percentile Speed or Posted Speed Limit Whichever is Higher (mi/h)	Minimum Passing Sight Distance (ft)
25	400
30	500
35	550
40	600
45	700
50	800
55	900
60	1,000
65	1,100
70	1,200

Source: MUTCD for Streets and Highways, 1988 Edition

oped. However, the FHWA and others recognized that the values in the MUTCD are not minimum passing sight distances, but rather they are minimum sight distance requirements. Furthermore, it was recognized that these two sets of values serve two different functions. *(4)*

Many past studies investigated the validity and practicability of these two sets of requirements. The general consensus was that the MUTCD values were too low. The AASHTO requirements were also questioned by some researchers as too conservative; others concluded that they were inadequate for car-passing-truck and truck-passing-truck scenarios.

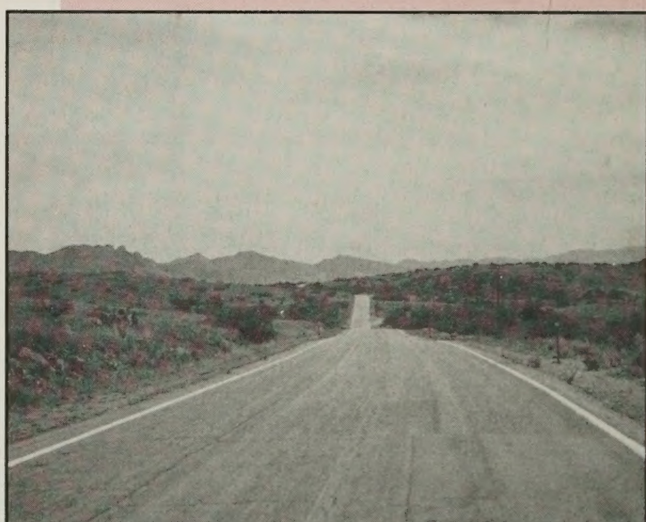
Other issues were overlooked or not addressed by past studies on this topic. For example, there was no complete investigation of accidents relating to passing zone pavement markings to determine if there is a passing zone safety problem, nor was the magnitude of the problem documented. Also, only a few investigations were conducted to determine and analyze the casual and/or contributory factors of passing accidents.

Assessment of previous studies identified the need to do a detailed analysis of passing accidents with respect to the above-described factors to determine if there are deficiencies in current practices for marking passing zones as specified in the MUTCD. In other words, the intent of this study was not to compare the AASHTO values to the MUTCD values but rather to assess the level of safety of the two-lane roads with respect to the vehicles passing each other as defined by the MUTCD. If deficiencies were identified, then steps would be taken to correct the problem. If it was determined that current marking practices do not create unsafe driving conditions, then other concerns, including those related to the different sets of sight distances, could be resolved.

Research Scope

The scope of this research project consisted of the study of the accident experience of two-way, two-lane highways with passing zones marked in accordance with MUTCD values. To fulfill study objectives, data were needed on passing zones that included a large number of accident, traffic, roadway, environmental, and vehicle factors. Information on passing zone pavement markings and their relationship to the accident data was also required. The only viable sources for these types of data are State files. Since the FHWA Highway Safety Information Systems (HSIS) has been developed using State data, it was selected for use in this project.

The HSIS is a roadway-based system that provides quality data on a large number of accidents,



Passing zones are determined by "minimum sight distance requirements."

Table 3.—Accident summary of the State data for 1985-89	
General Summary	
• Total number of accidents	375,690
Summary for Two-lane Roads	
• Two-lane road miles	44,690.5
• Annual million vehicle miles (MVM) of travel	17,603.9
• Accidents on two-lane roads for period 1985-89	198,185
• Total MVM of travel for period 1985-89	88,019.8
– Annual accident rate per 100 MVM on two-lane roads:	225
Summary for Two-lane, Rural Roads	
• Two-lane, rural road miles	34,216.9
• Annual MVM of travel	10,749.4
• Accidents on two-lane, rural roads for period 1985-89	69,104
• Total MVM of travel for period 1985-89	53,746.9
– Annual accident rate per 100 MVM on two-lane roads:	129

vehicles, drivers, roadway segments, and other roadside inventories for five States. Six years of data from 1985 through 1990 are currently available for each State. At the time that this research was conducted, data were available for the years 1985 through 1989. The five States were comparatively reviewed to determine the amount, nature, availability, and workability of variables and data points in order to select the State(s) to be used in this study.

Table 3 presents a summary of the accident data for the State that was eventually chosen. One of the key factors in the State selection process was the availability of data pertaining to the location of passing and no-passing zones. Since this information is not generally included on the accident report form, and because it was not feasible to collect these data in the field, it was imperative that the HSIS State chosen provide some means to stratify the passing accidents into the respective zones in which they occurred.

The selected State also had videodisc photologs that could provide the visual images of the accident sites and the location of the passing zones. On the videodisc photolog, pictures of the roadway are taken every 0.016 km (0.01 mi) from the driver's perspective. Using a combination of a videodisc player and personal computer, the images can be referenced easily according to location, and they can be quickly retrieved.

Research Methodology

In 1991, the FHWA funded a research effort to examine the key issues relating to passing zone design and markings and to develop study designs to address these issues. The contractor developed a plan to address the highest priority issue: Is there a safety problem associated with the current minimum sight distance requirements found in the MUTCD? If such a problem existed, then the magnitude of it was to be determined and, to the extent possible, the causes of the safety problem were to be identified.

A two-stage approach was used in this effort. Stage one involved the preparation of the data base, the determination of the most appropriate definition of a passing accident based on the variables in the data base, determination of the magnitude of the passing accident problem, and a comparative analysis of passing and nonpassing accidents. Stage two involved the creation of the passing zone inventory and analysis files and an analysis of the passing accidents with respect to the zones in which they occurred.

For this research effort, a passing accident was defined as one that either directly or indirectly involved a passing maneuver. In most cases, it was expected that the passing vehicle was directly involved in the accident. However, in some cases, the passing vehicle could have contributed to the accident but was not directly involved in the accident.

Since the accuracy and precision of selecting the correctly defined passing accidents determined the project's ultimate results, this was the most crucial task of the project. There is no one variable within the data base that identifies an accident as involving a passing maneuver. In fact, there are 37 variables in the HSIS accident file and 17 variables in the vehicle file that could be used in defining a passing accident. From these, two accident variables and three vehicle variables were selected:

- Accident variables:

  Accident diagram = sideswipe—passing.

Vehicle movement = sideswipe—passing not at an intersection and at an intersection.

- Vehicle variables:

  First contributing factor = improper overtaking or passing.

  Second contributing factor = improper overtaking or passing.

  Action prior to accident = vehicle—overtaking or passing.

A series of univariate and cross-tabulation tables were developed from these and other key related variables. This data manipulation gave some perspective to the selection of the most appropriate combination of variables that best fit the proposed definition. It was also determined at this point that the data should be further screened to drop the following observations from the final file:

- All passing accidents involving pedestrians and bicyclists.

- All "passing accidents" occurring at intersections or driveways from which any turning movements were possible.

Next, a micro-analysis of a random sample of 200 hard copy reports of these passing accident reports was undertaken. This analysis consisted

Table 4.—Variables used in the comparative analyses

Type of Factor	Name of Factor	Categories of Factor
DESCRIPTIVE	Accident Diagram	Rear End, Sideswipe, Ran off Road, Head on, Other
	Collision Type	Collision with motor other vehicle, with fixed object, overturn, other
	First Major Contributing Factor	Human, Environment, Vehicle, Roadway
	Damage Severity of Involved Vehicles	Light, Moderate, Severe
	Number of Injuries	1, 2, 3, 4, ≥ 5
	Number of Fatalities	1, 2, 3, 4, ≥ 5
	Number of Involved Vehicles	1, 2, 3, 4, ≥ 5
	Accident Severity	Fatal, A-injury, B-injury, C-injury, property damage only (PDO)
ENVIRONMENTAL	Hour	Morning, Afternoon, Evening, Night, Late Night
	Lighting Conditions	Daylight, Dark, Other
	Road Surface Conditions	Dry, Wet, Obscured, Other
	Weather Conditions	Clear, Adverse, Other
	Day of Week	Weekday, Week-End
HUMAN	Age of Driver	Under 19, 20-29, 30-39, 40-49, 50-59, ≥ 60
	Sex of driver	Male, Female
	Physical Condition of Driver	Normal, Impaired
GEOMETRICAL/ ROADWAY	Road Shoulder Type	No shoulder, Gravel + Soil, Asphaltic Concrete, Portland Concrete, Other
	Road Shoulder Width	0, < 5 ft, ≥ 5 ft
	Road Surface Type	No shoulder, Gravel + Soil, Asphaltic Concrete, Portland Concrete, Other
	Road Surface Width	0, < 5 ft, ≥ 5 ft
	Posted Speed	< 45 MPH, ≥ 45 MPH
TRAFFIC	Annual Average Daily Traffic	< 1,000, 1,000-1,999, 2,000-4,999, 5,000-9,999, ≥ 10,000
VEHICLE	Type of Vehicle	Motorcycle and smaller, passenger car, light truck, heavy truck, other heavy non-truck vehicles

of a manual review of the narrative and descriptive sections of this sample to confirm that the accidents extracted from the data base fit the definition of a passing accident. During this assessment, special attention was given to the identification of the factors that contributed to the accidents in order to get a better insight into the kinds of factors—human, vehicular, roadway, traffic, or environmental—that needed to be examined more closely.

This review revealed that the passing accidents that were coded "passing" from the accident diagram and/or the vehicle movement variables did not fit the desired definition of a passing accident. The term "passing" was used in these cases to refer to situations where two vehicles traveling in opposite directions collided in passing. In other words, none of the vehicles involved in these accidents was engaged in a passing maneuver. In the HSIS data base, this distinction between these two types of passing accidents was not possible. As a result of this finding, the passing accidents coded by the accident diagram and vehicle movement variables were deleted from the final passing accident file.

Passing Accident Analysis

Magnitude of passing accidents. To assess the magnitude of passing accidents, aggregate statistics were compiled on the following frequencies:

- All accidents.
- Fatal and incapacitating-injury accidents.
- All passing accidents.
- Fatal and incapacitating-injury passing accidents.

Rates, ratios, and percentages were developed on the four groups of accidents listed above. From these statistics, the indicators that were used to determine the magnitude of the problem were as follows:

$$\frac{\text{PA(2L)}}{\text{AA(2L)}} = \frac{\text{(Passing Accidents on Two-Lane Roads)}}{\text{(All Accidents on Two-Lane Roads)}}$$

$$\frac{\text{PA(2LR)}}{\text{AA(2LR)}} = \frac{\text{(Passing Accidents on Two-Lane Rural Roads)}}{\text{(All Accidents on Two-Lane Rural Roads)}}$$

$$\frac{\text{PF+IA(2L)}}{\text{AF+IA(2L)}} = \frac{\text{(Passing Fatal + Incapacitating Accidents on Two-Lane Roads)}}{\text{(All Fatal + Incapacitating Accidents on Two-Lane Roads)}}$$

$$\frac{\text{PF+IA(2LR)}}{\text{AF+IA(2LR)}} = \frac{\text{(Passing Fatal + Incapacitating Accidents on Two-Lane Rural Roads)}}{\text{(All Fatal + Incapacitating Accidents on Two-Lane Rural Roads)}}$$

Comparative analysis of the passing and nonpassing accidents. The second step of the passing accident analysis consisted of a comparative analysis between the passing accidents and all other accidents that occurred on two-lane U.S. and State rural roads. These roads were selected because the videodisc photolog coverage was limited to these two route systems. Even though these two route systems make up only 27.5 percent of all the State's rural roads, they account for approximately 69 percent of the passing accidents.

The comparison was conducted on the passing and nonpassing groups of accidents with respect to a list of variables that were selected based on findings from the literature review, the results of the hard-copy analysis, the experience of the highway officials consulted in this project,

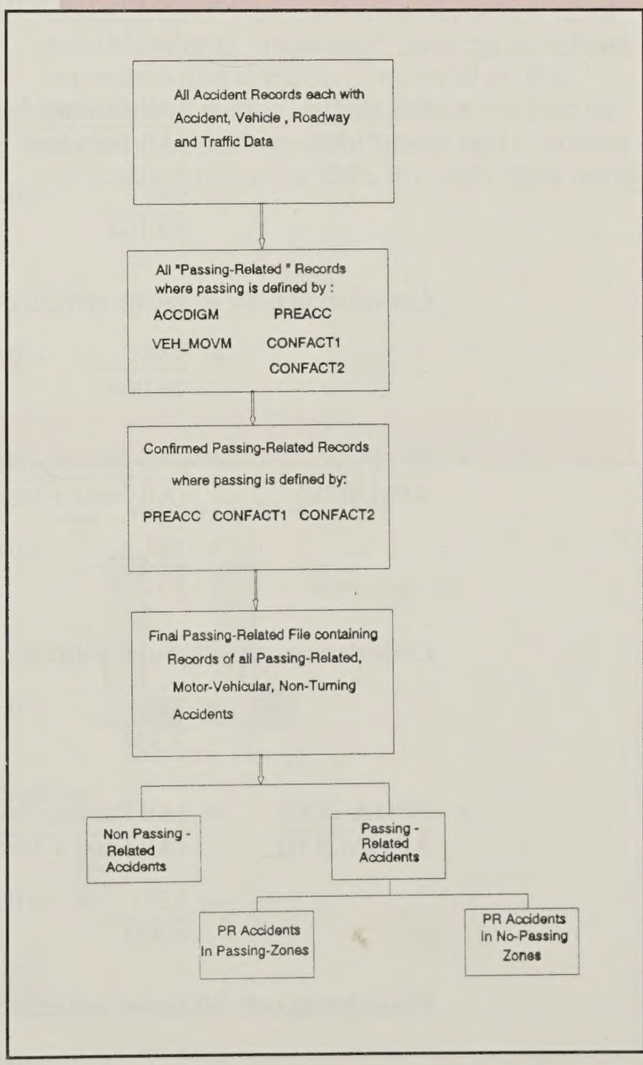


Figure 1.—Flowchart of the breakdown of files used in the analyses.

and the availability of the variables in the data base. The comparative analysis was done on the two data sets, taking one variable at a time, as listed in table 4.

