INCREMENTAL IMPROVEMENTS TO RURAL TWO-LANE HIGHWAYS

(MBTC 1098)

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The objective of this research was to examine certain aspects of passing lane operations, with a focus on 3-lane alternate passing designs in Arkansas. Aspects examined included effects of passing lane length on speed, effects of passing lane length on platooning, effects of passing lane length on passing, and crash histories of transitions and passing lanes. Five sets of field data were collected at four rural sites. Speed patterns were found to vary among sites. Platooning decreased after entering the passing lane, and eventually stabilized. Passing activity was greatest at the beginning of the segments. Five years of crash data were utilized. Even though the passing lane segment volumes were higher than the state average rural two-lane road volume, the passing lane crash rates were lower than the statewide average crash rate on rural two-lane roads. Sample size restrictions limited the information found about transition zones. The crash rates at the entering taper were less than at the ending taper.

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CHAPTER 1
INTRODUCTION

Roadways provide mobility and access to adjacent property. However, with increased volumes of traffic, roadways become congested and fail to provide mobility. Because of increased traffic, not only urban but also rural roads face the problem of congestion. Increased travel time, delay, driver frustration, accidents, noise, and air pollution are some of the by-products of congestion.

Many drivers on two-lane rural roadways try to reduce their travel time, delay, and congestion by passing slower moving vehicles. These passing maneuvers are complicated tasks, and may not always be performed safely. Where limited sight distances or oncoming traffic volumes restrict passing opportunities on rural two-lane highways, there may be increased risk taking and increased numbers of head-on or sideswipe collisions.

A number of actions have been taken to improve the performance and safety of two-lane rural highways. The 2001 edition of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (*Green Book*) (315-318) suggests that providing wider lanes and wider shoulders can improve the safety record of the highway. However, these alternatives may not always appreciably improve the level of service on two-lane rural highways. The passing sight distance can be increased through changes in both horizontal and vertical alignments, and such changes are likely to be expensive. Providing passing lanes addresses both issues of safety and level of service.

A passing lane is an added lane provided in one or both directions of travel on a conventional rural two-lane highway to improve passing opportunities (Harwood et al. TRR 1195, pp 79-97). Passing lanes differ from climbing lanes in that climbing lanes are provided for the uphill direction of travel in hilly areas, while passing lanes are not confined to the uphill direction.

Expanding an existing two-lane highway to a four-lane highway is very expensive. Providing occasional passing lanes is one cost effective improvement that bridges the gap between conventional two-lane highways and four lane highways. Depending upon topography and traffic flow, passing lanes can offer an economical alternative to major reconstruction.

Passing lanes can be provided in number of ways. Depending upon the circumstances, a passing lane could be provided continuously or it could be isolated. Providing a continuous passing lane implies that the pavement cross section is continuously three lanes wide, with the additional lane provided alternately for the two directions of travel. Roadways with a continuous three-lane wide section were termed “3-lane alternate passing” designs. Isolated passing lane segments have “regular” two-lane cross sections at both ends. Figure 1-1 is a schematic of one form of 3-lane alternate passing section.

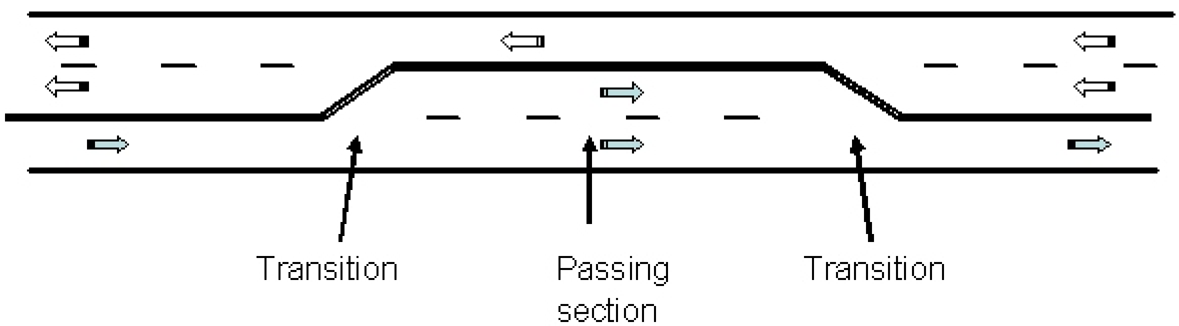

FIG. 1-1 Schematic Example of 3-lane Alternate Passing Design

The basic function of passing lanes is to allow passing maneuvers to occur without the restrictions of sight distances or oncoming traffic. The intended effects of passing lanes can be summarized as follows.

1. the number of passing maneuvers will increase
2. the percentage of vehicles in platoons will decrease
3. the amount of delay will be reduced
4. the number of crashes will decrease

Thus, passing lanes are intended to improve both the level of service and safety on two-lane rural roadways.

This research examined certain aspects of passing lane operations, with a focus on 3-lane alternate passing designs.

Effects of passing lane length on speed
Effects of passing lane length on platooning
Effects of passing lane length on passing
Effects of transition-type design
Crash history

Another objective was to examine the capacity of these designs. However, the studies conducted at the available sites did not produce any findings to address this issue, since the volumes at the sites were not sufficiently high to observe a noticeable decline in level of service, much less approach capacity. After discussions with Research Section personnel, an attempt was made to target one of the highest volume three-lane sections in the state, even though it lacked other desirable attributes for a study site; however, volumes at this site did not noticeably impact the level of service.

CHAPTER 2
BACKGROUND

Background information about 3-lane alternate passing and other related designs was obtained by two methods: a survey and a review of literature.

SURVEY

A survey of state and provincial transportation departments was conducted in late 1998. Responses were received from 30 states and 3 Canadian provinces. Appendix A presents the survey instrument that was mailed to the agencies. The following is a enumeration of responses.

NOTES: ADT = average daily traffic
LOS = level of service
veh/h = vehicles per hour
v/c - volume to capacity

		YES	NO
1.	Does your state/province currently have ...		
	3-lane alternate passing designs planned or under construction, but not yet open for traffic?	4	28
	3-lane alternate passing designs currently in operation?	4	27

2. What criteria do your agency currently use to justify the following 2-lane rural highway improvements? If you have a certain volume that may trigger the decision, please state it.

(2a) We consider expanding to a rural 3-lane section when ...

Our agency does not use this type of rural section.	24
A certain volume is reached; this volume is:	2
A certain crash rate is reached; this rate is	0
Other:	8

Reported quantitative thresholds included:

2000-10,000 ADT; LOS D

(2b) We consider expanding to a rural 4-lane undivided section when ...

Our agency does not use this type of rural section.	17
A certain volume is reached; this volume is	14
A certain crash rate is reached; this rate is	0
Other:	3

Reported quantitative thresholds included:

8,000 ADT; 10,000 ADT; 3- 15,000 ADT; 17,000 ADT; 18,000 ADT; 600 veh/h; 700 veh/h; LOS B; LOS C

(2c) We consider expanding to a rural 4-lane section (with continuous center turn lane) when ...

Our agency does not use this type of rural section.	17
A certain volume is reached; this volume is	11
A certain crash rate is reached; this rate is	9
Other:	1

Reported quantitative thresholds included:

6,000 ADT: 7,000 ADT; 15,000 ADT; 18,000 ADT; LOS B; LOS D; LOS E

(2d) We consider expanding to a rural 4-lane section with a non-traversable median when ...

Our agency does not use this type of rural section.	7
A certain volume is reached; this volume is	18
A certain crash rate is reached; this rate is	3
Other:	10

Reported quantitative thresholds included:

2-6,000 ADT; 7,000 ADT; 8,000 ADT; 8,200 ADT; 15,000 ADT; 18,000 ADT; 20,000 ADT ; 700 veh/h; LOS B; 2-LOS C; LOS E; v/c = 0.3

3. Are there any other factors that affect your decision to expand a 2-lane rural highway to 3-lane alternate passing, 4-lane undivided, 4-lane with continuous center turn lane, or 4-lane divided with non-traversable median?	politics classification ROW alignment crash rate

Few states reported the use of 3-lane alternate passing sections. More were using a more traditional approach (i.e., various four-lane designs) to increasing passing opportunities and reducing delay. There was considerable variation in reported ranges of threshold values at which agencies considered expanding two-lane rural highway.

LITERATURE REVIEW

A search was performed to identify available literature on the analysis of passing lanes. The various attributes of passing lanes that were addressed in the literature reviewed can be classified into two broad categories. One category deals with attributes related to the physical characteristics such as configuration, location, length, and transition zones of passing lanes. The other category deals with attributes related to the operational effectiveness such as crash rates, average speed of traffic along a passing section, platooning within passing lane segments, passing within passing lane segments, and level of service.