Passing Zone Accident Analysis

Passing zone inventory file preparation. The second stage of the research involved the analysis of the passing accidents with respect to the zones in which they occurred. First, the accidents had to be stratified into those that occurred in passing zones and those that occurred in no-passing zones. This delineation was done by reviewing the visual images of the passing accident sites on the HSIS Photolog Laser Videodisc Retrieval System.

The data extracted from the photologs were recorded on log sheets specially created for this purpose. The images on the photologs were taken between 1988 and 1990. Even though the accidents being analyzed occurred during the period 1985 through 1989, it is assumed that there were no changes to the pavement markings on these roads between the time that the accidents occurred and the time the roads were photologged.

Comparative analysis of passing zone and no-passing zone accidents. As in stage one, a com-

Table 5.—Aggregate statistics indicating magnitude of the passing accident problem

- $\frac{PA(2L)}{AA(2L)} = \frac{\text{(All Passing Accidents on 2-Lane Roads)}}{\text{(All Accidents on 2-Lane Roads)}}$

  $= \frac{1,516}{198,185} = 0.0076 = 0.76\%$

  Considering only all motor-vehicular, non-turning accidents:

  $= \frac{1,516}{33,231} = 0.0456 = 4.56\%$

- $\frac{PA(2LR)}{AA(2LR)} = \frac{\text{(All Passing Accidents on 2-Lane Rural Roads)}}{\text{(All Accidents on 2-Lane, Rural Roads)}}$

  $= \frac{986}{69,104} = 0.0142 = 1.42\%$

  Considering only all motor vehicular, non-turning accidents:

  $= \frac{986}{20,066} = 0.0491 = 4.91\%$

- $\frac{PF+IA(2L)}{AF+IA(2L)} = \frac{\text{(All Passing Fatal + Incapacitating Acc. on 2-Lane Roads)}}{\text{(All Fatal + Incapcitating Accidents on 2-Lane Roads)}}$

  $= \frac{187}{13,274} = 0.014 = 1.41\%$

  Considering only all motor vehicular, non-turning accidents:

  $= \frac{187}{3,334} = 0.0561 = 5.61\%$

- $\frac{PF+IA(2LR)}{AF+IA(2LR)} = \frac{\text{(All Passing Fatal + Incapacitating Acc. on 2-Lane Rural Roads)}}{\text{(All Fatal + Incapcitating Accidents on 2-Lane Rural Roads)}}$

  $= \frac{137}{6,474} = 0.021 = 2.11\%$

  Considering only all motor vehicular, non-turning accidents:

  $= \frac{137}{2,347} = 0.0584 = 5.84\%$

Table 6.—Accidents on U.S. and State rural roads		
	Accidents	Vehicles
All accidents	38,080	61,445
Passing accidents	683 (1.8%)	1,174 (1.9%)
Nonpassing accidents	37,397 (98.2%)	60,271 (98.1%)

Figure 2.—Descriptive characteristics of passing and nonpassing accidents.

parative analysis was conducted on the two groups of passing accidents—those occurring in no-passing zones and those occurring in passing zones. The comparison was conducted for each variable as listed in table 4. The research approach used in the preparation of the data files for these analyses is summarized in figure 1.

Results

Magnitude of Passing Accidents

Table 5 presents the results of the aggregate statistics developed to determine the magnitude of the passing accidents. From this table, the following were observed:

- A slightly higher percentage of passing accidents occurred on two-lane rural roads than on all two-lane roads.
- The percentage of fatal and incapacitating passing accidents on two-lane rural roads was also higher than that on all two-lane roads.
- The number of passing accidents that occurred between 1985 and 1989 was very small—less than 1 percent of all two-lane road accidents and just over 1 percent of all two-lane rural road accidents. However, passing accidents represent just under 5 percent of all the nonturning motor vehicle accidents that occurred on both two-lane roads and two-lane rural roads during the 1985 through 1989 period.

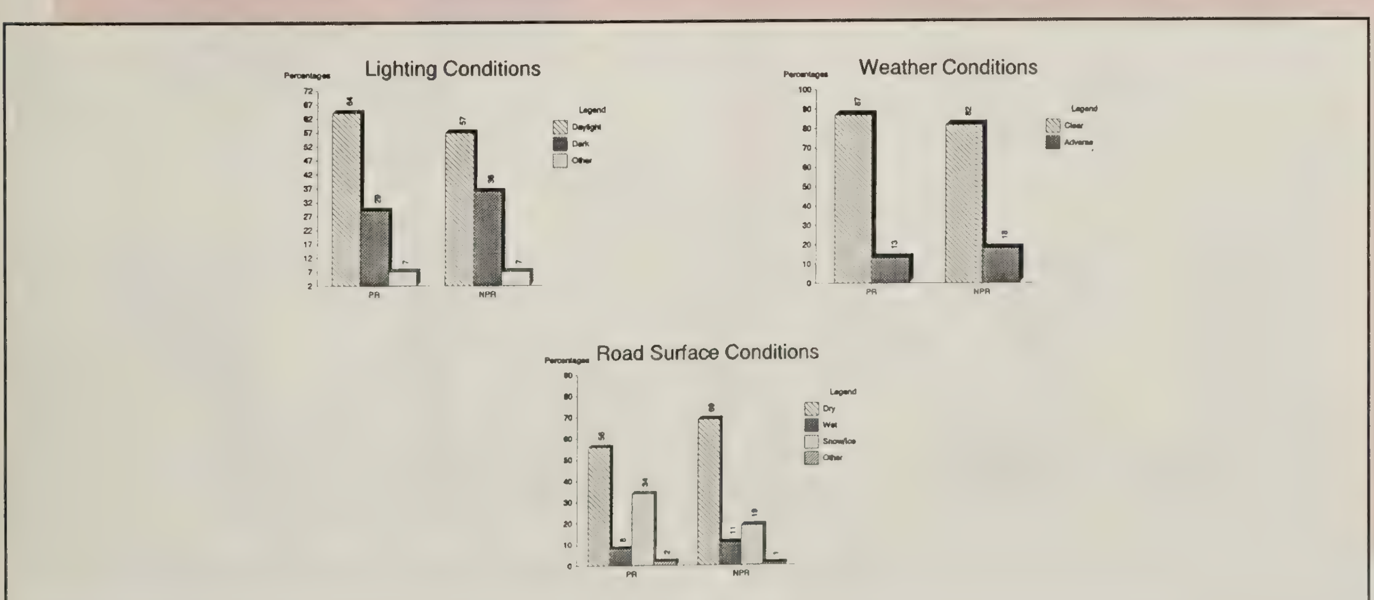


Figure 3.—Environmental conditions of passing and nonpassing accidents.

Comparative Analysis of Passing and Nonpassing Accidents

Table 6 presents a breakdown of the accidents that occurred on U.S. and State rural roads that were used in the comparative analysis of these two accident groups. For this analysis, passing accidents excluded those involving turning movement, pedestrians, and nonmotorized vehicles.

Several variables showed marked differences between the passing and nonpassing data sets. These variables are presented in table 7 and are examined more fully in figures 2 through 4.

Descriptive characteristics. The variables in this group present descriptive characteristics of accidents that occurred; they do not represent causal or contributory factors. Figure 2 highlights key differences and similarities for passing and nonpassing accidents among these descriptive variables. Analysis of all descriptive characteristics yielded the following observations:

- Over half of both passing and nonpassing accidents involved collisions with another motor vehicle. Vehicles involved in passing accidents were about 7 percent more likely to overturn than were those in nonpassing accidents.
- Occupants of vehicles involved in passing accidents had a slightly greater likelihood of sustaining injuries and fatalities than those involved in nonpassing accidents.

Environmental conditions. Figure 3 illustrates those environmental factors that showed the most marked difference between the two data sets. These factors are discussed below:

- Nonpassing accidents were more likely to occur under non-ideal environmental conditions—e.g., dark lighting or inclement weather. This observation might indicate that motorists attempt fewer passing maneuvers under non-ideal environmental conditions when the effective passing sight distances might be significantly reduced.
- Partial or total obscurement of pavement markings by snow or ice presents more of a potential driving hazard to the passing motorist than to the nonpassing motorist. This finding might be an indication of the level of mo-

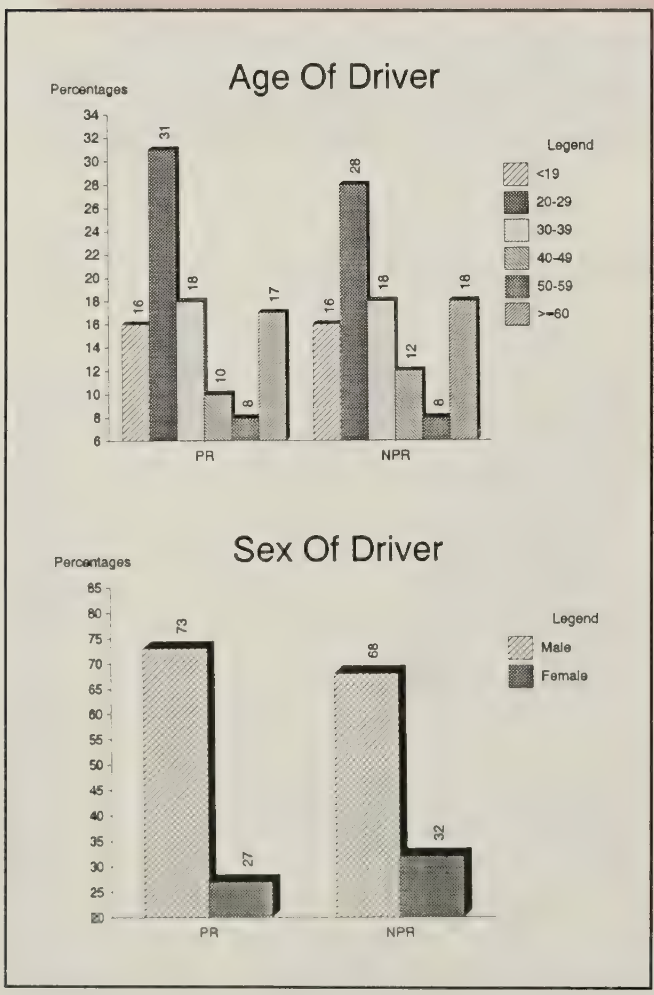


Figure 4.—Human characteristics of motorists in passing and nonpassing accidents.

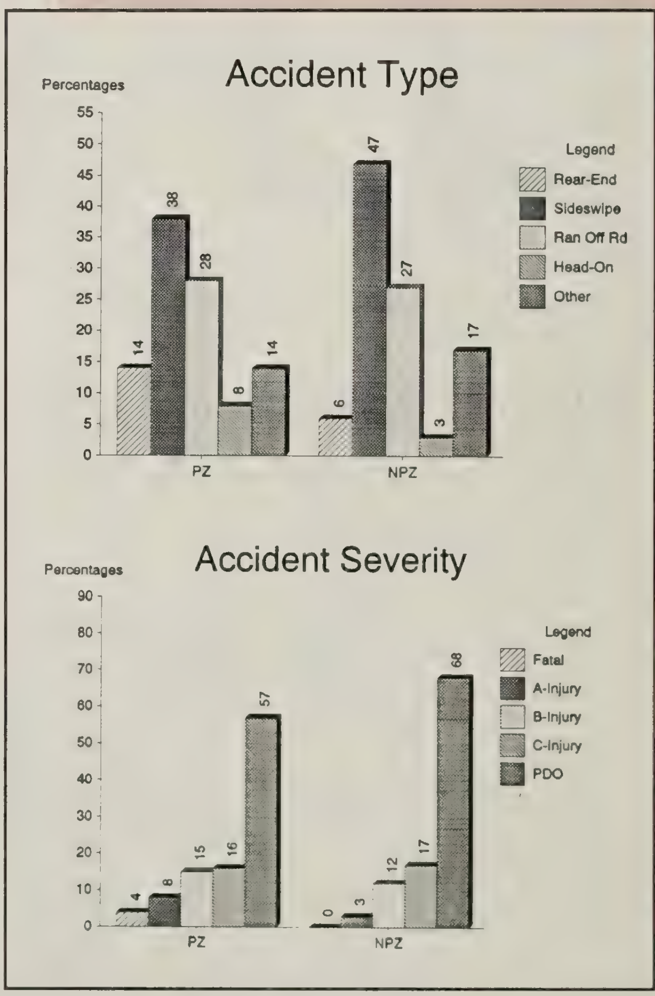


Figure 5.—Descriptive characteristics of passing and nopassing zone accidents.

Table 7.—Passing accidents on U.S. and State State rural roads		
	Accidents	Vehicles
All passing accidents	683	1,174
Passing zone accidents	617 (90.3%)	1,056 (89.9%)
No-passing zone accidents	66 (9.7%)	118 (10.1%)

Table 8.—Variables that differed between the passing and no-passing zone accident groups	
Variable Group	Distinguishing Variables
General Descriptive	Accident type, Number of injuries, Accident Severity, Number of Vehicles Involved
Environmental	Lighting Conditions, Road Surface Conditions, Weather
Human	Age of Driver
Traffic	Average Daily Traffic

torist compliance with, or their dependency on, existing pavement markings. The obscurement of pavement markings seems to add a hazardous element to vulnerable driving maneuvers, such as those involved in passing. Although this finding might seem to contradict the previous observation, it should be noted that obscured pavement markings can easily exist under daylight or non-inclement weather conditions.

Human characteristics. Figure 4 illustrates those human factors that showed the most marked difference between the two data sets. The findings from the review of these factors follow:

- Driver age did not appear to affect passing accidents. Even though experience seems to improve the ability of drivers to make better driving decisions, it is apparent that for senior drivers other physical impairments may affect their driving abilities. However, because exposure data by age were not available, no further investigation into the magnitude of the older driver problem could be conducted.
- Overall, the number of male drivers involved in both passing and nonpassing accidents was twice that of females. There was a slightly higher proportion of males involved in passing accidents than in nonpassing accidents.

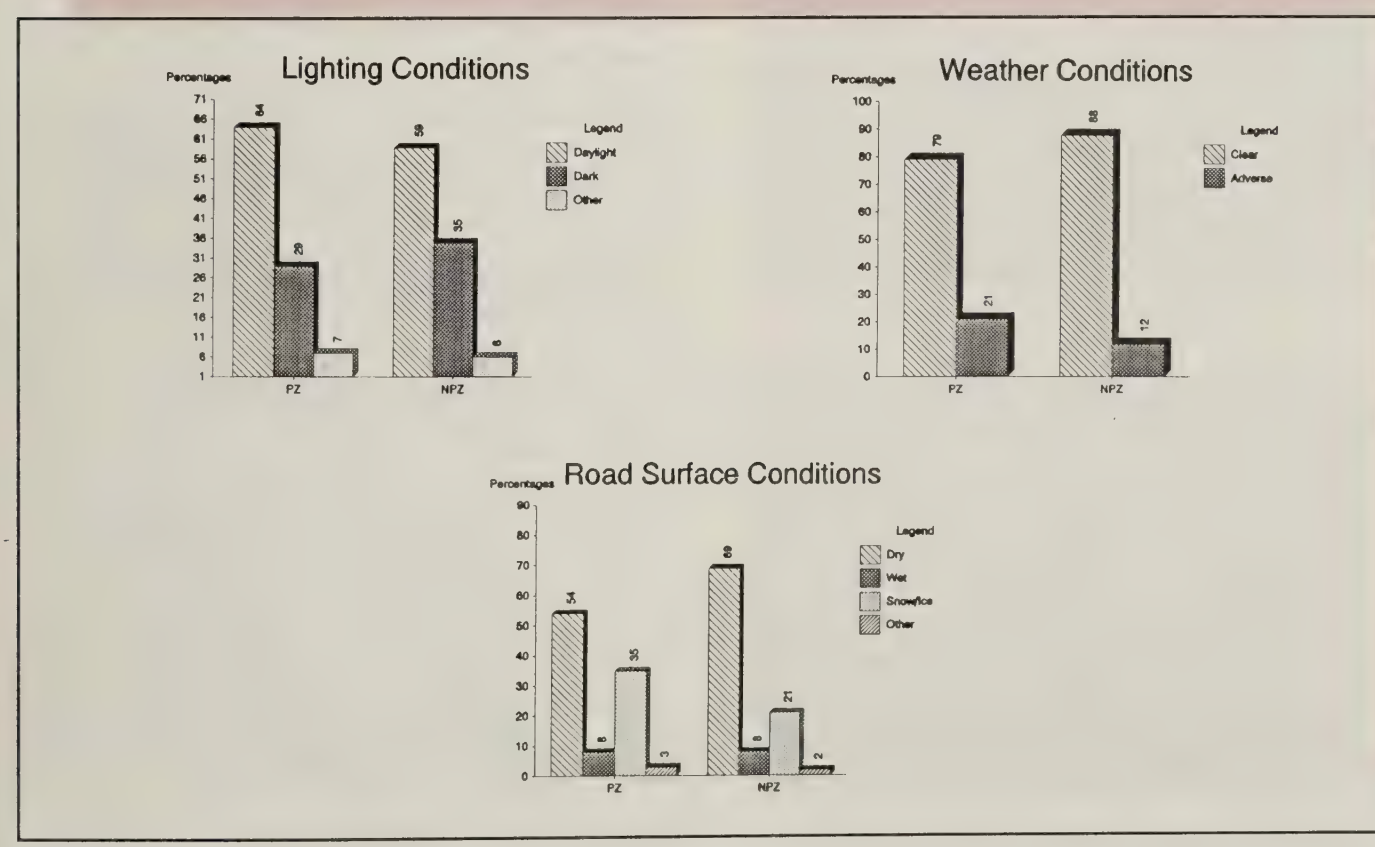


Figure 6.—Environmental conditions of passing and no-passing zone accidents.

Geometric/roadway characteristics and conditions. Some of the variables analyzed from this group included roadway characteristics, posted speed, shoulder type and width, and pavement type and width. The results of the comparative analysis indicated that there were marked differences for these variables between the two groups. However, due to the direct correlation between roadway design and the type of accidents that would occur, it is difficult to examine and make inferences about these variables unless exposure data for each variable were available.

Comparative Analysis of Passing Accidents in Passing Zones and No-passing Zones

Table 7 presents the passing accidents that are categorized by zone type. Following is a discussion of the comparative analysis conducted on these two groups of passing accidents:

Table 8 lists the variables that showed the most marked differences between the two groups of passing accidents.

Descriptive characteristics. Figure 5 highlights findings from the analysis of descriptive characteristic variables. From this analysis, the following observations were apparent:

- There was a greater tendency for sideswipe-in-passing accidents to occur in no-passing zones, while the tendency for head-on and rear-end collisions was noticeably higher in passing zones.
- Occupants involved in passing zone accidents were more likely to sustain injuries and fatalities than those involved in no-passing zone accidents.

Environmental conditions. Figure 6 depicts the key environmental conditions that differed between the two sets of data. These findings were observed regarding environmental conditions:

- Accidents in no-passing zones were more likely to occur under dark lighting conditions. This finding seems to indicate that the adverse effect of limited sight distance is further compounded under limited lighting conditions for the passing motorist in no-passing zones.
- Passing zone accidents were more likely to occur under adverse weather conditions than were accidents in no-passing zones. This finding may indicate that drivers passing in a no-passing zone are more hesitant to execute the passing maneuver under adverse weather conditions.
- The higher portion of passing zone accidents that occurred when pavement markings were obscured by snow or ice may reflect the fact that motorists had to rely on their own judgment of effective sight distance in determining whether to attempt passing maneuvers. That is, even under these hazardous conditions, drivers still feel the need to pass other vehicles. It is expected that drivers recognize the added hazards and will not execute a pass if a certain level of risk is exceeded. When accidents occur, it is evident that some drivers are not capable of assessing the level of risk on their own and that, at a minimum, they require the guidance provided by the pavement markings and signs.

Human characteristics. Driver age, presented in figure 7, was the only human characteristic variable that showed a marked difference between

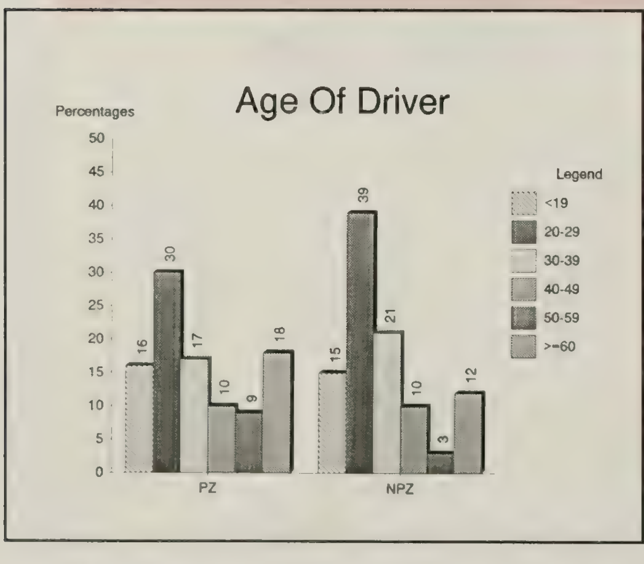


Figure 7.—Human characteristics of motorists in passing and no-passing zone accidents.

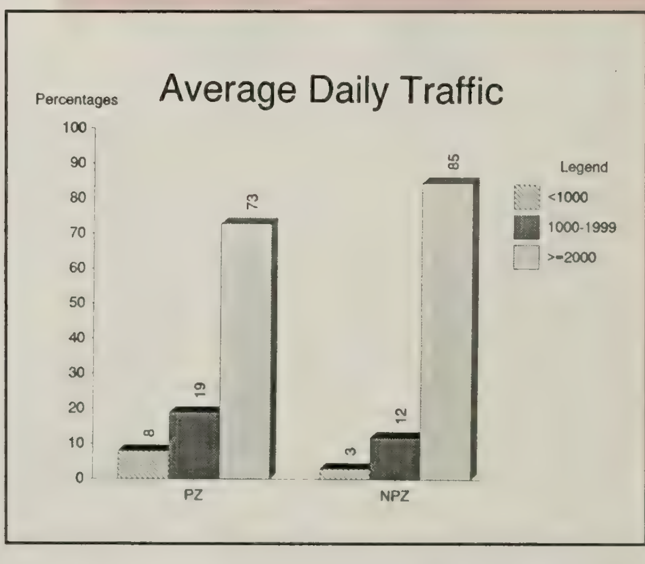


Figure 8.—Traffic characteristics of passing and no-passing zone accidents.

When passing zone markings are obscured, motorists often must rely on their own judgment.

the two data sets. From a review of this variable, the following was apparent:

- Driver age has no relationship to accident zone.
- Of the drivers involved in no-passing zone accidents, 75 percent were under the age of 40; 63 percent of the drivers involved in accidents in passing zones were also under 40. This finding might be a reflection of the higher risk-taking behavior and lack of experience on the part of younger drivers.

Geometric/roadway characteristics and conditions. Some of the variables analyzed from this group included terrain, posted speed, shoulder type and width, and pavement type and width. The results of the comparative analysis indicated that these variables showed marked differences between the two groups. This finding is expected, because these geometric/roadway variables are in direct correlation to the type of passing zone in which the accidents occur. Definite inferences regarding these variables cannot be made without exposure data for each variable.

Traffic conditions. Figure 8 shows average daily traffic. Accidents in no-passing zones were more likely to occur than accidents in passing zones when daily traffic volumes were greater than or equal to 2,000 vehicles. Higher volumes indicate that motorists will have a higher urge to pass but fewer opportunities to do so. Consequently, they may be more likely to attempt a pass when they perceive an acceptable gap regardless of pavement markings. In no-passing zones, when the availability of these gaps are few and far between, increased driver frustration may cause motorists to attempt passing maneuvers even when sight distances are inadequate.

Conclusions

Magnitude of Passing Accidents

From the aggregate statistics developed to determine the magnitude of passing accidents, it can be concluded that there is not a significant problem in this area. In fact, the pattern of occurrence of passing accidents seems to be extremely random. Thus, based on the findings of this project, the current MUTCD minimum sight distance requirements do not appear to pose a driving hazard to motorists. Consequently, there is no immediate need to change these values.

Comparative Analysis of Passing and Nonpassing Accidents

From the results of this analysis, the following can be concluded:

- Most accidents involve property damage only, but when there are injuries, passing accidents seem to be slightly more severe than nonpassing accidents.

Signs, in addition to pavement markings, are helpful.

- Most accidents, both passing and nonpassing, occurred under favorable driving conditions—dry roadway surfaces, straight and level roads with shoulders, and clear weather.

- When pavement markings cannot be seen because of partial or total obscuring of the markings by snow or ice, motorists are forced to rely on their own judgment in determining passing sight distances. The findings of this study show that motorists have difficulty in making such judgments.

Comparative Analysis of Passing Accidents Between Passing and No-passing Zones

From the results of this analysis, the following can be concluded:

- Most of these accidents involve property damage only; however, when an injury occurs, passing zone accidents seem to be more severe than no-passing zone accidents.

- No geometric, environmental, or traffic factor was confidently identified as a primary cause of accidents in these two types of zones. Further, no definite conclusions can be drawn relating these variables to the accident experience unless exposure data are available for the analyses. Some factors seem to contribute to a degree, however. The data indicate that percentages of accidents were lower in no-passing zones for such variables as adverse weather and obscured road surface conditions. This finding is probably an indication that passing in a no-passing zone is a dangerous maneuver even under good driving conditions, and fewer of these maneuvers are attempted under poor driving conditions.

- Most of the drivers involved in passing zone accidents were under the age of 40.

- Increased driver frustration, brought on by the availability of fewer passing opportunities on high volume roads, appears to lead motorists to attempt passing maneuvers in no-passing zones even when sight distances were inadequate.

Recommendations

The following recommendations are based on the findings of the comparative analyses:

- Besides pavement markings, other traffic control devices such as the No-passing pennant should be installed more frequently to further demarcate a passing zone from a no-passing zone or a change between the two—especially where existing pavement markings are obscured.

- Since drivers' inabilities seem to contribute to the occurrence of many accidents, workshops should be conducted to further educate all drivers—especially those under the age of 40—about maneuvers in passing zones.

- Passing lanes should be provided on two-lane rural roads that have high average daily traffic volumes and high posted speeds.

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Investigation of Passing Accidents Using the HSIS Data Base

by Yusuf M. Mohamedshah

Introduction

The Federal Highway Administration's (FHWA's) study of passing accidents on two-lane, two-way rural roads, discussed on pages 49-60 of this issue, found that the magnitude of passing accidents in one State was very low for the 5-year period 1985 through 1989. The present study was undertaken to determine whether a similar trend in passing accidents could be found in other States.

This study assessed the magnitude of the passing accident problem in two States from 1985 to 1989 on two-lane rural roads and two-lane rural and urban roads. Study results were compared to those from the previous FHWA study. (For clarity, the State cited in that study is here referred to as State A, and the States studied in the present research are here designated as States B and C.) This study was conducted using the FHWA's Highway Safety Information System (HSIS) data base.

Methodology

The Highway Safety Information System has accident and roadway data from five States (Illinois, Maine, Michigan, Minnesota, and Utah) that have been collected over a 5-year period. The data are available in linkable accident, vehicle, roadway, and traffic files. States B and C were chosen for inclusion in this study because of the availability of variables for these States similar to those used to define passing accidents in the State A study.

Table 1 provides a summary of the accident and roadway data available for States A, B and C. As shown in the table, the total number of accidents on all roads and on two-lane rural roads is highest in State A for the 1985 through 1989 period. State B has the second highest number of total accidents, while State C has the second highest number of accidents on two-lane rural roads. Not surprisingly, States A and C also

Table 1.—Summary of total accidents and mileage for States A, B and C, 1985-89

Description		State B	State C	State A
Total accidents available on all roads (rural and urban) for 5 years (1985-89)		242,311	201,319	375,690
Total mileage for two-lane roads	Rural	5,428.30	14,043.17	34,216.95
	Rural and urban	6,461.51	17,201.93	44,690.51
Total annual million vehicle miles (MVM) of travel on two-lane roads	Rural	2,014.43	5,756.42	10,749.39
	Rural and urban	4,014.45	8,809.00	17,603.95
Total accidents occurring on two-lane roads for 5 years	Rural	21,407	54,113	69,104
	Rural and urban	68,489	100,776	198,185
Average annual accidents on two-lane roads per 100 MVM of travel	Rural	213	188	129
	Rural and urban	341	229	225

"Improper overtaking" is the primary factor in passing accidents.

have the highest two-lane roadway mileage. State A's mileage is almost seven times that of State B, and State C's mileage is more than double that of State B. As a result, the average annual accidents on two-lane roads per 100 million vehicle miles (MVM) of travel is higher for State B as compared to States A and C.