PHYSICAL ATTRIBUTE LITERATURE

The following discussion explains past research done on the influence of various physical attributes of passing lane segments (configuration, location, length and transition zones) on behavior of the traffic within passing lane segment.

Configuration

Harwood et al. (TRR 1026, pp 31-39) noted that passing lanes can be provided in two ways, either alone or as a part of a series of passing lanes in an alternating manner. The authors also mentioned that the isolated short four-lane sections provided to improve passing opportunities essentially operate as two passing lanes in opposite directions at the same location.

An isolated passing lane may be used for reducing the delays at a specific bottleneck along the highway section, whereas other passing lane combinations can be used depending upon the type of traffic improvement needed (Mutabazi et al., TRR 1658, pp 25-33). Harwood et al. (TRR 1195, pp 79-91) stated that both divided and undivided short four-lane sections could be appropriate where the intent is for the highway to be expanded to four lanes in the future.

Location

Mutabazi et al. (TRR 1658, pp 25-33) suggested that crossroads (i.e., intersections) should be avoided within passing lane sections. If there is a crossroad within the passing lane section, then the vehicles turning to/from the crossroad must cross additional lanes. Other factors to consider when locating passing lanes are as driver expectations and construction costs.

Harwood et al. (TRR 1195, pp79-91) suggested that passing lanes should be located so that physical constraints such as bridges and culverts do not interrupt an otherwise continuous shoulder. The location should be so selected as to incur minimum costs.

Length

May (TRR 1303, pp 63-73) concluded that the number of passes, reduction in percent delay, and savings in travel time are dependent on the length of the passing lane. Short passing lane lengths from 0.4 kilometer (km) to 1.21 km (0.25 miles [mi.] to 0.75 mi.) in length are most effective in improving passes, decreasing percent time delay, and saving travel time. The study also investigated the effect of passing lane length on downstream percent time delay conditions. The results indicated that passing lengths of 0.4 km to 1.21 km (0.25 mi. to 0.75 mi.) are most desirable. Depending on downstream design and traffic conditions, passing lanes of such lengths provide relief for downstream distances of 0.32 km to 1.21 km (0.2 mi. to 0.5 mi.) before percent time delay increases to its original higher value.

Harwood et al. (TRR 1195, pp 79-91) calculated needed length of a passing lane based on traffic flow rates. As the flow rate increases, optimum length of the passing lane also increases. For flow rates up to 200 vph in one direction of travel, passing lane lengths between 0.25 to 0.75 miles are most effective. For very high flow rates such as 700 vph in one direction of travel, the length of passing lanes ranges from 1.0 to 2.0 miles. However, passing lanes longer than 1.0 mile may not be desirable. This is mainly because of possible suboptimal utilization during remainder of the day when the volumes are low. The authors also suggested that more short passing lanes would be more effective than fewer long passing lanes.

Enberg and Pursula (TRR 1572, pp 33-42) conducted simulation studies to analyze the effect of passing lane lengths. The model calculated the optimum passing lane length based on flow rate, with the number of overtakings as the measure of effectiveness. At low flow rates (about 500 vph) the optimum length of passing lane was 1 km (0.62 mi) or less. At medium flow rates (about 1000 vph) the optimum length worked out to be 1.5 km (0.93 mi). At high flow rates (about 2000 vph) the optimum length was 2 km (1.24 mi).

Transition Zones

Harwood et al. (TRR 1026, pp 31-39) found no indication of any marked safety problem in lane addition and lane drop transition areas of the passing lanes (the research paper did not describe the types of transitions examined). However, the authors suggested that the transition area should be designed carefully to prevent safety problem from developing.

May stated that the entrance design influenced the lane distribution at the beginning of the passing lane section, but its effect on the other characteristics was not significant (TRR 1303, pp 63-82).

OPERATIONAL ATTRIBUTE LITERATURE

The following discussion explains past research done on the influence of passing lane segments on various operational attributes, such as crash rates, average speed, platooning, passing, and level of service.

Crash Rates

Passing lanes provide safety benefits along the segment. After combining the results from other studies, Harwood et al. (TRR 1195, pp 79-91) concluded that passing lanes reduced accident rates by 25%.

Harwood et al. (TRR 1026, pp 31-39) compared 13 passing lane sites with 13 corresponding untreated sites. The authors found that the average total accident rate on the passing lane sites was 38% less than the average rate on the untreated sites. The fatal and accident injury accident rates were 29% lower.

Taylor and Jain (TRR 1303, pp 83-91) compared the crashes on highways with and without passing lanes. In order to compare crash rates, crashes were grouped on the basis of average daily traffic (AADT) levels: less than 5000, between 5000 and 10,000, and greater than 10,000. For all groups, crashes on the highways with passing lanes were lower than those without passing lanes.

Average Speed of Traffic along the Passing Section

Enhanced passing opportunities result in increased average speed. Enberg and Pursula (TRR 1572, pp 33-42) found that there was a statistically significant increase in the speed of traffic along the passing section as a result of passing lanes, but the passing lane had no significant effect on the downstream speeds.

Harwood et al. (TRR 1026, pp 31-39) noted that the effect of passing lanes on traffic speeds varies widely from site to site. The authors concluded that the vehicle speeds are influenced more strongly by local geometrics (namely grade, alignment curvature of road) at the upstream and downstream measurement sites than by presence of passing lanes.

Platooning Within the Passing Lane Segment

Vehicle platooning is a more sensitive measure of traffic service than mean speed (Harwood et al. TRR 1026, pp 31-39). The authors concluded that the percentage of vehicles in platoon decreased on average from 35.1 % immediately upstream of a passing lane to 20.7 % within passing lane. Immediately downstream of the passing lane, the percentage of the vehicles in the platoon increased to 29.2 %, on average, still 5.9 % lower than the upstream percentage.

Enberg and Pursula (TRR 1572, pp 33-42) conducted simulation studies to evaluate the effect of passing lanes on platooning (the authors considered the vehicles to be in platoon in the headway between two successive vehicles was less than 5 sec). The authors concluded that passing lane sections had a smaller percentage of platoons than did two-lane sections.

Harwood et al. (TRR 1195, pp 79-91) proposed that when a passing lane is added, the percentage of vehicles following in the platoon falls dramatically and stabilizes at about half the value for the two-lane road. The authors also concluded that because the platoons are broken up in the passing lane, installation of passing lanes on two-lane highways can improve traffic operations on the entire highway.

Passing Within the Passing Lane Segment

The possibility of passing slow moving vehicles in the passing lane sections increases overall passing rates. The passing rate has a strong relationship with traffic flow and passing-lane length (Harwood et al. TRR 1026, pp 31-39). The passing rate decreases with increasing passing-lane length, and increases with increasing vehicular flow and increasing upstream percentage of vehicles in platoon. Enberg and Pursula (TRR 1572, pp 33-42) found that the passing rate increases with increasing traffic flow. However, the authors found that the passing lane length had a negligible effect on the passing rate. May (TRR 1303, pp 63-82) found that the number of passes increased with vehicular flow.

Level of Service

The 2000 edition of the *Highway Capacity Manual* (12-12) classifies two-lane highways into two categories, namely Class I and Class II. Class I highways are the two-lane highways on which motorists expect to travel at higher speed. Class I facilities most often serve long distance trips. Generally, major intercity and primary arterials are assigned to Class I. Class II highways are the two-lane highways on which motorists do not necessarily expect to travel at higher speeds. Class II facilities most often serve shorter trips. Two-lane highways that serve as access to Class I highways or the highways that pass through rugged terrain are assigned to Class II. For Class I two-lane highways, level of service is defined in terms of both percent time spent following and average travel speed, whereas level of service for Class II is defined in terms of average travel speed alone.

A study by Morrall and Werner (TRR 1287, pp 62-69) proposed the use of overtaking ratio, obtained by dividing the number of passings achieved (the total number of passings for a given two-lane highway) by the number of passing desired (the total number of passings for a two-lane highway with continuous passing lanes with similar vertical and horizontal geometry) as a supplementary indicator of the level of service of two-lane highways. The ratio takes in to account the effect of percentage of no passing zones and passing lanes on overtaking opportunities. The authors suggested the use of overtaking ratio as a supplementary measure of level of service on two-lane highways.

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CHAPTER 3
RESEARCH PROCEDURES

There were two overall categories of data in this study. One effort focused on analyzing traffic flow attributes in passing lane zones. The other examined passing lane crash history.