The first step in developing a final data set for passing accidents for the three States was to merge the accident, vehicle, and roadway files of all accidents occurring on two-lane roads in the 5-year period. Accidents on unpaved roads were eliminated from the final data set.

The next step was to identify the passing accidents that occurred on the two-lane roads in States B and C. This process entailed defining the specific variables for each State that were to be used in identifying a passing accident.

The vehicle file for State B has two variables that indicate contributing factors to a particular accident (CONTRIB1 and CONTRIB2) and one variable for precrash maneuver (INTENT). An accident was defined as passing if contributing factors indicated "improper overtaking" or precrash maneuver indicated "overtake."

The vehicle file for State C also has two variables indicating contributing factors (CONTRIB1 and CONTRIB2); another variable (MANEUV) is the precrash maneuver of the vehicle. Passing accidents in State C were defined as those whose contributing factors indicated "improper passing" or whose precrash maneuver indicated "overtaking, passing."

Several single-variable tables were next developed from this passing vehicle file to determine whether the remaining accidents were truly passing accidents. These tables revealed that some of the vehicles included in the file had been involved in some kind of turning movement—either a left turn, right turn, or U-turn. Also, several accidents were determined to be either pedestrian or bicycle accidents. The records for turning accidents and pedestrian/bicycle accidents were deleted from the final file.

The final passing accident files for two-lane rural roads contained 495 accidents involving 860 vehicles for State B. State C had 1,422 accidents involving 2,524 vehicles. Figures 1 and 2 show how these numbers relate to the overall numbers of ac-

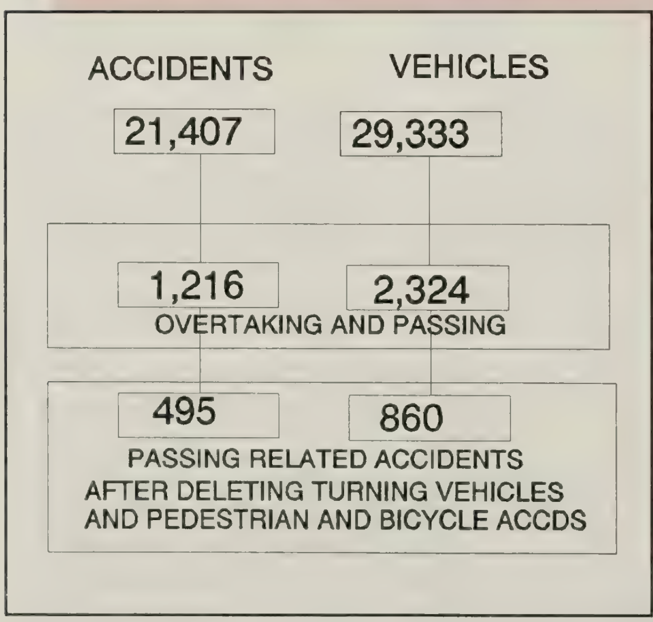

Figure 1.—Accidents and vehicles involved on two lane, rural roads in State B, 1985-89.

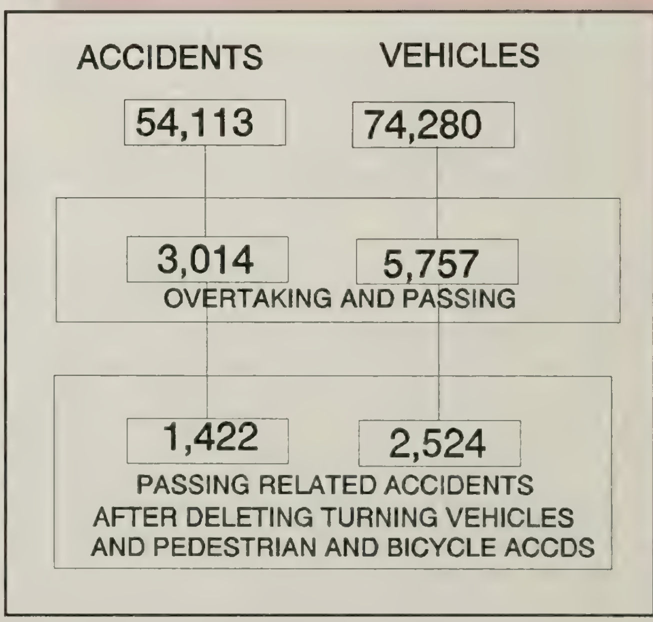

Figure 2.—Accidents and vehicles involved on two lane, rural roads in State C, 1985-89.

cidents and involved vehicles. The accidents that did not satisfy the constraints of passing accidents were classified as nonpassing accidents.

Comparison Between the States

Indicator Ratios

In order to compare the passing accidents within each State and between the States, two indicator ratios were developed. These ratios, and their values for each of the three States compared in this study, follow:

Indicator ratios for State B

1. $\frac{PRA(2L)}{AA(2L)} = \frac{\text{(Passing Accidents on Two-Lane Roads) } 922}{\text{(All Accidents on Two-Lane Roads) } 68{,}484} = 1.35\%$

2. $\frac{PRA(2LR)}{AA(2LR)} = \frac{\text{(Passing Accidents on Two-Lane Rural Roads) } 495}{\text{(All Accidents on Two-Lane Rural Roads) } 21{,}407} = 2.31\%$

Indicator ratios for State C

1. $\frac{PRA(2L)}{AA(2L)} = \frac{\text{(Passing Accidents on Two-Lane Roads) } 2{,}325}{\text{(All Accidents on Two-Lane Roads) } 100{,}776} = 2.31\%$

2. $\frac{PRA(2LR)}{AA(2LR)} = \frac{\text{(Passing Accidents on Two-Lane Rural Roads) } 1{,}422}{\text{(All Accidents on Two-Lane Rural Roads) } 54{,}113} = 2.63\%$

Indicator ratios for State A

1. $\frac{PRA(2L)}{AA(2L)} = \frac{\text{(Passing Accidents on Two-Lane Roads) } 1{,}516}{\text{(All Accidents on Two-Lane Roads) } 198{,}185} = 0.76\%$

2. $\frac{PRA(2LR)}{AA(2LR)} = \frac{\text{(Passing Accidents on Two-Lane Rural Roads) } 986}{\text{(All Accidents on Two-Lane Rural Roads) } 69{,}104} = 1.43\%$

Comparing the ratios within and between the States reveals the following:

- In all three States, passing accidents are higher on two-lane rural roads than on all two-lane roads.

Table 2.—Severity distribution of accidents on two-lane rural roads for State B, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	12.56% (2,627)	18.99% (94)	12.71% (2,721)
Non-incapacitating	10.42% (2,180)	13.33% (66)	10.49% (2,246)
Possible injury	7.36% (1,540)	11.31% (56)	7.46% (1,596)
Property damage only	69.65% (14,565)	56.36% (279)	69.34% (14,844)
Total	100% (20,912)	100% (495)	100% (21,407)

Note: Number of accidents are in parentheses.

Table 3.—Severity distribution of accidents on two-lane roads (rural & urban) for State B, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	9.65% (6,520)	15.62% (144)	9.73% (6,664)
Non-incapacitating	10.70% (7,227)	11.17% (103)	10.70% (7,330)
Possible injury	12.45% (8,425)	10.74% (99)	12.45% (8,524)
Property damage only	67.19% (43,395)	62.47% (576)	67.12% (45,971)
Total	100% (67,567)	100% (922)	100% (68,489)

Note: Number of accidents are in parentheses.

- In all three States, there are much fewer passing accidents than nonpassing accidents on all two-lane roads.

- State C has the highest percentage of passing accidents followed by State B and then State A.

Severity Distributions

Tables 2 through 7 also show the severity distributions of passing accidents versus nonpassing accidents for States B, C and A on rural and rural/urban two-lane roads.

Comparison of severities within each State shows that passing accidents are somewhat more severe than nonpassing accidents. In State A, the percentage of fatal and incapacitating passing accidents is higher than that of nonpassing accidents. Also, figures 3 and 4 show that fatal and incapacitating passing accidents are highest in State B, followed by State A, and then State C. Non-incapacitating and possible injury accidents are slightly higher in States C and A than in State B. Interestingly, the percentages of non-injury (i.e., property damage only) accidents in each State are quite similar.

Accident Types

Some transportation professionals believe that passing-related accidents are more frequently of a head-on nature than they are of other accident

Table 4.—Severity distribution of accidents on two-lane rural roads for State C, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	5.71% (3,008)	7.45% (106)	5.75% (3,114)
Non-incapacitating	15.71% (8,277)	16.17% (230)	15.72% (8,507)
Possible injury	14.89% (7,846)	16.46% (234)	14.93% (8,080)
Property damage only	63.69% (33,560)	59.92% (852)	63.59% (34,412)
Total	100% (52,691)	100% (1,422)	100% (54,113)

Note: Number of accidents are in parentheses.

Table 5.—Severity distribution of accidents on two-lane roads (rural & urban) for State C, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	4.43% (4,366)	6.28% (146)	4.48% (4,512)
Non-incapacitating	12.94% (12,739)	13.38% (311)	12.95% (13,050)
Possible injury	13.95% (13,735)	13.94% (324)	13.95% (14,059)
Property damage only	68.67% (67,611)	66.41% (1,544)	68.62% (69,155)
Total	100% (98,451)	100% (2,325)	100% (100,776)

Note: Number of accidents are in parentheses.

Table 6.—Severity distribution of accidents on two-lane, rural roads for State A, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	9.30% (6,337)	13.89% (137)	9.37% (6,474)
Non-incapacitating	16.00% (10,905)	15.42% (152)	16.00% (11,057)
Possible injury	15.02% (10,232)	15.52% (153)	15.03% (10,385)
Property damage only	59.67% (40,644)	55.17% (544)	59.60% (41,188)
Total	100% (68,118)	100% (986)	100% (69,104)

Note: Number of accidents are in parentheses.

Table 7.—Severity distribution of accidents on two-lane roads (rural & urban) for State A, 1985-89

Severity	Nonpassing accidents	Passing accidents	All accidents
Fatal, incapacitating	6.65% (13,087)	12.34% (187)	6.70% (13,274)
Non-incapacitating	13.97% (27,469)	14.38% (218)	13.97% (27,687)
Possible injury	14.46% (28,429)	13.32% (202)	14.44% (28,631)
Property damage only	64.92% (127,684)	59.96% (909)	64.89% (128,593)
Total	100% (196,669)	100% (1,516)	100% (198,185)

Note: Number of accidents are in parentheses.

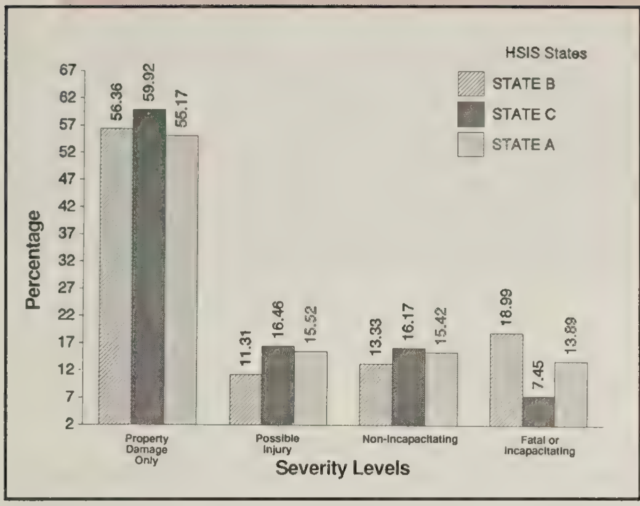

Figure 3.—Severity of passing-related accidents on two lane, rural roads.

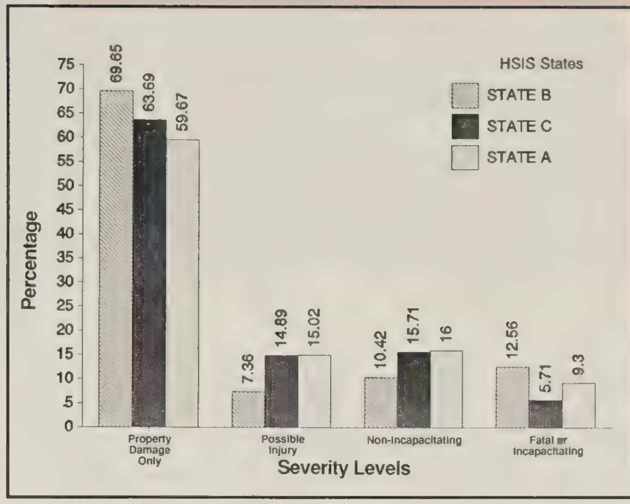

Figure 4.—Severity of nonpassing-related accidents on two lane, rural roads.

Table 8.—Collision type for passing-related accidents on two-lane, rural roads for State B, 1985-89

Collision type	Accident nos.	Percent	Cumulative frequency	Cumulative percent
Any single vehicle	169	34.1	169	34.1
Rear-end	125	25.2	294	59.3
Sideswipe	75	15.2	369	74.5
Same, turning	67	13.6	436	88.1
Head-on	33	6.7	469	94.8
Opposite turning	16	3.2	485	98.0
Approach angle	5	1.0	490	99.0
Approach turning	3	0.6	493	99.6
Other	2	0.4	495	100.00

Table 9.—Accident type for passing-related accidents on two-lane, rural roads for State C, 1985-89

Collision type	Accident nos.	Percent	Cumulative frequency	Cumulative percent
Rear-end/sideswipe	575	40.4	575	40.4
Ran off road	436	30.7	1,011	71.1
Head-on/sideswipe	258	18.1	1,269	89.2
Rollover	79	5.6	1,348	94.8
Fixed object	34	2.4	1,382	97.2
Intersection	27	1.9	1,409	99.1
Other	10	0.7	1,419	99.8
Jackknife	2	0.1	1,421	99.9
Submersion	1	0.1	1,422	100.0

types. To investigate this premise, a set of tables was developed to examine the types of accidents involved in a passing maneuver. The collision type variable was used for State B, the accident type variable was used for State C, and the accident diagram variable was used for State A to develop these tables. Despite the differences in their respective terminology, the variables used by States A and C are actually very similar categories; State B, however, does not have such categories. Instead, a collision type variable was used for State B since this variable indicates the motion of the vehicle at the time of impact. This information is similar to that collected under the State A and C categories.

Table 8 for State B shows that 34.1 percent of the passing accidents are single vehicle, followed by rear-end accidents (25.2 percent) and sideswipe accidents (15.2 percent). Table 9 shows that rear-

Table 10.—Accident type for passing-related accidents on two-lane, rural roads for State A, 1985-89

Collision type	Accident nos.	Percent	Cumulative frequency	Cumulative percent
Sideswipe passing	315	31.9	315	31.9
Ran off road right	134	13.6	449	45.5
Other	125	12.7	574	58.2
Rear-end	120	12.2	694	70.4
Ran off road left	117	11.9	811	82.3
Sideswipe opposite	81	8.2	892	90.5
Head-on	63	6.4	955	96.9
Unknown	31	3.1	986	100.0

end accidents in State C predominate (40.4 percent), followed by ran-off-road accidents (30.7 percent) and head-on/sideswipe accidents (18.1 percent). Table 10 shows that sideswipe passing accounts for the largest proportion of passing accidents (31.9 percent) in State A, followed distantly by rear-end accidents (12.2 percent) and head-on accidents (6.4 percent). These results contradict the supposition that passing accidents on two-lane rural roads primarily consist of head-on accidents. All three States show a relatively low percentage of head-on accidents as compared to other accident types.

Conclusion

This study was performed to determine the magnitude of passing accidents on two-lane roads. The data show that the total number of passing accidents with respect to all accidents is in the range of 2 percent to 3 percent for the three States studied. These percentages are very low as compared to other types of accidents; this indicates that passing accidents do not appear to be a significant problem.

The severity of passing accidents is slightly higher than the severity of nonpassing accidents for the three States. Although there are some differences in injury severity among the three States, the total percentages of injury accidents are similar. The States also exhibit similar trends with regard to the severity of their nonpassing accidents. Comparing passing accident type shows that head-on type accidents are less frequent than other types; this finding is contrary to popular belief.

The percentage of passing accidents with respect to all accidents for States B and C reinforces the conclusion of an earlier study made of State A. The low number of passing accidents as compared to total accidents indicates that the potential to improve safety on two-lane roads by changing standards for marking in passing zones is small.

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Transfer Lengths in Rectangular Prestressed Concrete Concentric Specimens

by Susan N. Lane

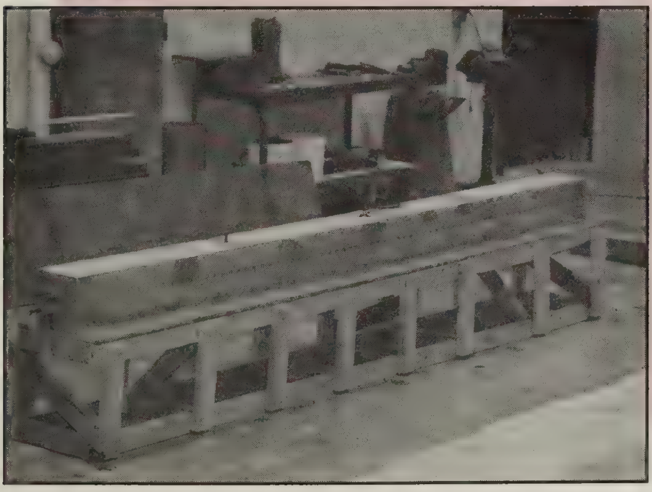
Introduction

Since the 1950's, the use of prestressed concrete in bridge construction has steadily increased. It is now incorporated in nearly half of the 5,000 new bridge projects undertaken each year in the United States. *(1)*[1]

There are two methods of prestressing: post-tensioning and pretensioning. In a post-tensioned member, the prestressing force is transferred from the strand to the concrete through the end anchorages. In a pretensioned member, the prestressing force in a strand is transferred from the strand to the concrete by bond.

The development length is the distance, measured from the end of a pretensioned member, required for the steel strand and the concrete to bond and support the ultimate load of the member.

In October 1988, the Federal Highway Administration (FHWA) issued a memorandum about the use of prestressing strand in a pretensioned application for prestressed concrete bridges. The memorandum:



- Disallowed the use of 15.2-mm (0.6-in) diameter strand in a pretensioned application.
- Restricted the minimum strand spacing.
- Increased the required development length for fully bonded strand by 1.6 times and for debonded strand by 2.0 times the development length specified by the American Association of State Highway and Transportation Officials (AASHTO). *(7)*

The memorandum noted that these restrictions were an interim measure pending further research, and the research results were adopted by AASHTO. *(2)*

Because of the FHWA memorandum, development length of prestressing strand has become a widely discussed issue. Several research studies on this topic are either now under way or have been recently completed in the United States and Canada.

The FHWA began its own research on this topic in the spring of 1990. The study, "Investigation of Development Length of Uncoated and Epoxy-Coated Prestressing Strand," is being conducted at the FHWA's Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. Study variables include the strand diameter and number of strands. The second phase of the study to begin in early 1993 will include research on full-size I-girders.

This article describes results of the FHWA development length study to date. A general description of the first phase of the study, involving rectangular prestressed concrete specimens, is presented and is followed by the results for the rectangular concentric specimens only. Results for both uncoated and epoxy-coated prestressing strands are presented. This article is the first of a series of articles about this major study.

[1]Italic numbers in parentheses identify references on page 71.

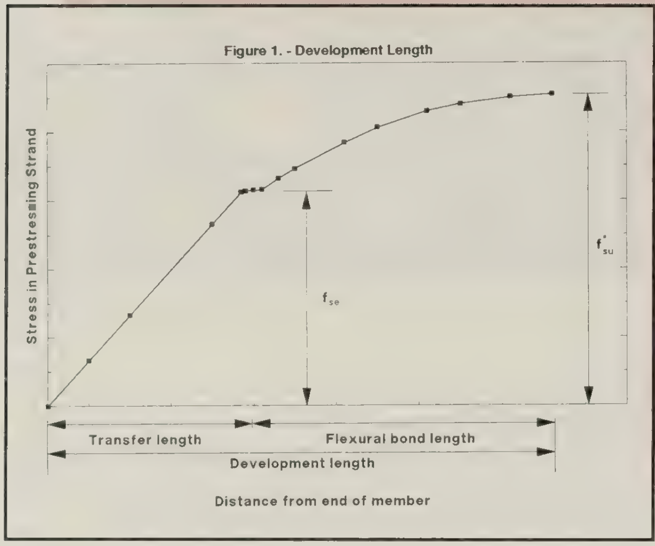


Figure 1.—Development length of prestressing strand.

Background

The development length is made up of two components: transfer length and flexural bond length. As seen in figure 1, the transfer length corresponds to the distance needed from the end of the member to develop the effective prestressing stress, f_{se}, in the strand. *(2, 4, 5, 6)* The flexural bond length is the length needed beyond the transfer length to achieve bonding between the steel strand and the concrete in order to attain the stress in the strand at the ultimate load of the member, f^*_{su}. *(2, 4, 5, 6)*

In article 9.27 of the AASHTO Specifications, development length is given by equation 9-32 as: *(7)*

$$(f^*_{su} - 2/3\ f_{se})D \qquad (1)$$

where D equals nominal diameter of the strand in inches.

This expression can be rewritten in order to examine its constituent parts: *(3)*

$$L_d = f_{se}\ D/3 + (f^*_{su} - f_{se})D \qquad (2)$$

where

L_d	= development length
$f_{se}\ D/3$	= transfer length
$(f^*_{su} - f_{se})D$	= flexural bond length

The AASHTO specifications further state that transfer length may be assumed to be equal to 50 times the strand's nominal diameter. *(7)* No expression is given for flexural bond length. *(2)*

Fifty prestressed concrete rectangular specimens were fabricated in the first phase of the study. Twenty-four specimens contained concentric strands (strands centered at the neutral axis of the specimen). Another 24 specimens contained eccentric strands (strands centered at a point a certain distance from the neutral axis). The remaining two specimens were used to monitor shrinkage of the concrete. The transfer and development lengths of the specimens were determined; however, only the transfer length results will be reported here because the rest of the data has not been fully analyzed.

Description of Specimens

The twenty-four rectangular, prestressed concrete, concentric specimens were fabricated in four casts at the Structures Laboratory of the TFHRC. All of these specimens:

- Contained either uncoated or epoxy-coated strand(s).
- Contained either one strand or four strands.
- Ranged in size from 102 mm x 102 mm (4 in x 4 in) to 229 mm x 229 mm (9 in x 9 in).
- Were 3658 mm (12 ft) long.
- Were at least twice as long as the "expected" transfer length, so that values for transfer length could be experimentally determined for each end of each specimen.
- Had approximately the same maximum allowable compressive stresses (0.60 f'_{ci} before losses and 0.40 f'_c after losses).
- Did not contain any shear reinforcement.

Prestressing Strand

All of the prestressing steel used in the specimens was Grade 270 (1,860 MPa [270 ksi] guaranteed ultimate tensile strength), seven-wire low-relaxation strand, conforming to American Society for Testing and Materials (ASTM) standard A416. All of the prestressing strand was donated by Florida Wire and Cable Company. The average value of the strand's modulus of elasticity was 197,022 MPa (28.6 x 10^3 ksi).

The epoxy-coated strand contained a fusion-bonded epoxy coating, with an average coating thickness of 0.79 mm (0.031 in). The coating covered the outside surfaces of the six outer wires of

Table 1.—Concrete mix proportions		
Components	Quantities	
Cement	390 kg/m^3	(658 lb/yd^3)
Fine aggregate	867 kg/m^3	(1,462 lb/yd^3)
Coarse aggregate	1,099 kg/m^3	(1,852 lb/yd^3)
Water	132 kg/m^3	(224 lb/yd^3)
Water-reducing admixture	0.73 l/m^3	(1.23 lb/yd^3)
Entrained air	None required	
Maximum aggregate size	19 mm	(3/4 in)
Slump	50.8 mm - 101.6 mm	(2 in - 4 in)
Water to cement ratio	0.49 maximum	

Table 2.—Summary of transfer lengths

Strand dia. (in)	Average				$\frac{f_{se}D}{3}$ (in)		AASHTO 50D
	Uncoated		Epoxy-coated				
	One strand	Four strands	One strand	Four strands	One strand	Four strands	
3/8	26.9 (71.7)	33.7 (89.9)	16.8 (44.9)	21.6 (57.7)	21.7 (57.9)	19.6 (52.3)	(50)
0.5	33.0 (66.1)	40.0 (80.1)	20.2 (40.3)	26.0 (52.1)	26.5 (53.0)	25.7 (51.4)	(50)
0.6	43.2 (72.0)	>72.0 (>120.0)	26.0 (43.3)	26.2 (43.8)	31.7 (52.8)	31.0 (51.7)	(50)

Notes: 1) Numbers in parentheses are values expressed in terms of the number of strand diameters.
2) English units are used because AASHTO equation 9-32 requires that the parameter "D" be in inches, and comparisons are made with this equation.
3) 1 in = 25.4 mm

the seven-wire strand; there was no coating on the center wire. Small aluminum oxide particles, called "grit," were impregnated into the outer surface of the epoxy coating. The grit helped develop bond between the epoxy-coated prestressing strand and the concrete.

The strands were stressed with a center-hole hydraulic jack and a hand pump. The maximum stress in the strand after transfer was 75 percent of the guaranteed ultimate tensile strength of the strand.

Concrete

The concrete mix was designed to obtain a 28-day compressive strength, f'_c, which was greater than or equal to 34.4 MPa (5,000 psi) and less than or equal to 44.8 MPa (6,500 psi). The concrete mix proportions, listed in table 1, were designed by the ready-mix supplier, who batched and delivered the concrete for four concrete casts. The specimens were moist-cured until concrete cylinders indicated a compressive strength of at least 27.6 MPa (4,000 psi); at this point, the specimens were detensioned by flame-cutting the strand. The average concrete strength at detensioning was 29.8 MPa (4,330 psi), and the average 28-day concrete strength was 40.7 MPa (5,910 psi) for the four casts.

Instrumentation of Specimens and Test Procedures

Each concentric specimen was instrumented with gage points spaced at 50-mm (1.97-in) intervals along the full length of both sides of the concrete surface. Due to the large number of gage points involved, threaded brass inserts were preattached to the formwork and cast into the concrete.

Once the concrete attained a compressive strength of 27.6 MPa (4,000 psi), the formwork was stripped, and a baseline measurement of the distance between each of the gage points on each specimen was taken using a Whittemore-style mechanical strain gage. Another set of readings using the same equipment was taken immediately after detensioning. The difference in values between the two readings was used to determine the strain in the concrete after detensioning. These strains were then plotted. The transfer length for each end of the specimen could then be determined from this plot. The transfer length is the distance from the end of the beam to the point on the curve equal to the average value of strain for the plateau portion of the graph. A full set of Whittemore readings was taken after detensioning, 1 day after detensioning, and at concrete ages of 7, 14, 28, 56, 90, 180, 270, and 365 days. The transfer lengths for each end of each specimen were determined at each of these time intervals.

To measure the end slip of each strand, a small fixture was attached to a strand adjacent to the end of each specimen. Holes were bored in the fixture to accept a digital depth gage, which was used to measure the distance from the fixture to the concrete surface. This distance was measured before and after detensioning and at each of the time intervals mentioned above.

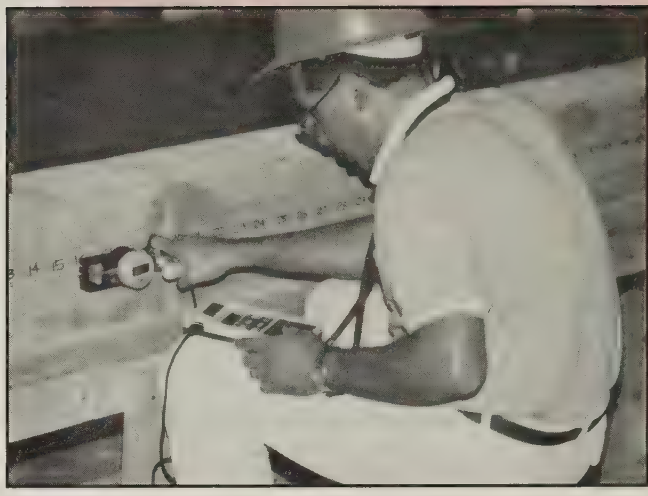
Results and Conclusions

Transfer length

The experimentally determined transfer length values at a concrete age of 365 days are summarized in table 2. The two specimens containing four 15.2-mm (0.6-in) diameter uncoated strands are listed as having transfer lengths greater than 1,829 mm (72.0 in); this is because the graphs of strains versus distance never reached a plateau, but were essentially pointed plots. Therefore, the transfer length for each end of the beam was greater than half of the beam's length.