TRAFFIC FLOW DATA COLLECTION SITES

The Arkansas Highway and Transportation Department (AHTD) has constructed passing lanes at number of locations along the two-lane rural highways. The AHTD furnished a preliminary list of locations where there were three-lane cross sections.

The AHTD maintains a video log of highways throughout the state. The video logs of these highway segments were viewed to confirm the locations of continuous passing lanes, determine site attributes, and to identify suitable sites for data collection. Viewing the tapes helped identify and eliminate segments that were not continuous passing lanes, or the segments that were only climbing lanes instead of passing lanes. From the video tapes, the log km of the beginning of the transition zone, the beginning of the passing lane, the end of the passing lane, and the end of the transition zone were noted. Appendix B lists the potential sites identified for the research.

Selecting Sites for Traffic Flow Data Collection

Criteria were established to determine which sites were best suited for study. Most of following criteria were desirable but not mandatory.

1. The roadway must be a rural road with a three-lane passing section, and preferably have continuously alternate passing lanes.
2. The roadway must have a transition from two-lanes to three-lanes (cannot be four-lane immediately in advance of the three-lane segment).
3. The three-lane segment should be at least 4.5 km (2.79 miles) long.
4. The segment should be on a level grade.
5. The horizontal alignment of the segment should be straight.
6. The traffic volume should be relatively high.
7. The passing section should have minimal number of intersecting side roads.

The researchers were surprised by how few sites in the state had most of the needed attributes. After careful study and examining more promising sites in the field, the sites listed in Table 3-1 were considered to be the best available for field data collection.

Description of Traffic Flow Data Collection Sites

The following narrative describes some of the attributes of each site selected for study, where SB denotes southbound, EB denotes eastbound, and WB denotes westbound.

US 65 Section 1 SB — This study site was located at northwest corner of Boone County. This roadway is no longer a US route, as it has been replaced by a four-lane divided roadway on a new alignment.

US 70 Sections 9 and 10 WB This study site was located at eastern edge of Garland County and western edge of Saline County near Lonsdale, AR.

US 70 Section 10 EB This study site was located at the western edge of Saline County, east of Lonsdale, AR.

US 82 Section 1 EB This site was located east of Texarkana in Miller County. This site was selected after discussion with the AHTD Research Section to satisfy the need for a higher-volume traffic site. The site was one of a series of five passing sites that were each separated from the others by some distance. Thus, the passing lane was not continuously alternating for both directions of travel. Unfortunately, it was discovered during data collection that a good deal of this traffic turned off the road into subdivisions some distance from the route, shielded from view from the road by pine forests.

Table 3-1 Sites Selected for Collecting Field Data

Route/ Section	County	Date(s) of data collection	# of stations	Number of lanes at station: 1	2	3	4
65/1	Boone	April 1999	3	2	3	3	-
70/9-10	Garland	July 1999,	3	2	3	3	-
	-Saline	July 2002	4	2	3	3	2
70/10	Saline	December 2000	4	2	3	3	3
82/1	Miller	March 2001	4	2	3	2	2

At each site, data were collected at a series of stations (sta). The initial station was positioned just before the number of lanes began to expand from two to three. Subsequent stations were spaced at 1.5 km (0.9 mi) intervals. Initially, data were collected at only three stations at each site. However, after examining the data collected in the second study (US 70 WB 1999), the need to expand from three stations to four stations was realized. Hence for US 65 SB 1999 and US 70 WB 1999 the data were collected at three stations, and for the rest of the studies the data were collected at four stations. Table 3-2 presents information on geometric features of these segments. From this table, one can see that horizontal alignment would be expected to have no effect on speed, but at some locations the vertical alignment might slightly slow traffic.

Table 3-2 Geometric Features of Data Collection Sites

Site	Alignment	STA 1	STA 2	STA 3	STA 4
US 65 SB	Horizontal:	Straight	Curve to right	Curve to right	--
	Vertical:	Upgrade	Level	Slight Upgrade	--
US 70 WB (Sec 9 & 10-Saline and Garland County) west of bridge LM 2.27	Horizontal:	Curve to left R=711 m (2330 ft)	Curve to left R=686 m (2250 ft)	Curve to right R=1151 m (3778 ft)	Curve to left R=873 m (2865 ft)
	Vertical:	+1%to-1%	+1% to -1%	Near end of short +1.9%	Upper end of +2.78%
US 70 EB (Sec 10-Saline County) east of bridge LM 3.29	Horizontal:	Straight	Curve to left, end of, R=582 m (1910 ft)	Curve to left, R=3493 m (11460 ft)	Curve to left, R=861 m (2825 ft)
	Vertical:	+1%to-1%	+1% to -1%	Upper end of upgrade, near crest, +3.54%	Upper end of upgrade of +3.70%
US 82 EB	Horizontal:	Straight	Straight	Straight	Straight
	Vertical:	-0.8%	Near end of -0.8%	Upgrade	Near end of -2.0%

The following Figure 3-1 shows station 1 of US 65 SB. An upgrade can be seen in the photo.

FIG. 3-1 US 65 SB Station 1

Figures 3-2 and 3-3 show the equipment setup at station 4 of US 70 WB and station 3 of US 70 EB, respectively. An upgrade of 3.54% at station 3 of US 70 EB can be seen in the photo.

FIG. 3-2 US 70 WB Station 4

FIG. 3-3 US 70 EB Station 3

The following Figure 3-4 presents Station 2 of US 82 EB 2001. A slight upgrade downstream of the station can be seen in the photo.

FIG. 3-4 US 82 EB Station 2

EQUIPMENT FOR COLLECTING TRAFFIC FLOW DATA

Data to examine speed, platooning, and passing attributes were collected. This section describes equipment deployed and the setup of equipment.

Traffic Classifier

Traffic classifiers collected speed and platooning data. Pneumatic tubes connected to the classifiers were the sensors. The classifier calculated speed of the vehicle from known spacing between the tubes and the time difference between the actuations of the two tubes. One classifier was placed at each station.

The tubes were laid perpendicular to the direction of travel and were affixed to the road surface with tape. The spacing between the tubes varied from 2 to 10 feet. The movement of the tubes was restrained with the help of clamps that were nailed to both shoulders of the road. The clamps also ensured that the pneumatic tubes were always stretched and there was no slack in them. One end of the tube was sealed with a plug and the other end was connected to the classifier. Every time a vehicle crossed the tubes, the classifier sensed the change in pressure and recorded the time.

For the stations located immediately upstream and downstream of the passing section, only one pair of the pneumatic tubes was used to record the data. For the stations located along the three-lane section of the segment, two pairs of pneumatic tubes were used. One pair of the tubes recorded the data for the inside lane and the other pair recorded the data for the outside lane. For the tubes recording the traffic data for the outside lane, a knot was tied at the lane line, and for the tubes recording the data for the inside lane, a knot was tied at the road centerline.

Lidar and Radar Gun

Lidar and Radar guns can measure vehicle speed. One gun was included as a backup for collecting the speeds in case a classifier malfunctioned.

Video Camera

Video cameras were deployed to record the flow of the traffic. Three 8 mm video cameras and one VHS camera were used. One camera and one observer were deployed at each station. The observer, stationed adjacent to the camera, called out the first three characters of each vehicle's license plate.

Traffic Flow Data Collection Procedure

Before data collection began, the time displays of all classifiers and cameras were synchronized. The pneumatic tubes were laid at each station. The tubes were connected to their respective input terminals of the classifier. The first few readings of the classifier were observed carefully to check if the classifier was installed correctly. Only when the researchers were satisfied with the classifier readings was the data collection initiated.

The video camera was also positioned at the station. The camera was so aligned that it could record all the vehicles moving in the desired direction. Figure 3-5 is the schematic presentation of a typical equipment setup.

SPEED AND PLATOONING DATA REDUCTION

The data from the classifier were transferred to the computer through the use of software supplied by the classifier manufacturer. The software converted the data from hex form to readable binary form. This raw data contained the time when the vehicle passed the classifier tube, speed of the vehicle, number of axles, the axle spacing, and the lane in which the vehicle was traveling.

The classifier assigned vehicles traveling in the inside lane to a "category lane 1" and those traveling in the outside lane to a "category lane 2". If the vehicle traveling in the opposite direction happened to register in the classifier, then such vehicles were assigned to category lane '9' or lane '10'. For obvious reasons, the data for lanes 9 and 10 were discarded.