Several observations were made after examining the transfer length values:

- In every case, the transfer lengths of specimens containing epoxy-coated strand(s) of a given strand diameter were shorter than the transfer lengths for the specimens containing the uncoated strand(s).
- The transfer lengths for uncoated strands were approximately 1.6 times the transfer lengths of epoxy-coated strands.
- In every case, transfer length increased as strand diameter increased.



- Transfer lengths for specimens containing four strands were greater than those for specimens containing one strand, regardless of the presence of coating on the strand. The percentage increase in transfer length for four-strand specimens compared to one-strand specimens was close to 25 percent for 9.5-mm (3/8-in) and 12.7-mm (1/2-in) diameter strands. The percentage increase varied greatly for specimens with 15.2-mm (0.6-in) diameter strands.

Values for $f_{se}D/3$ are also given in table 2. These values correspond to the transfer length component in the development length equation. It was observed that values of $f_{se}D/3$ were conservative for all specimens containing one epoxy-coated strand. However, these values were not conservative for all other specimens, except those with four 15.2-mm (0.6-in) diameter epoxy-coated strands.

AASHTO's assumed values of transfer length, also listed in table 2, were conservative for all specimens containing one epoxy-coated strand. However, as with the values for $f_{se}D/3$, the assumed values were not conservative for all other specimens except those with four 15.2-mm (0.6-in) diameter epoxy-coated strands.

Change in Transfer Length

Values for percentage change in transfer length were calculated. These values represent the percentage change between average transfer length values determined immediately after detensioning and at a concrete age of 365 days. There was no pattern to the values for percentage change in transfer length.

Ongoing Research

This article describes only the transfer length results for the concentric specimens, which represent a small portion of the research to date. Transfer length and development length results are currently being determined for the eccentric specimens. Experimentation to evaluate the effects of elevated temperatures on the bond strength of epoxy-coated strand is also ongoing. The second phase of the study, to begin in early 1993, will include transfer and development length research on full-size I-girders.

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THE IMPACTS OF ALTERNATIVE URBAN DEVELOPMENT PATTERNS ON HIGHWAY SYSTEM PERFORMANCE

by Patrick DeCorla-Souza, A.I.C.P.

Introduction

Urban planners have long recognized that development patterns influence travel demand and congestion levels and that transportation system supply and performance characteristics in turn influence development patterns. As traffic congestion worsens, an important question is being asked with regard to development: What is the potential contribution of development patterns to the moderation of highway travel demand and traffic congestion levels in urban areas?

The Federal Highway Administration (FHWA) sought to answer this question through studies of the impacts of alternative development patterns in U.S. cities. The studies were done under FHWA sponsorship by the Metropolitan Planning Organizations (MPOs) in four urban areas — Baltimore, Dallas, Washington, DC, and Seattle. This article documents the results of these studies and draws some general inferences from their analyses.

A second question of interest, particularly to the environmental community, is: What are the development effects of transportation system (particularly highway) supply and performance characteristics? The FHWA is currently pursuing a multiyear study on the affects of transportation system performance on development patterns.

Background

The FHWA studies of four U.S. cities were macro level studies that sought to investigate the potential of alternative patterns of future growth to affect highway system performance. The studies used computerized simulation to determine the travel consequences of growth in a target year in the long-range future (2010 or 2020). Each MPO developed its own set of alternative long-range urban development patterns for analysis. They compared the alternatives to development forecasts previously adopted by their policy bodies in order to draw conclusions about the relative impacts of the alternatives on travel demand and highway system performance.

Traffic congestion is a major problem in most urban areas.

The studies were done using the traditional four-step travel demand modeling process to simulate travel demand and congestion impacts. Baltimore, Dallas, and Washington, DC, varied only land use inputs into the modeling process, keeping transportation system characteristics the same as the base case. Seattle tested combinations of land use and transportation system strategies. The results of all four studies are summarized in the following sections.

Baltimore

The Baltimore study looked at the effects of three alternative patterns of future residential development, keeping future growth in employment concentrated in a few activity centers. The alternatives were compared to a base scenario which essentially combined forecasts of household and employment location distributions provided by Baltimore's six local jurisdictions.

The first alternative concentrated regional household growth anticipated between 1990 and 2010. A significant portion of anticipated growth was allocated to areas within the region's "development envelope." The second alternative decentralized household growth, assigning a significant portion of the growth to areas outside the development envelope. The third alternative allocated regional household growth only to those areas with a high level of transit accessibility. In all three alternatives, anticipated regional employment growth was assigned to existing activity centers, creating more intense employment clusters. The programmed future transportation network was assumed for each alternative and the base. Table 1 shows the impacts of the alternatives.

The redistribution of the 1990-2010 growth changed the proportions of total households and employment within the development envelope by less than 3 percent. Over the 20-year period, total households were projected to grow by 24 percent over the 868,000 households existing in 1990, and total employment was projected to grow by 17 percent over the 1,357,000 jobs existing in 1990. These increases were not high enough relative to the 1990 base to significantly affect existing patterns of concentration.

The analysis indicated that the regionwide transportation impacts of the three alternatives would be relatively small. Person trips do not vary much between alternatives; the variation in vehicle trips reflects the greater propensity to use transit and ridesharing modes as urban development is concentrated.

The impacts with respect to regionwide vehicle miles of travel (VMT) and congestion indicators were also relatively small, although larger than vehicle trip impacts. The highway system performed best under the centralized alternative—severely congested VMT and severely congested lane miles were both reduced by more than 1.5 percent relative to the base. This improvement was primarily due to the reduction in total regionwide highway travel demand, an almost 1-percent reduction in regionwide VMT.

Highway system performance deteriorated relative to the base under the other two alternatives. Under the decentralized alternative, severely congested VMT and lane miles increased by 1.6 and 3.0 percent, respectively, due to the increase in total VMT of almost 2 percent. Under the transit-oriented alternative, severely congested VMT increased by over 2 percent—even more than under the decentralized alternative. However, the congestion was more localized under this alternative, occurring on fewer lane miles.

The results of the Baltimore study suggest that concentrations of residential development can benefit highway system performance and reduce new highway capacity needs. Concentrations of residential development within areas with good transit access may not reduce highway capacity needs relative to base policies, but they could reduce new highway capacity needs relative to a decentralized pattern of development. Apparently, the transit-oriented alternative does not appear to reduce new highway capacity needs because vehicular travel demand is channelled into locations with little spare highway capacity.

Dallas

The three alternative development patterns studied in the Dallas urban area closely paralleled Baltimore's alternatives. Redistribution of growth in the Dallas alternatives was restricted to growth projected within the service area of the Dallas Area Rapid Transit (DART) system. As in Baltimore, the first alternative concentrated employment growth within predefined activity centers and distributed anticipated residential growth to

Table 1.—Impacts of alternative development patterns in Baltimore

	Base case (adopted)	Impacts of alternatives (percent change)		
		Alt. 1 (centralized)	Alt. 2 (decentralized)	Alt. 3 (transit)
Percent households within development envelope	87.8	+1.8	-1.8	+2.8
Percent employment within development envelope	94.2	+0.5	+0.5	+0.5
Daily internal trips:				
Person	7,867,500	-0.3	+0.5	-0.3
Vehicle	5,551,700	-0.6	+0.6	-0.5
Daily travel: VMT	54,757,200	-0.9	+1.8	-0.7
Avg speed (mi/h)	20.7	0.0	-1.9	-4.8
Severely congested VMT	17,093,400	-1.7	+1.6	+2.3
Severely congested lane mi	1,280	-1.6	+3.0	+1.0

The transit-oriented alternative concentrates both employment and residential growth near transit system stations.

zones within a specified distance from each activity center. A second alternative allocated employment and residential growth to currently uncongested areas, which are in dispersed locations. This alternative was designed to assess the impact of confining new development to areas with underused roadways. The third alternative was transit-oriented; it concentrated growth—both employment and residential—within a 3.5-mi radius of DART rail stations.

The alternatives were compared to forecasts from the region's transportation plan for the year 2010. Table 2 summarizes the results of the comparisons. Employment growth over a 25-year period (1986-2010) in the DART service area amounted to about 0.6 million or about 30 percent of total year 2010 employment in the service area. For the second alternative, the analysis area was expanded slightly because of a lack of sufficient uncongested areas within the DART service area. Significant redistribution of employment growth occurred with all three alternatives.

Population growth reallocated within the analysis area amounted to about 20 percent of total year 2010 population. For the first two alternatives, the change in the distribution of this population growth was less significant than for employment.

With respect to travel demand and congestion indicators, the alternative that dispersed growth in uncongested areas was the only one to reduce VMT significantly (by about 5 percent) and to produce significant improvements in level of service on the highway system. Average speed increased by 2 percent; travel time spent in delay was reduced by 4 percent; and roadway congestion was reduced by 10 percent.

The transit-oriented alternative failed to reduce VMT or improve highway levels of service. Reductions in VMT were insignificant due to relatively insignificant increases in transit ridership (about 35,000 additional linked transit trips regionwide daily). Higher congestion levels were the result of higher employment concentrations around the central business district.

The activity center-oriented alternative did not change either VMT or levels of congestion significantly. The somewhat slower average speed and increase in delay time are probably the effects of higher volumes of traffic being concentrated in the vicinity of activity centers.

Washington, DC

A somewhat different approach was taken in the selection of alternative urban development patterns for the Washington, DC, area. Two alternatives were selected. The first sought to promote a closer balance between employment and housing growth within the region. The second built upon the first and additionally sought to promote transit use by concentrating employment growth in areas of high transit accessibility.

Table 2.—Impacts of alternative development patterns in Dallas

	Base case (2010 Plan)	Impacts of alternatives (% change)		
		Alt. 1 (Act. ctrs)	Alt. 2 (Dispersed)	Alt. 3 (Transit)
Employment growth: In activity centers	173,848	+135	—	—
In uncongested areas	256,620	—	+103	—
In areas within 3.5 mi. of rail	378,443	—	—	+40
Population growth: In act. ctr. & tributaries	278,817	+13	—	—
In uncongested areas	355,737	—	+5	—
In areas within 3.5 mi. of rail	130,861	—	—	+143
Daily Travel: Vehicle trips	7,221,024	-1	-1	-1
Average speed (mph)	30.9	-2	+2	-3
VMT	63,048,000	0	-5	0
Percent travel time spend in delay	36.6	+3	-4	+5
Percent roadways congested	20.3	0	-10	+2

Table 3.—Impacts of alternative development patterns in Washington, DC

	Base case (Adopted)	Impacts of alternatives (% change)	
		Alt. 1 (Jobs/housing)	Alt. 2 (Transit)
Employment growth: In emp. grow. areas	604,000	0	+7.3
In high potential transit use areas	165,000	0	+100.0
In whole region	713,000	0	0
Household growth: In emp. growth areas	143,000	+181	+181
In balance of region	125,000	-47	-47
In whole region	268,000	+75	+75
Regionwide daily travel: Vehicle trips	12,020,000	+5.7	+4.7
VMT	103,800,00	+1.0	+1.3
Avg pk hr speed (mi/h)	16.9	+1.2	+1.8
Travel per household: Vehicle trips daily	6.8	-5.0	-6.0
Average trip length	8.6	-4.5	-3.2
VMT daily	59.0	-9.2	-8.8

The alternatives were compared to a base reflecting adopted 2010 forecasts, which were based on "pipeline" development proposals, zoning, available land, and other factors developed in cooperation with local jurisdictions. The results of the comparisons are presented in table 3.

Employment growth projected over a 15-year period (1995-2010) amounted to 713,000, a 27-percent increase over the 1995 base of 2,605,000. The distribution of this growth was unchanged for the first alternative. For the transit-oriented alternative, seven high employment growth areas that have superior transit accessibility were allocated twice the number of new jobs previously allocated.

The adopted 2010 forecasts for the region indicated an 18-percent increase in households. The 1995 base is 1,489,000 households. This increase of 268,000 households, assuming 1.5 workers per household, is about 200,000 fewer households than needed to balance the projected 713,000 new jobs projected. To minimize commuting into the study area from external counties, an additional 200,000 households were added to the two alternatives, resulting in an increase of 75 percent above the household growth in the base.[1]

Jobs and housing were also balanced within subareas. To balance the 604,000 new jobs projected within 29 employment growth areas, about 402,000 new households were needed, but only 143,000 were allocated to these areas in the base. The two alternatives sought to achieve a balance in those areas by drawing 200,000 households from outside the study area (as previously discussed) and the balance of 59,000 from other areas within the study area.

The additional 200,000 households represented an increase of 11 percent above the base total households of 1.75 million. In spite of this increase, regionwide VMT in the alternatives exceeded base VMT by only about 1 percent (about 1 million VMT). This was the result of reduced vehicle trips per household due to greater transit use and to shorter average trip lengths because of greater proximity of housing to jobs. The 200,000 new households, had they located outside the area, would have generated about 10 million VMT of which about 5 million would have been outside the study area. This 5 million VMT was saved outside the area with the two alternatives, at a cost of about a 1 million increase in VMT inside the study area.

The transit-oriented alternative did not appear to increase the effectiveness of the jobs/housing balance alternative with respect to VMT reduction.

Seattle

Seattle's base case consisted of a composite of local growth patterns determined by each city and county in the region. In the base, new employment was scattered in office parks, shopping malls, and strip centers, with some new employment in major downtown areas. Most new housing development occurred in suburban areas. Transportation system improvements included a regional rapid transit system and modest expansion of highway capacity.

The alternative strategies consisted of changes to both the land use patterns as well as to transportation system characteristics. The first, a major centers alternative, concentrated new employment growth in a few major centers and encouraged higher density residential development

[1]Italic numbers in parentheses identify references on page 78.

The multiple centers alternative balances new employment opportunities and housing growth, served by a good road network.

within walking distance of major transit access points. Transit investments were emphasized, including high-occupancy vehicle (HOV) lanes. Highway capacity expansion was restricted to critical links, and transportation demand management (TDM) programs were supported.

The second alternative focused on multiple centers. It concentrated new employment and housing growth in a relatively large number of centers with a balance of jobs and housing within each center's area of influence. Transit emphasis was high although less than the major centers alternative. Highway capacity expansions involved 60 percent more new lane miles than in major centers, while TDM programs were similar.

The third alternative was a dispersed growth scenario. It dispersed employment and housing into newly developing areas where new highways or major highway widening could be provided or where existing highways have spare capacity. This was similar to the dispersed alternative in Dallas. Only moderate investments in transit, sufficient to maintain present levels of service, were included. Highway capacity expansions included extensive radial and circumferential highways to serve the newly developing areas. TDM measures were supported.

The comparisons of the alternatives with the base are summarized in table 4. Over the 30-year analysis period (1990-2020), population was projected to grow by 52 percent over the 1990 population of 2.7 million; jobs were projected to grow by 66 percent over the 1990 employment of 1.3 million. None of the alternatives were expected to materially affect the rate or amount of regionwide growth. The relative variation among the alternatives with respect to the distribution of growth is indicated by the changes in the growth rate for King County (the central county) as shown in table 4.

Variations in regionwide travel demand are relatively small, ranging from a 4-percent reduction in VMT under the major centers alternative to a 3-percent increase with dispersed growth. As in the Dallas study, concentration of growth in a few centers (major centers alternative) was found to increase congestion levels, especially in the vicinity of the centers, and to reduce average speeds. Concentration of growth in many centers (multiple centers alternative), on the other hand, was found to reduce overall delay and congestion somewhat. But there was no change in average regional speeds, and a more detailed review of the network indicated that congestion in critical travel corridors was significantly higher, particularly in suburban and rural areas. The dispersed alternative was less effective in reducing congestion than multiple centers, probably due to higher VMT.

Inferences From the Studies

The studies suggest that concentrating urban development may reduce vehicular travel demand and congestion, as indicated in the Baltimore study. However, when there is excessive concentration at a few high-density centers, high

Table 4.—Impacts of alternative development patterns in Seattle

	Base case (Existing plans)	Impacts of alternatives (% change)		
		Alt. 1 (Major centers)	Alt. 2 (Multiple centers)	Alt. 3 (Dispersed)
King County (percent increase over 1990):				
Employment	63	+2	-11	-22
Population	44	+5	0	-18
Daily travel: VMT	98,000,000	-4	-1	+3
Avg peak period speed (mi/h)	15	-6	0	0
Hours of delay	830,000	+16	-2	-1
Percent network miles congested	21	+10	-10	-5

Urban Development Studies

Urban development patterns can be studied at the micro level, macro level, or in combination. **Micro level studies** look at the impacts of localized strategies. For example, the physical layout of new developments can be designed to create circulation patterns and environments conducive to travel by transit, bicycles, and walking. In addition, developments can be designed with mixed land uses to spread travel to them throughout the day; different types of land uses have different travel peaking characteristics. Mixed use developments can increase use of carpools, vanpools, and transit since people will not need their cars during midday if service establishments are within walking distance. Mixing employment areas and residential land also provides opportunities for those who wish to live near their workplaces, encouraging bicycling and walking trips.

Macro level studies look at the regional impacts of urban form alternatives. For example, development in a region can be either concentrated or decentralized. It can be confined to transit accessible corridors, or it can be dispersed to the periphery of urban areas where spare highway capacity is available. Employment can either be concentrated in a few major activity centers, or it can be distributed to many small centers. Jobs and housing may be balanced within subareas, or disproportionate amounts of housing may be developed on the fringes of urban areas and in the exurbs, which is the region beyond the suburbs, to take advantage of lower housing costs.

congestion levels may be expected in the vicinity of the high-density activity centers, as indicated in the Dallas and Seattle studies.

Concentrating development in areas with superior transit access does not appear to shift sufficient travel to transit modes to reduce congestion levels although some reductions in regionwide VMT may be achieved. However, vehicle trips may have been overestimated in high-density zones due to limitations in the study methodology. Trip production rates in regional models are generally not sensitive to zonal density characteristics. Also, the shift to transit may have been underestimated by the modeling approach used in three of the four studies. Further analysis is needed to determine whether improvements to transit service and increases in parking costs could shift sufficient numbers of peak period highway users to transit or ridesharing modes to significantly affect peak period congestion levels and new highway capacity needs in these high-density areas.

Dispersed growth patterns may reduce congestion levels if growth is directed to areas where spare highway capacity exists. However, total travel demand (VMT) will generally rise. If growth is not properly directed, both VMT and congestion levels will rise.

Providing affordable housing within current urban boundaries and in proximity to employment growth areas can significantly reduce highway travel demand (VMT) in the broader region including surrounding counties and exurbs. The Washington, DC, study indicates that VMT per household can be reduced by as much as 10 percent. However, VMT and congestion levels could rise within the urban boundaries due to the accommodation of housing units which would otherwise be outside the urban boundary.

Macro level, land use strategies that simply relocate future growth appear to have relatively little impact on highway travel demand. Regional VMT did not change by more than 2 percent in Baltimore, 5 percent in Dallas, and 4 percent in Washington, DC, and Seattle. While regional VMT may not be greatly affected, congestion levels can be influenced to a much greater extent because new development can be either forced into existing dense areas with little spare highway capacity, or it can be spread out to developing areas where spare capacity exists. Changes in average congestion measures of as much as 10 percent were observed in the studies.

The relatively small impacts on travel demand may be explained by the fact that three of the four studies did not look at transportation infrastructure investments and TDM measures in combination with land use alternatives, and none of the studies looked at further changes that might be induced by micro level, land use strategies in combination with TDM measures and infrastructure investments. Currently, regional models generally cannot be used to analyze urban design options. An FHWA research project is currently under way to improve the ability to model the impacts of micro level strategies and combined strategies.

Conclusions

These four studies were an important step in improving understanding of the general magnitude and direction of the impacts of macro level, land use strategies. Limited study resources precluded extending the scope of the studies to get more refined impact estimates based on recursive modeling approaches— for example, by including the effects of transportation system supply and performance characteristics on trip generation, trip distribution, land use location decisions, and mode choice. Research is under way at the FHWA to develop such modeling enhancements for wider application in urban areas.

Study results suggest that urban areas should add macro level, land development decisions to the toolbox for congestion management. Regional land use planning can make a significant difference. However, if urban areas are to succeed in implementing such regional strategies, they will have to enhance their intergovernmental structures and processes to facilitate the key policy decisions needed to guide urban development into patterns that are more effective in reducing congestion.

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RECENT PUBLICATIONS

The following are brief descriptions of selected publications recently published by the Federal Highway Administration, Office of Research and Development (R&D). The Office of Engineering and Highway Operations R&D includes the Structures Division, Pavements Division, Materials Division, and Long Term Pavement Performance Division. The Office of Safety and Traffic Operations R&D includes the Intelligent Vehicle-Highway Systems Research Division, Design Concepts Research Division, and Information and Behavioral Systems Division. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&T Report Center.

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Development of an Integrated Survey Vehicle for Measuring Pavement Surface Conditions at Highway Speeds, Vol. II: Technical Details, Publication No. FHWA-RD-90-012

by Pavements Division

The objective of this study was to develop an integrated survey vehicle for measuring pavement surface conditions at highway speeds. This was accomplished by determining the requirements and operating characteristics for such a system, preparing a design, and estimating initial and operating costs.

This volume contains detailed information about the design, costs, specifications, and software associated with the integrated survey vehicle. The system drawings for the vehicle are provided. The name, part number, and cost of each part required to build the vehicle are listed. Estimates are provided for the costs of labor and materials required to manufacture custom components. The estimated cost of the vehicle (arranged by system) is presented. A complete software package was written (based on off-the-shelf software as well as software developed in-house). The in-house software is outlined, and source listings are provided.

This volume is the second in a series. The other volume is: FHWA-RD-90-011, Integrated Survey Vehicle-Technical Report.

This publication may only be purchased from the NTIS. (PB No. 92-176213/AS, price code: A12.)

Evaluation of Wetland Mitigation Measures, Vol. I: Final Report, Publication No. FHWA-RD-90-083

by Material Division

This report presents the results of an evaluation of the performance of wetland mitigation efforts taken by several State departments of transportation. These mitigation efforts, in response to State and Federal requirements to protect wetland values, have attempted to compensate for wetland impacts directly and indirectly related to highway construction projects. The FHWA and State participants in this "pooled research study" were concerned that little had been done to monitor the various mitigation projects to determine whether or not the desired goals had been met or whether there had been any unforeseen impacts (positive or negative) which have occurred as a result of the mitigation.

The report analyzes 17 mitigation projects in 14 States, comparing them to natural control wetlands to evaluate the effectiveness of the mitigation to perform wetland functions and values. Mitigation projects include six sites where existing wetland systems were enhanced, six sites where wetlands were created from uplands, two sites which were combinations of enhancements and creation, and three sites where existing wetlands were restored. The efficiency of a wetland to perform a number of functions and values was evaluated to determine success. Field biologists used a number of assessment techniques, including the Wetland Evaluation Technique (WET 2.0) and the Hollands-Magee assessment models. Conclusions and recommendations for wetland mitigation are made. Success was found to be less related to mitigation type (i.e. enhancement, restoration, or creation) than the adequacy of planning, design elements, and implementation/follow-through.

This publication may only be purchased from the NTIS. (PB No. 92-220607/AS, price code: A16)

This volume is the first in a series. The other volume is: FHWA-RD-90-084, Volume II: Field Data Sheets. Volume II is available through NTIS. (PB 92-220615/AS, price code: A13.)

Ramp Signing for Trucks, Publication No. FHWA-RD-91-042

by Design Concepts Research Division

The research addressed methods for treating interchange ramps that are prone to cause high center of gravity vehicles to lose control and overturn. A critical review of the pertinent literature was conducted, and a state-of-the-practice review was conducted in 12 States. This review determined the nature and extent of the truck rollover accident problem, determined problem ramp identification procedures, and identified active and passive treatments currently being used at problem ramps. A "design-a-sign" study was conducted using 61 professional truck drivers to identify critical ramp characteristics and to develop innovative procedures for effectively communicating this information to approaching drivers.

A series of laboratory studies were conducted using truckers and non-truckers to identify the specific sign elements (words or symbols) and format (including relative visibility) that most effectively warn truck drivers about potentially dangerous ramps.

A field test was conducted at two interchange ramps in Virginia and Maryland that had high incidences of truck rollover accidents. A truck tipping sign with activated flashing beacons was installed at the ramp, and an advance warning sign was installed prior to the ramp. Analysis indicated that the speeds of tractor-trailers were not affected by the experimental treatments, but automobiles showed a small but statistically significant speed reduction. Despite the conclusion that truckers understand rollover problems and the meaning of tipping signs, field tests failed to show an operational effect to support this awareness. Nevertheless, the high level of understanding of the signs suggests that their use at high accident locations may be appropriate.

This publication may only be purchased from the NTIS. (PB No. 92-204254/AS, price code: A06.)

Improved Grouts for Bonded Tendons in Post-tensioned Bridge Structures, Publication No. FHWA-RD-91-092

by Structures Division

FHWA initiated this study to develop and test new mixture designs for grouts, to develop and perform accelerated corrosion test methods on the new grouts, and to compare the corrosion performance of the new grouts with the standard grouts.

The deterioration of concrete bridges due to corrosion induced by chloride intrusion in the concrete is a serious problem, particularly with the steel tendons in prestressed concrete structures. The structural integrity of the bridge relies on the high tensile loading of the tendons, and any corrosion or corrosion-induced cracking of the tendon could lead to catastrophic failure of the structure. Grout is the final line of defense against corrosion of the steel tendon.

Several modifiers and additives for grouts were examined, and several experimental grouts provided improved properties compared to the present standard grouts.

Through an accelerated corrosion test method, it was shown that any experimental grout that lowered the chloride permeability increased the time for corrosion and typically decreased the corrosion rate following initiation. Also a calcium nitrite inhibitor appears to produce the most significant improvement in corrosion performance of steel tendons embedded in grout.

This report is the conclusion of the research study described in the Interim Report, FHWA-RD-90-102, dated November 1990, about the grouting technology for bonded tendons in post-tensioned bridge structures.

This publication may only be purchased from NTIS. (PB No. 92-222561/AS, price code: A07.)

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Safety and System Applications and the Office of Research and Development (R&D), Federal Highway Administration. Some items by others are included when they are of special interest to highway agencies. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&T Report Center.

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Performance of Bridge Joint Systems Designed for Large Movements, Publication No. FHWA-SA-92-018

by Office of Engineering

An earlier effort to evaluate bridge expansion joints was augmented to concentrate on those joints designed to accommodate large movements. Several States were included in this new project, and modular and finger systems were evaluated for their in-place condition. A total of 136 modular joint systems and 42 finger joint systems were included in the survey. The project focus was to evaluate the performance of each type to assist the States in determining the performance and cost effectiveness of using either modular or finger joints for large movements. Each joint in the survey was evaluated to determine its in-place condition. The condition of the surface elements as well as the hardware below the deck surface was rated using the prescribed evaluation criteria. Additionally, each joint was examined for its ability to control bridge roadway runoff and protect the structural components below the deck.

For the most part, the modular joints reviewed, with the exception of a few locations, appeared to be performing as intended. The majority of the hardware was in very good condition. Buildup of debris was present in the recessed sealing elements in most of the modulars, particularly heavy at the shoulder areas of the deck. Most of the joints less than 11 years old were watertight, with only 3 that were actively leaking and several others which showed evidence of water getting through the joint. The ones incorporating aluminum components had varying degrees of surface damage and adjacent concrete deterioration.

The finger joints also were performing as designed; however, the open finger variety presented most of the problems for this joint type. The surface of the joints exhibited minor scrapes and gouges at about half of the sites. There was some cracking of the header concrete. All of the troughs inspected contained varying amounts of roadway debris. The joints with troughs appeared to be handling the surface water adequately. On the other hand, the condition of the components below the open joints was poor in several locations.

Limited copies of this publication are available from the R&T Report Center. Copies may also be purchased from the NTIS. (PB No. 92-224948/AS, price code: A04.)

State of the Practice—Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier, Publication No. FHWA-SA-92-022

by Office of Engineering

This document is a comprehensive overview of the terminology, processes, products, and applications of crumb rubber modifier (CRM) technology. This technology includes any use of scrap tire rubber in asphalt paving materials. In general, CRM technology can be divided into two categories—the wet process and the dry process. When CRM is incorporated into an asphalt paving material, it will modify the properties of the binder (asphalt rubber) and/or act as a rubber aggregate (rubber modified hot mix asphalt). The five concepts for using CRM discussed in the report are McDonald, PlusRide, generic dry, chunk rubber asphalt concrete, and continuous blending asphalt rubber.