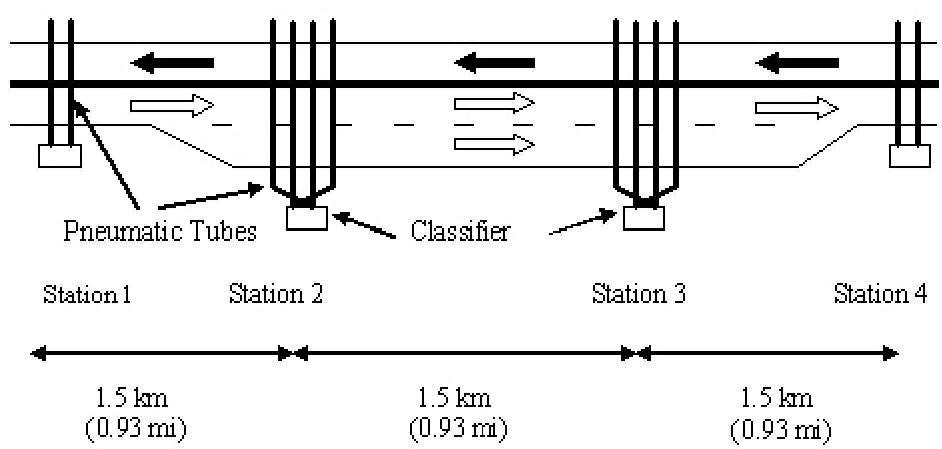

FIG. 3-5 Typical Equipment Setup

Upon examining the raw data, it was evident that certain adjustments were called for. These adjustments are mentioned below.

Duplicate Vehicle Records

The raw data classified the vehicle information based on the lane in which the vehicle was traveling. Because of the peculiar layout of tubes, vehicles traveling in the outside lane (lane 2) were recorded both as traveling in the outside lane and traveling in the inside lane (lane 1) (see Figure 3-6).

The duplicate vehicles were identified by sorting the data from both lanes in ascending order of time. By comparing the time stamps associated with each vehicle, the vehicles that had been recorded in both lanes were identified. If the vehicle was recorded as traveling in lane 1 as well as lane 2 at the same time and speed, then it was concluded that the vehicle was traveling in outside lane (lane 2). Ideally, the speeds should have been the same for both the readings. If the classifier recorded slightly different speeds for the same vehicle, the mean of two speeds was considered as the speed of the vehicle. The inside lane entry was not considered for analysis.

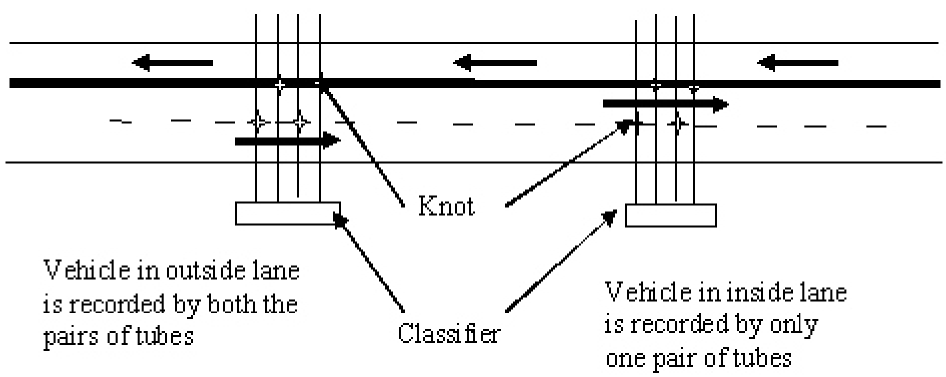

FIG. 3-6 Duplicate Vehicle Records

Closely Spaced Vehicles

If two or more vehicles were traveling in a closely spaced formation, the classifier sometimes could not differentiate between the two vehicles. In this event, it recorded and stored an erroneous very high speed value. The database was examined for such inaccuracies and the wrong data were deleted from the database.

Slow Moving Vehicles

After studying the traffic behavior, it was decided that the vehicles traveling at speeds less than 35 mph probably represented either entering/leaving vehicles or an anomaly. These vehicles were atypical, and hence all the vehicles traveling at speeds less than 35 mph were discarded from the analysis.

PASSING DATA REDUCTION

The video tapes that were recorded at each of the station were viewed in order to reduce passing data from them.

Determination of Time Windows

The first step was to identify the time windows during which the video recordings were available simultaneously for all the four stations. All the tapes were viewed to identify the time periods during which the data were available for all the four stations.

Tracking the Vehicles

Once these usable time windows were found, the data from video tapes were recorded for each five minute interval for each station. The data obtained from viewing the video tapes were entered into the spread sheet. As the stations were located 1.5 km (0.9 mi) apart, most vehicles had a time lag of approximately one minute between any two successive stations.

The sequence of vehicles was observed and all the vehicles that could be tracked at all the stations were marked. The vehicles that did not traverse the entire segment were identified. This information was used for computing and “through volume” (i.e., the volume of traffic that traversed the entire passing lane segment) and computing “total volume” (i.e., the total number of vehicles that passed a particular station).

Because of inherent variability in perception of the observers, many vehicles were not identified in the same manner at all the four stations. For example, if the observer at one station was not able to read out the license plate of a particular vehicle, then he might have called the description of the vehicle, whereas the observer at the other station might have called the license plate instead. In order to correctly track such vehicles, the video tapes were viewed again for that particular stretch of time during which the vehicle was recorded. This problem was typical for tractor-trailer combinations, or vehicles traveling very fast.

CRASH DATA REDUCTION

The crash data for the period 1995 through 1999 were obtained from the summary crash database furnished by the AHTD. The following discussion explains the crash data reduction procedure.

Definition of Passing Lane Segments and Transition Zones

A transition zone is basically a lane-addition or a lane-drop area. A diverge transition zone (entering taper) is a lane-addition area of the passing lane. This study defined a diverge transition zone as the length between the beginning of the transition taper and the beginning of pavement markings for three lanes. A merge transition taper (ending taper) is a lane-drop area. This study defined a merge transition zone as the length between the end of the lane line and the end of the transition taper.
The portion of a passing lane between two transition tapers was defined as a segment. The following Figure 3-7 illustrates the parts of the passing lane.

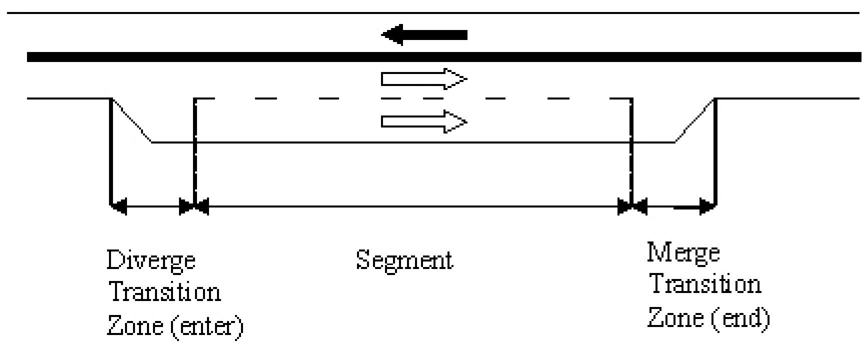

FIG. 3-7 Definition of Segment and Transition Zone

Transition Zone Configuration

Transition zones can occur at the beginning (Enter) of a passing lane section and at the end (End) of a passing lane section. At an "Enter", the extra lane may be added on the inside or on the outside, depending upon how the roadway is marked. The researchers identified two basic arrangements at the end of a transition zone: no head-on and head-on.

1. No head-on transition zones: The projected trajectories of vehicles traveling in the opposite directions were not in conflict with each other.
2. Head-on transition zones: The projected trajectories of vehicles traveling in the opposite directions were aligned or "head-on" with each other.

The following Figures 3-8a through 3-8e shows the arrangements of transition zones.

ENTER: INSIDE LANE

With the "Enter-Inside Lane" arrangement, the additional lane appears on the inside, or adjacent to the roadway centerline. One or both the lanes of the two-lane section are shifted away from each other to accommodate a passing lane between them (Figure 3-8a).

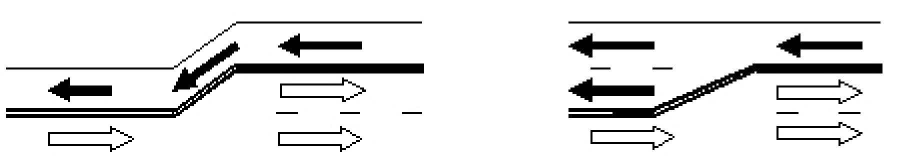

FIG. 3-8a Enter: Inside Lane

ENTER/END: OUTSIDE LANE

The "Outside Lane" transition has both an "Enter" and an End taper. In this arrangement, the passing lane is provided on the right side or outside of the traveled lane. As shown in Figure 3-8b, the End merge may be arranged so either the inside lane merges with the outside lane, or vice versa. The vehicles traveling in the opposing directions are never in conflict in this type of transition zone.

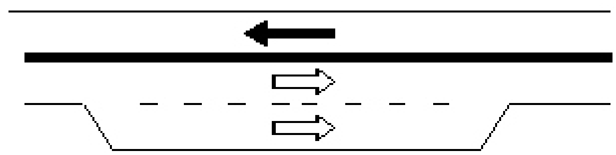

FIG. 3-8b Enter/End: Outside Lane

END: NO HEAD-ON LEFT TURNING LANE

No head-on left turning lane transition applies to ending taper only. As shown in Figure 3-8c, the inside lane becomes left turning lane, and the outside lane continues ahead. The transition involves merging of inside lane with outside lane.

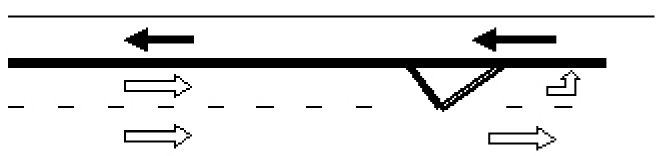

FIG. 3-8c End: No Head-on Left Turning Lane

END: HEAD-ON WITH BUFFER

Head-on transition with buffer applies to both entering and ending tapers. One or both the lanes of the two-lane rural highway are shifted away from each other to accommodate a passing lane between them (Figure 3-8d). The transition zone is such that the projected trajectories of the vehicles moving in the opposite direction are in line with each other. A buffer zone at the end of passing lanes separates the vehicles traveling in opposite directions.

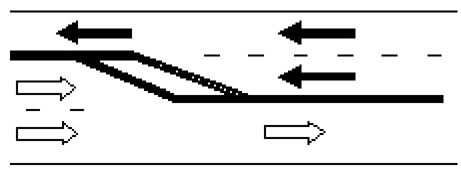

FIG. 3-8d End: Head-on with Buffer

END: HEAD-ON WITHOUT BUFFER

As shown in Figure 3-8e, head-on transition without buffer arrangement of passing lane is aligned like head-on with buffer except there is no buffer that separates vehicles traveling in the opposite directions. This arrangement applies to both enter and end tapers. However, for the highway segments studied in this project, this arrangement was provided only at the end taper.

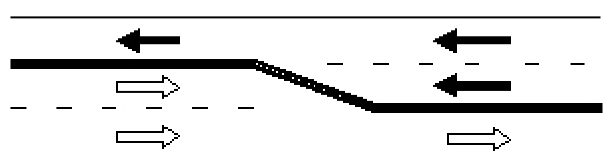

FIG 3-8e End: Head-on without Buffer

The following Table 3-3 lists various passing lane segments as per the types of transition provided.

Table 3-3 Types of Transition Zones Encountered

Type of Transition	Passing Lane Segment
Enter-Inside	62-8, 62-12, 69-2
Enter-Outside	15-3, 15-5, 15-6, 62-8, 62-12, 63-1, 65-1, 69-2, 70-9, 70-10, 82-1, 82-4, 82-5, 82-7
End-Head-on without buffer	15-3, 69-2
End-Head-on with buffer	1-13, 62-8, 62-12, 63-1, 65-1, 70-9
End-No head-on left turning lane	63-1
End-Outside	15-5, 15-6, 62-8, 63-1, 65-1, 69-2, 82-1, 82-4, 82-5, 82-7

Calculation of AADT

The AADT's for each highway segment under study for the period 1995 thru 1999 were estimated with the help of annual average traffic daily records from the AHTD. For every route, the AADT for each year was found and subsequently the average AADT for each route was obtained. The period during which the particular route was under construction was subtracted from total period for the calculation of the average AADT.

If the AADT volumes varied along the path, then average of all the volumes was calculated. The only exception was route 82-1, which had a high variation in volume over the length of the section. So based on the AADT, route 82-1 was split in to five different parts 82-1a, 82-1b, 82-1c, 82-1d and 82-1e (Table 3-4). Each sub-section of 82-1 was analyzed separately.

Table 3-4 Division of US 82, Section 1

Segment	Log Miles	
	From	To
82-1 a	3.72	4.92
82-1 b	5.9	7.17
82-1 c	9.53	10.74
82-1 d	13.6	14.80
82-1 e	17.47	18.65

Estimation of Number of Crashes from the AHTD Database

The log kilometer of the points at which the transition began, the full-three lane segment began, the full three-lane segment ended, and the transition ended had been previously identified by viewing video tape logs of the roadways. To locate crashes on three-lane segments and on transitions into these segments, the statewide crash database for each of the five years studied was queried for route, section, and county. The resulting crashes were sorted in ascending order of log miles. The needed window of log miles was expanded by 0.5 miles in order to include any wrong entry in the database.

The format of the crash database for the years 1995 and 1996 was different from that of the years 1997, 1998 and 1999. In order to compile all of the crash data in a uniform manner, a master spreadsheet was created and the records of the various crashes that took place within the useful time window were copied in it. Each file was named after the route and section it represented.

Adjustment for Construction Schedule

A schedule of road construction was obtained from the AHTD. All the crashes that occurred before and during construction of passing lanes were identified and excluded from the analysis. The crashes that were entered as having occurred in the work zone as well those took place on a two-lane road section were excluded from the listing. The crashes that had been coded as occurring within city limits were examined to determine the true location, since none of the study segments were inside of a city.

Corrections

The initial list of crashes within the limits being queried was reviewed to determine the presence of seeming incorrect entries. For instance, crash number 9855978, on US 63, Section 1, was listed to have occurred on 3-lane segment, but after checking video records and maps it was found that the crash had taken place on a 2-lane segment. Crash number 199928963 was listed to have occurred on US 70 Section 9, but after checking with maps and video logs it was found that actually it was Section 8 and not Section 9. Crash number 9847367 on US 62 Section 12 was listed to have occurred outside city limits, but after checking with maps it was found that the location of the crash was within the city limits.
The accuracy of the crash milepoint locations was checked by identifying and cross checking the crash location both on AHTD maps and AADT estimate records which show the log miles.

Categorizing Crash Data

The log mile information previously obtained from video log sheets helped determine which crashes were in the three-lane segments and which were in transition zones. The crashes in transition zones were separated from those in three-lane segments.

The crashes in passing lane segments and in the transition-end zones were analyzed as per crash severity and the type of collision. The AHTD database had five types of crash severity: fatal (F), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and property damage only (PDO). The crash database had nine types of collision: single vehicle crash, head-on collision, rear end collision, right angle, sideswipe same direction, sideswipe opposite direction, backing, other, and unknown.

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CHAPTER 4
DATA ANALYSIS AND RESULTS

Data were collected at sites denoted as US 65 SB, US 70 EB, US 70 WB and US 82 EB. Due to a variety of causes, some of the data from the US 65 SB and the US 70 WB 1999 studies were unusable.

Two measures of volumes were used, "total volume" and "through volume". Total volume was the total traffic volume that passed a particular station, while through volume was the volume of traffic that traversed through all of the data collections stations (i.e., the entire passing lane segment). For speed and platooning analysis, total volume was used. For passing analysis, through volume was used. All 15-minute flow rates are expressed as equivalent hourly volumes. Table 4-1 lists ranges of one-direction hourly flow rates during data collection.

Table 4-1 One-Direction Flow Rates

Study	Minimum	Average	50th %	90th %	Maximum
US 70 WB 1999	260	445	384	608	724
US 70 EB 2000	216	307	300	360	428
US 82 EB 2001	104	164	168	216	232
US 70 WB 2002	176	322	312	420	504

Note: Volumes expressed in vehicles per hour (vph).

ANALYSIS OF SPEED DATA

Speed data were studied to ascertain what change in the traffic speed occurred through the passing-lane segment. The speeds were measured at stations established at predetermined locations along the passing lane segment of the highway.

The speed data from each station at each of the study sites were divided into 15-minute interval groupings. For each 15-minute interval, the mean speed, standard deviation and number of vehicles recorded were found. Figure 4-1 is the graph of average vehicular speed observed at all the four stations. A visual inspection of the plot revealed that the speed trends across the passing lane segments were not uniform for all the study sites. As mentioned in the reviewed literature, the traffic speeds could have been influenced by many factors such as traffic volumes, geometric features of the road segment, etc.