There are two principal unresolved engineering issues related to the use of CRM in asphalt paving materials. On the national level, the ability to recycle asphalt paving mixes containing CRM has not been demonstrated. At the State and local levels, these modified asphalt mixes must be field-evaluated to establish expected levels of performance.

The appendices provide guidelines for material specifications, mix design, and construction specifications. An experimental work plan for monitoring performance and a stack emission testing program are also included.

Limited copies of this publication are available from the R&T Report Center. Copies may also be purchased from the NTIS. (PB No. 92-203900/AS, price code: A05.)

NEW RESEARCH

The following new research studies reported by the FHWA's Office of Research and Development are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description:

- FHWA Staff and Administrative Contract Research contact *Public Roads.*
- State Planning and Research (SP&R), formerly called Highway Planning and Research (HP&R), contact the performing State highway or transportation department.
- National Cooperative Highway Research Program (NCHRP) contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.
- Strategic Highway Research Program (SHRP) contact the SHRP, 818 Connecticut Avenue, NW, 4th floor, Washington, DC 20006.

NCP Category A—Highway Safety

A.1: Advanced Traffic Control Methods and Devices

Title: Assessment of Capabilities—Iowa Driving Simulator

Objective: The University of Iowa is constructing an advanced driving simulator—the Iowa Driving Simulator (IDS)—at the Iowa City campus. Full operational readiness without motion is scheduled for the summer of 1992.

Until the National Advanced Driving Simulator (NADS) comes on- line in 1996, we plan to use the FHWA Highway Driving Simulator (HYSIM) and the IDS in conjunction to provide the breadth of simulator capabilities that are required for several research programs. Recent enhancements to the HYSIM to bring its visual capabilities in line with future research requirements have been completed.

Performing Organization: University of Iowa

Expected Completion Date: October 1993

Estimated Cost: $152,721 (FHWA)

Title: Changeable Message Sign-control and Warning Messages

Objective: Develop and test word and symbol messages to be used on variable message signs. They will be tested for condition-responsive, traffic control and hazard warnings for use on streets and highways. Such messages include work zone conditions, road and environmental hazards, lane drops, accidents and incidents ahead, congestion, etc.

Performing Organization: Center for Applied Research, Inc.

Expected Completion Date: August 1994

Estimated Cost: $176,999 (FHWA)

Title: Evaluation of Rural Guide Signing

Objective: Develop guidelines to better rural guide sign practices. The literature will be reviewed. Texas guide sign practices will be determined and sign deficiencies will be noted. Sign legibility will be evaluated on different highway classes along with driver confusion with the directional information. Studies will be conducted to measure driver confusion, and alternate guide signs will be developed and tested.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1995

Estimated Cost: $197,504 (SP&R)

Title: Improved Winter Weather and Traffic Information Gathering and Distribution System for the I-80 Corridor

Objective: Develop a system to gather information on weather, roadway, and traffic to include roadway surface temperatures, local meterological sensor data, and vehicle travel times for the Interstate-80 corridor during winter. The information will be used to warn drivers of hazardous conditions and traffic delays as well as scheduling roadway deicing, snow removal, and chain control.

Performing Organization: Caltrans

Sponsoring Organization: California

Expected Completion Date: June 1996

Estimated Cost: $868,310 (SP&R)

Title: Effectiveness of Changeable Message Signs and Automated Speed Displays in Controlling Vehicle Speeds and Speed Profiles in Work Zones

Objective: Collect speed and volume data in work zones with and without an automated speed changeable message sign that will activate when speed is measured to be 5 mi/h above the posted speed limit. The signs will read, "Slow down—You have exceeded the speed limit" or "Slow down now." Video cameras will be used to record at 0.1-second intervals. Both day and night data will be collected.

Performing Organization: Virginia Trans. Research Council

Sponsoring Organization: Virginia

Expected Completion Date: October 1993

Estimated Cost: $143,500 (SP&R)

A.2: Improving Driver Visibility of Roadway Environment

Title: Feasibility of Ultraviolet Activated Sign and Marking Materials

Objective: Develop a state of the art assessment of current technology to produce fluorescent pigments suitable for use in retroreflective traffic control devices. The study will identify those materials likely to produce stable, long life devices and what specific problems must be addressed before any implementation is undertaken. A model shall be produced to demonstrate how ultraviolet (UV) activated fluorescent traffic controls might appear.

Performing Organization: IIT Research Institute

Expected Completion Date: June 1993

Estimated Cost: $230,731 (FHWA)

Title: Safety Benefits of Roadway Lighting Using Small Target Visibility

Objective: Compare lighting-safety correlations. This research will compare the accident experience on a large group of lighted roadways using the original design data to calculate (1) the new small target visibility (STV) design values and (2) the conventional lighting design values such as luminance and horizontal illumination.

Performing Organization: The Last Resource

Expected Completion Date: July 1994

Estimated Cost: $192,182 (FWHA)

Title: Visibility Requirements for Symbolic Traffic Signals

Objective: Develop replacement criteria for in service symbolic traffic signals based on minimum luminance and luminance distribution. Color, shape, size, and recognizability should also be investigated for all roadway users. The results of this research shall apply to all types of traffic signals, including conventional signals, programmable signals, fiber optics, and LEDs.

Performing Organization: The Last Resource

Expected Completion Date: November 1994

Estimated Cost: $218,511 (FHWA)

A.3: Highway Safety Information Management

Title: Evaluation of Accident Analysis Methodology

Objective: Apply the regression to the mean accident analysis methodology to highway safety analyses. It is critical that the methodology is thoroughly tested with real data if the highway safety analysts are to adopt and use it to its fullest capability.

Performing Organization: Texas A&M Research Foundation

Expected Completion Date: September 1994

Estimated Cost: $297,184 (FHWA)

A.4: Special Highway Users

Title: Trends and Crashes Involving Older Pedestrians

Objective: This study will be conducted in cooperation with NHTSA. Existing data bases will be used to classify various pedestrian accidents by type and location. Contributing factors (such as alcohol, drugs, etc.) will be identified for the various types of accidents. Recommendations will be developed for directing future research and implementation efforts.

Performing Organization: The Center for Disease Control

Expected Completion Date: October 1994

Estimated Cost: $300,825 (FHWA)

A.5: Highway Safety Design Practices and Criteria

Title: Retrofit W-Beam Bridge Rails

Objective: Review existing State designs for low-cost retrofit bridge rails, and develop and test up to three low-cost retrofit bridge rail designs. Computer-assisted drawings of these low-cost designs will be prepared.

Performing Organization: Texas A&M Research Foundation

Expected Completion Date: April 1994

Estimated Cost: $246,356 (FHWA)

Title: Fiber-Reinforced Composite Materials of Transportation Structures

Objectives: Continue a research program in composite materials, maintain expertise in the area of composite materials, and develop an educational program that will train and retrain qualified U.S. engineers.

Performing Organization: The Catholic University of America

Expected Completion Date: June 1995

Estimated Cost: $53,196 (Cooperative Agreement)

Title: Grants for Highway Safety Research

Objective: Establish cooperative agreements with universities which have graduate programs in highway safety research. These grants will be used to foster safety research and increase the number of people working on highway safety issues. This responds to a need identified in TBR SR 229, "Safety Research for a Changing Highway Environment."

Expected Completion Date: August 1994

Estimated Cost: $600,000 (Cooperative Agreement)

Title: Finite Element Models of Motor Vehicles

Objective: Develop a finite element model of a Honda Civic. FHWA has selected the general purpose finite element code, DYNA3D, as the computational engine for the next generation of the impact/handling simulation model. The Honda Civic has been widely used in crash tests, and the model will be used in a number of calibration studies using DYNA3D. Models of other motor vehicles may be developed.

Performing Organization: EASI Engineering

Expected Completion Date: March 1993

Estimated Cost: $109,086 (FHWA)

A.6: Human Factors Research of Highway Safety

Title: Delineation of Hazards for Older Drivers

Objective: Determine appropriate guidelines for hazard marker design and implementation that account for the needs and capabilities of older drivers.

Performing Organization: COMSIS

Expected Completion Date: August 1994

Estimated Cost: $125,000 (FHWA)

NCP Category B—Traffic Operations/ Intelligent Vehicle-Highway Systems
B.3: Commercial Vehicle Operations

Title: Systems Planning for Automated Commercial Vehicle Licensing and Permitting Systems

Objective: Perform all the necessary activities leading up to the actual hardware and software design for automated licensing and permitting systems including the preparation of working papers to examine the major technical and institutional carriers, the conduct of a feasibility and cost-benefit study for each of the major components of such systems, the development of the functional requirements for each of the major components, and the development of a detailed work plan for implementing a pilot program.

Performing Organization: Cambridge Systematics, Inc.

Estimated Cost: $568,536 (FHWA)

NCP Category C—Pavements
C.1: Evalution of Rigid Pavements

Title: An Interlayer Stress Absorbing Composite (ISCA) System for Mitigating Reflective Cracking

Objective: Develop, fabricate, and evaluate a stress absorbing composite interlayer which will reduce asphalt concrete reflection cracks. Use thermal and structural models to determine the required material properties for the interlayer. Fabricate one or more interlayer stress absorbing composite (ISAC) systems. Conduct laboratory and field evaluations on the performance of the systems without joint or crack treatment. Prepare a final report on study findings.

Performing Organization: University of Illinois at Urbana

Sponsoring Organization: Illinois

Expected Completion Date: June 1994

Estimated Cost: $150,045 (SP&R)

C.2: Evaluation of Flexible Pavements

Title: Evaluation of Asphalt Additives for Improving Cracking and Rutting Resistance of Asphalt Paving Mixtures

Objectives: Evaluate the effects of a few asphalt additives that might be considered for use in Florida on the cracking and rutting resistance of asphalt paving mixtures under Florida conditions. Determine the optimized combination of asphalt cements and additives for improved rutting and cracking resistance for Florida conditions. Evaluate the applicability of the new SHRP-proposed, performance-related tests and criteria for asphalt binders and modified asphalt binders for Florida conditions.

Performing Organization: University of Florida

Sponsoring Organization: Florida

Expected Completion Date: November 1994

Estimated Cost: $175,205 (SP&R)

Title: Recycling Second Generation Asphalt Rubber Pavements

Objective: Identify potential problems with current mix design and construction techniques the might preclude the possibility of successfully recycling pavements containing rubber.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1994

Estimated Cost: $200,000 (SP&R)

Title: Short-Term Guidelines to Improve Asphalt Rubber Pavements

Objective: Optimize performance of asphalt rubber concrete pavements through the development of materials and construction specifications, mixture design and testing procedures, binder testing procedures, and quality control and construction guidelines.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1994

Estimated Cost: $240,000 (SP&R)

Title: Application of Resilient Modulus Tests to Texas Base Material for Pavement Design

Objective: Develop a reliable and efficient procedure for resilient modulus testing of granular base materials.

Performing Organization: University of Texas at Austin

Sponsoring Organization: Texas

Expected Completion Date: August 1994

Estimated Cost: $178,000 (SP&R)

Title: Improved Prime Coat Methods

Objective: Investigate alternatives to asphalt cutbacks for use in prime coats. A prime coat is an application of low viscosity asphalt to a granular base in preparation for an asphalt surface course. The specific objectives are to: (1) examine the importance of the bond between base and surface; (2) explore materials and construction techniques that will permit installation of an effective prime coat, including solvent-free products which offer promise in achieving better penetration; (3) field test and evaluate the various alternatives; (4) develop appropriate construction specifications and test procedures with criteria for quality assurance and control; and (5) suggest material specifications for products which may be developed.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1994

Estimated Cost: $165,331 (SP&R)

C.4: Pavement Management Strategies

Title: Movement of Superheavy Loads Over the State Highway System

Objective: Determine effects of movement of superheavy loads on pavement structures. Texas is issuing permits for movement of these loads over the State highway system; implementing a field test using ground penetration radar, falling weight deflectometer and video camera, and measurement of deflections from multidepth deflectometers MDD's on up to 10 superheavy load movements; determining soil strength using the Texas triaxial test machine; and providing a report describing the damage caused on each superheavy load movement.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1995

Estimated Cost: $376,022 (SP&R)

NCP Category E—Materials and Operations

E.1: Asphalt and Asphaltic Mixtures

Title: Laboratory Development of Third Generation Sulphex Binders

Objective: Develop a third generation Sulphlex binder that can be prepared in a single reaction vessel that has performance properties—especially low ambient temperature properties—at least as good as the second generation Sulphlex, which requires preparation as two separate reaction batches which are then mixed together.

Performing Organization: Texas A&M Research Foundation

Expected Completion Date: June 1994

Estimated Cost: $192,315 (FHWA)

Title: Calibration of Marshall Compaction Hammers

Objective: Develop method for measuring the energy transmitted by the Marshall equipment. Evaluate energy variability using currently available equipment. Provide recommended revisions to test or calibration method.

Performing Organization: National Institute of Standards and Technology

Expected Completion Date: April 1993

Estimated Cost: $135,000 (Interagency Agreement)

E.3: Geotechnology

Title: Prediction of Pile Capacity Utilizing an Energy Approach

Objective: Compile the University of Lowell's load test data onto the FHWA deep foundation data base forms and to establish a simplified method which enables the reliable prediction of pile capacity in the field, invoking an energy approach for dynamic measurements during driving onshore and offshore piles.

Performing Organization: University of Massachusetts at Lowell

Expected Completion Date: May 1993

Estimated Cost: $50,165 (FHWA)

Title: Geotechnical Laboratory Support Services

Objective: Fill and compact laboratory soil tanks and outdoor test pits to prepare for load tests on model piles and spread footings. Provide technician and engineering support for instrumenting and monitoring load tests on model foundations.

Performing Organization: Earth Engineering and Sciences, Inc.

Expected Completion Date: June 1994

Estimated Cost: $371,149 (FHWA)

E.5: Highway Maintenance

Title: Using Ground-Penetrating Radar for Pavement Evaluation

Objective: Evaluate ground-penetrating radar's (GPR) potential for locating voids beneath rigid pavement, measuring thickness of rigid pavement, and identifying areas of stripping in asphalt pavement. A prototype GPR system will be assembled and evaluated on both laboratory test slabs and larger, outdoor test sections with simulated defects. The system will be evaluated on a number of inservice pavements in Texas.

Performing Organization: Texas Transportation Institute

Sponsoring Organization: Texas

Expected Completion Date: August 1995

Estimated Cost: $342,923 (SP&R)

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