The following paragraphs discuss the changes in speed across the segments with respect to average total volume, geometric and topographical features of the segment. The given traffic volumes are for one direction of travel.

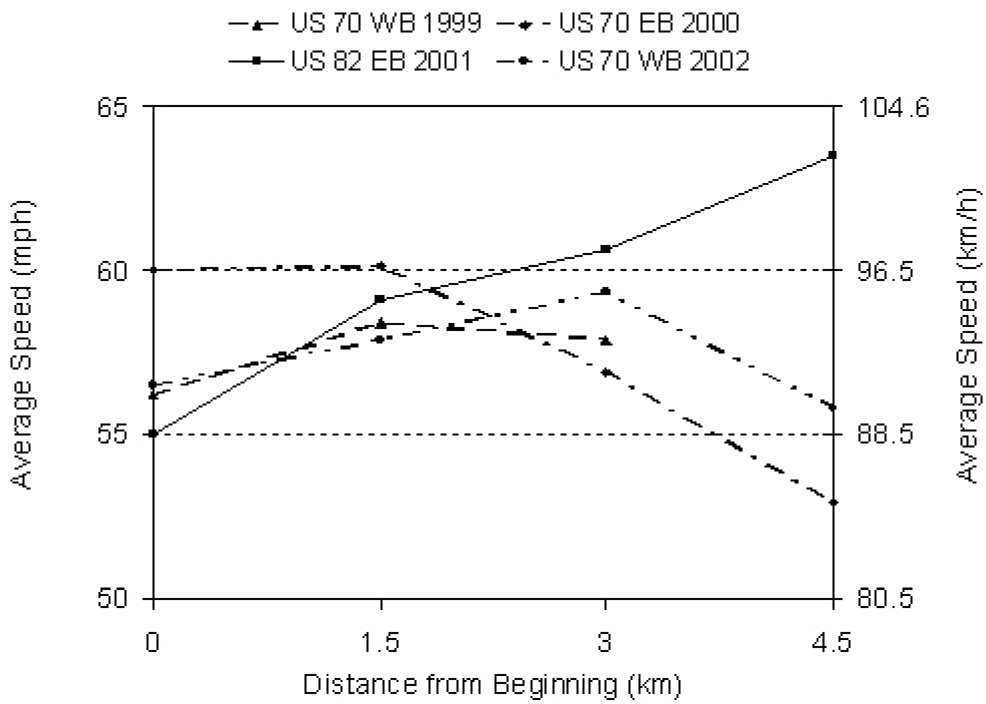


FIG. 4-1 Average Speeds at Various Stations

US 70 Westbound 1999

This site had three stations. The first station had two lanes, one for eastbound traffic and one for westbound traffic. Stations two and three had three lanes, two lanes for westbound traffic and one lane for eastbound traffic.

Figure 4-2 shows the average speeds and volumes during data collection. The average speed increased from Station 1 to Station 2, and then dropped slightly. The speed at the end of the segment was higher than the speed at the beginning of the segment. This slight reduction in the average speed from station 2 to station 3 could have been due to the +1.9 % upgrade near Station 3.

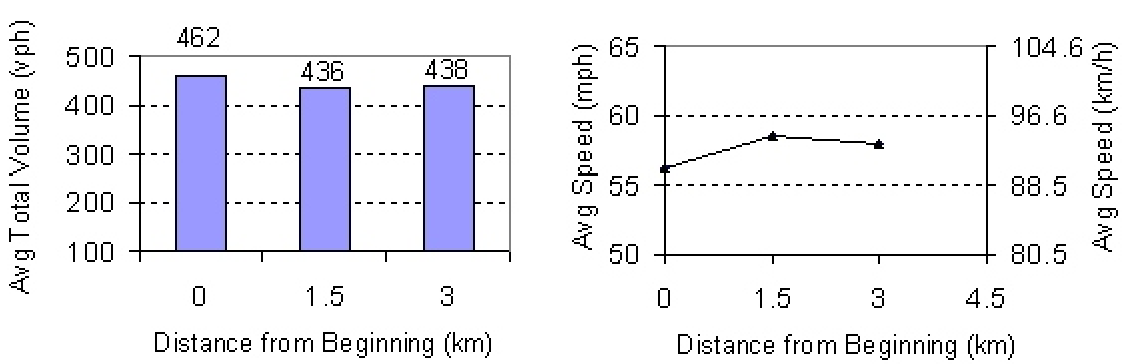


FIG. 4-2 Speed and Volume US 70 WB 1999

US 70 Eastbound 2000

This site had four stations. The first station had two lanes, one lane for each direction of travel. Stations two, three and four had three lanes, one lane for westbound traffic and two lanes for eastbound traffic.

Figure 4-3 displays average speed and volume. In this case, a decrease in the average speeds could be observed along the passing segment. One reason for the speed drop could be the + 3.54% and + 3.7% upgrades at Stations 3 and 4 respectively.

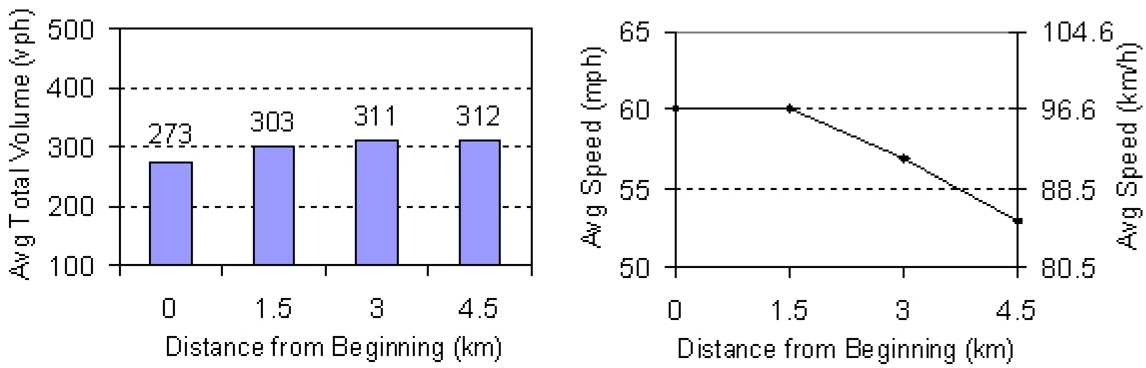


FIG. 4-3 Speed and Volume US 70 EB 2000

US 82 Eastbound 2001

This site had four stations. Stations one, three and four had two lanes, one lane for each direction of travel. The station two had three lanes, one lane for westbound traffic and two lanes for eastbound traffic.

Figure 4-4 shows the average speed and volumes along the segment. The average traffic speeds increased along the passing segment. There was also a reduction in volumes through the passing segment. The - 2% downgrade at Station 4 may have helped speed-up traffic.

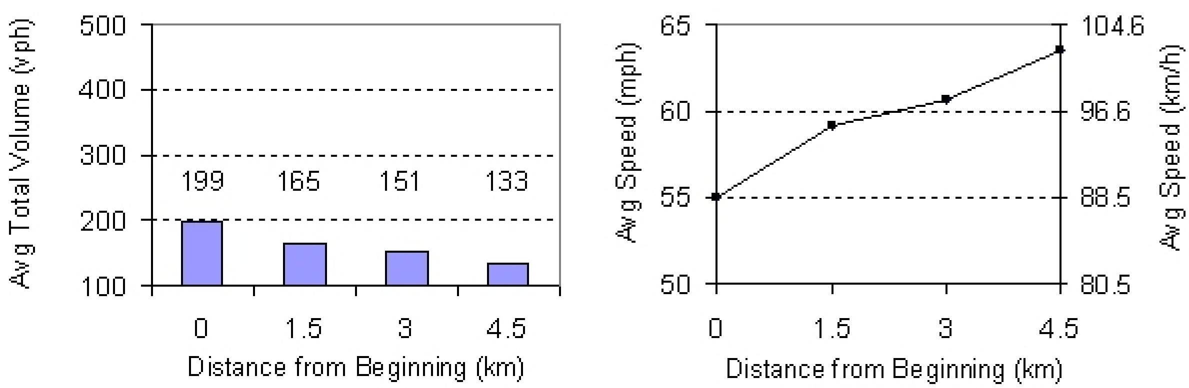


FIG. 4-4 Speed and Volume US 82 EB 2001

US 70 Westbound 2002

This site had four stations. Stations one and four had two lanes, one lane for each direction of travel. Stations two and three had three lanes, one lane for eastbound traffic and two lanes for westbound traffic.

Figure 4-5 describes the average speed and volume. The average speed increased until Station 3, and then decreased after that. The decrease in the average traffic speed could be because of the +2.78% upgrade at Station 4.

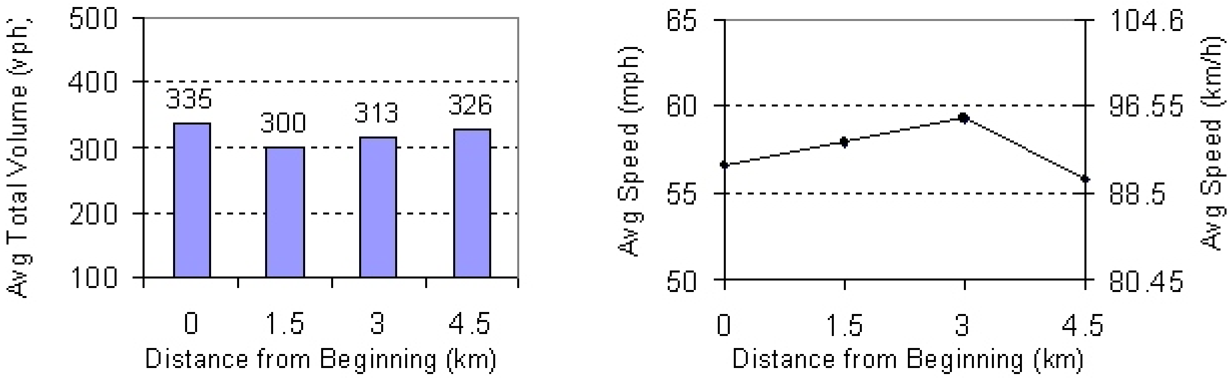


FIG. 4-5 Speed and Volume US 70 WB 2002

ANALYSIS OF PLATOONING DATA

The study considered the effects of passing lane length and traffic volume on platooning. As per the 2000 edition of the *Highway Capacity Manual* (12-12), the vehicles were said to be in platoon if the headway between the two successive vehicles was less that 3 sec. A study by Gattis et al. (TRR 1579, pp 27-34) concluded that for speeds higher than 80 km/h (50 mph), headways more than 3 seconds do not encourage drivers to undertake passing maneuvers. In other words, for high speed roads (speeds more than 80 km/h (50 mph) as per definition of high speed obtained from AASHTO Green Book page 72), drivers may feel congestion if headways were less than 3 seconds, and may undertake passing maneuvers.

The headway between two successive vehicles was calculated and the vehicles in a platoon were assigned the numeric value “1”. As mentioned earlier, for each study site, some stations were located on a highway segment having no passing lane and the other stations were located on the passing lane section of the segment. In order to be consistent in comparing platooning at stations having passing lane with those stations having no passing lane, it was assumed that two vehicles, traveling in the adjacent lanes, were still in platoon if the headway between them was less than 3 seconds. This assumption was based on the fact that the vehicles traveling in the adjacent lanes eventually had to merge at the end of the passing lane segment.

The data were analyzed in 15-minute intervals. The data were analyzed for all the sites and stations combined, and for individual sites. A statistical analysis follows.

Analysis of Platooning Data Combined for all the Sites and all the Stations

Figure 4-6 and Figure 4-7 are the plots of number and percent of vehicles in platoon at each station for all sites combined. There were fewer data points for station 4 than for the other three stations because only three sites (US 70 EB 2000, US 82 EB 2001, and US 70 WB 2002) had four stations. Equivalent volume is a 15-minute flow rate multiplied by four.

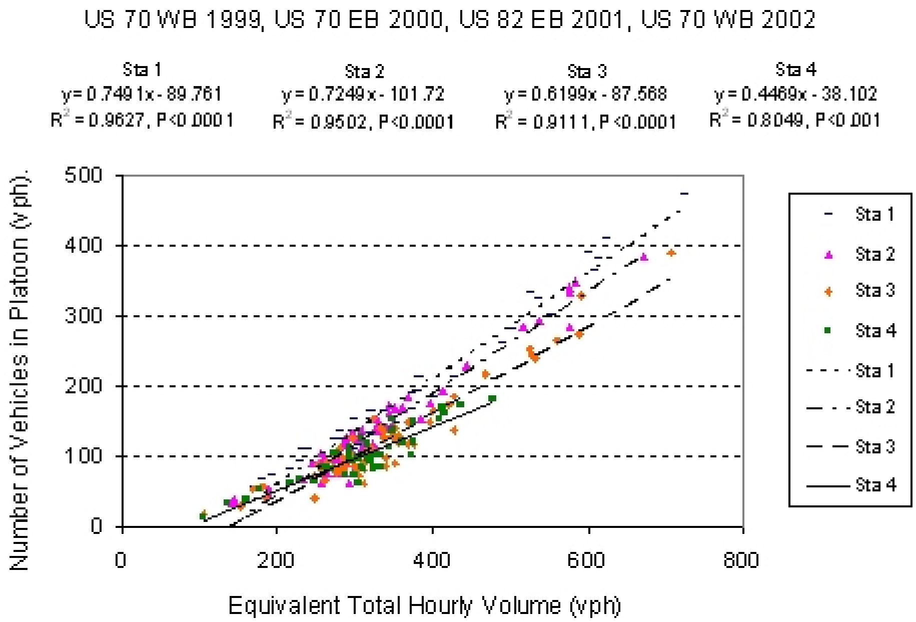


FIG. 4-6 Combined Number of Vehicles in Platoon

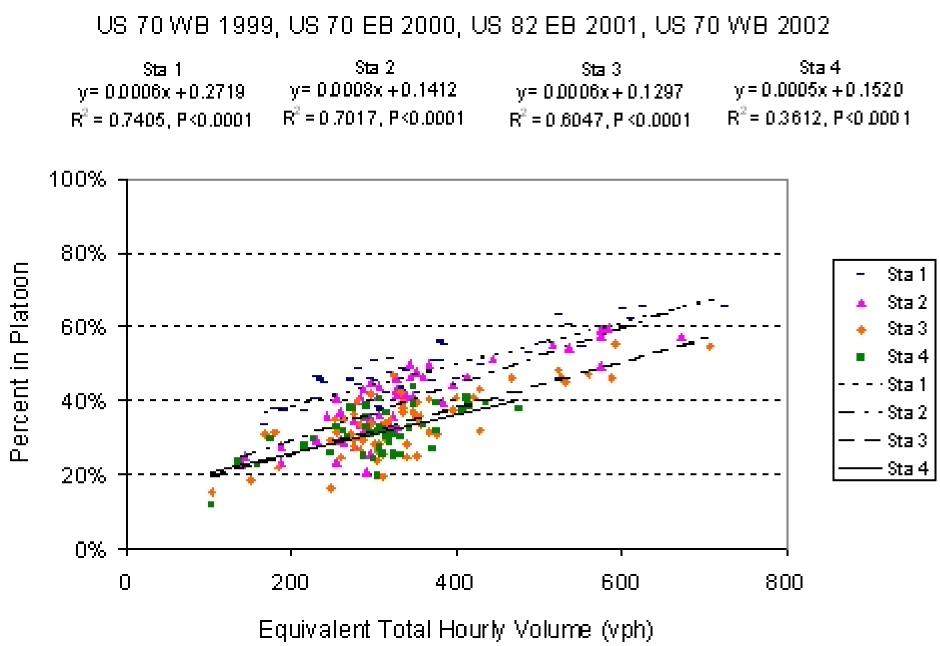


FIG. 4-7 Combined Percent of Vehicles in Platoon

As shown in the plots, for the same volume, platooning at station 1 (immediately prior to the beginning of the passing lane) was always higher than at any other station. The vehicles in platoons decreased at successive stations. As volumes increased, there was a greater reduction in platooning between stations 2 and 3. The plots show that the platooning at the end of passing lanes was less than the platooning at the beginning of the passing lanes.

Analysis of Platooning Data for Individual Sites

The following Figures 4-8 through 4-15 show the number and the percentage of vehicles in platoons, and the traffic volumes along the passing lane segment for each of the studies which had sufficient data.

US 70 WESTBOUND 1999

This site had three stations. The first station had two lanes, one for eastbound traffic and one for westbound traffic. The second and the third stations had three lanes each, two lanes for westbound traffic and one lane for eastbound traffic. Figure 4-9 shows the platooning decreasing along the segment. Thus for the same volume, there were fewer vehicles in platoons at station 3 than at the first two stations.

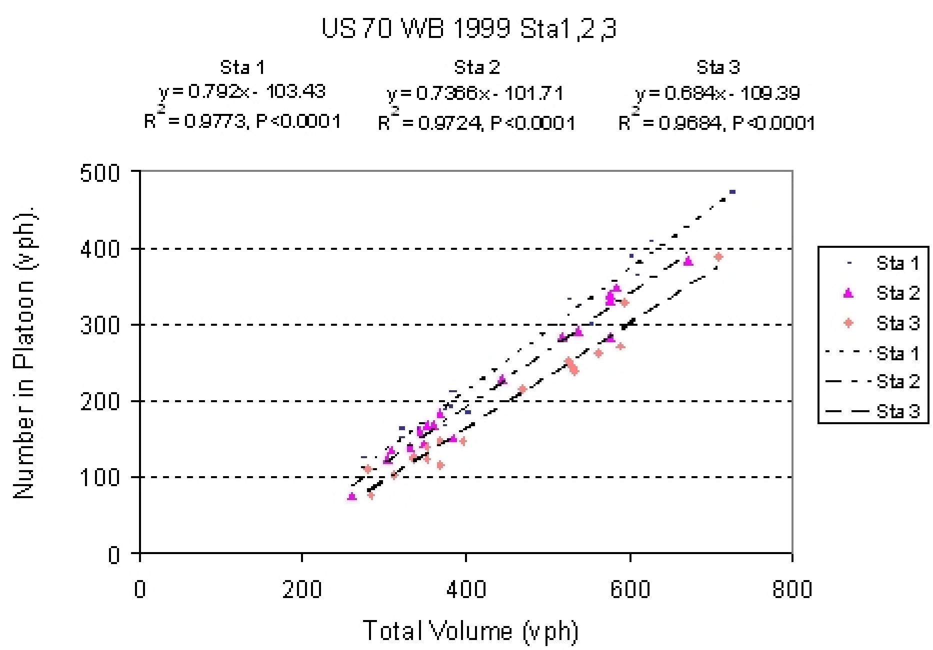


FIG. 4-8 Number of Vehicles in Platoon and Volume US 70 WB 1999

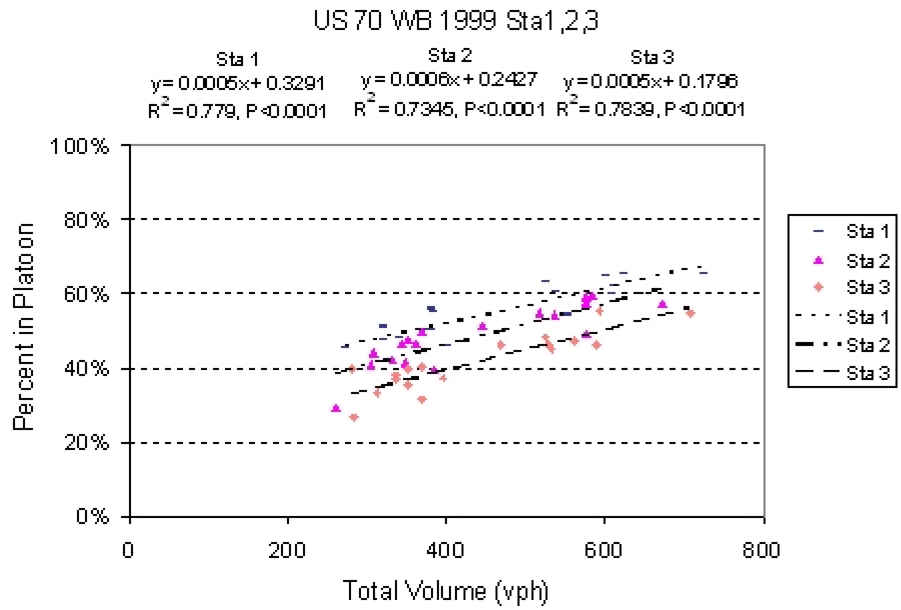


FIG. 4-9 Percent of Vehicles in Platoon and Volume US 70 WB 1999

US 70 EASTBOUND 2000

This site had four stations. The first station had two lanes, one lane for each direction of travel. The second, the third, and the fourth stations had three lanes each, one lane for westbound traffic and two lanes for eastbound traffic. The plot shows that for the same volume, station 1 had highest percentage of vehicles in the platoon. The percentage of vehicles in platoons decreased along the passing lane.

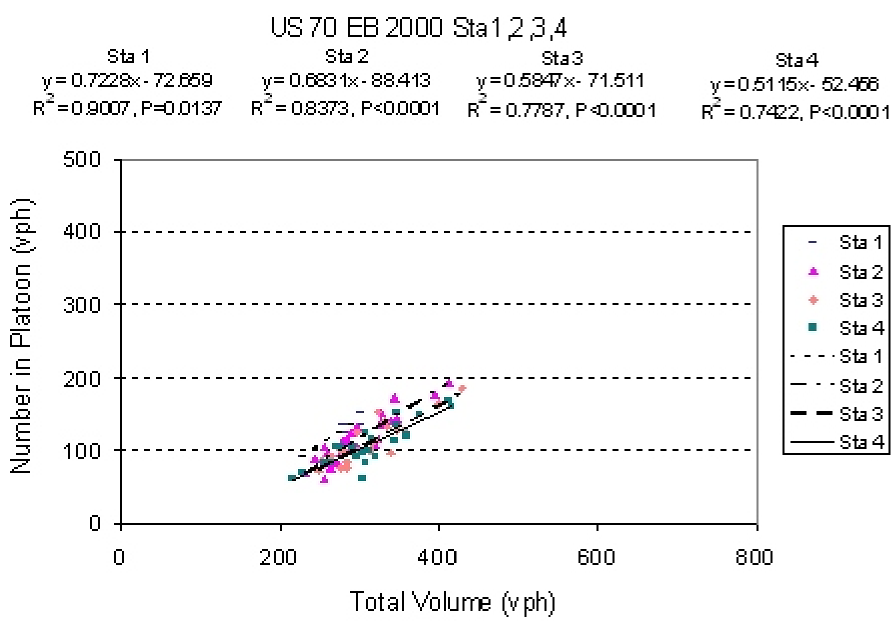


FIG. 4-10 Number of Vehicles in Platoon and Total Volume US 70 EB 2000

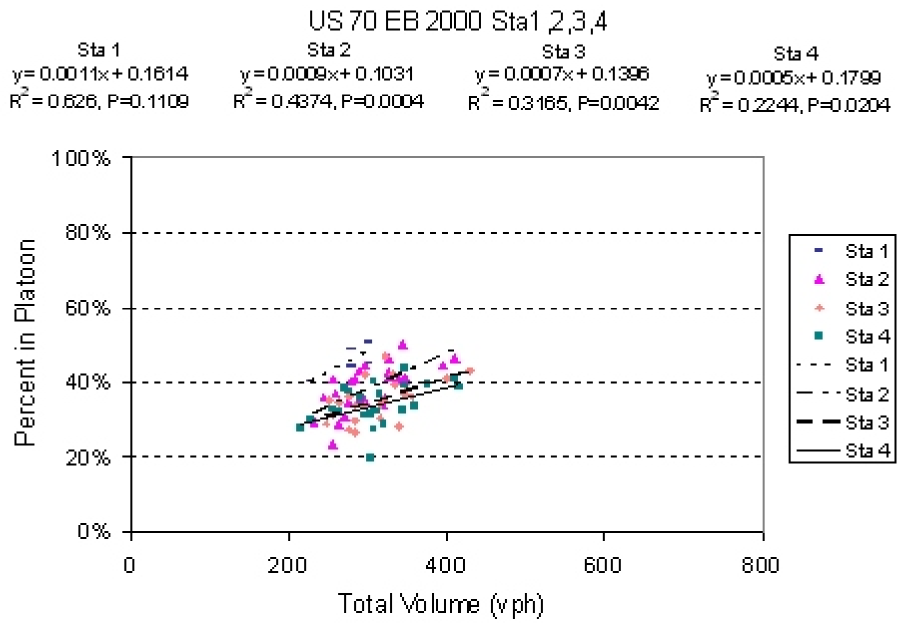


FIG. 4-11 Percent of Vehicles in Platoon and Total Volume US 70 EB 2000

US 82 EASTBOUND 2001

This site had four stations. Stations one, two, and four had two lanes each, one lane for each direction of travel. Station two had three lanes, one lane for westbound traffic and two lanes for eastbound traffic. The data for this study were confined to a narrow range of volumes. Although the coefficient of determination (R^2) values were high, the low "p" values indicated a weak relationship between the two variables.

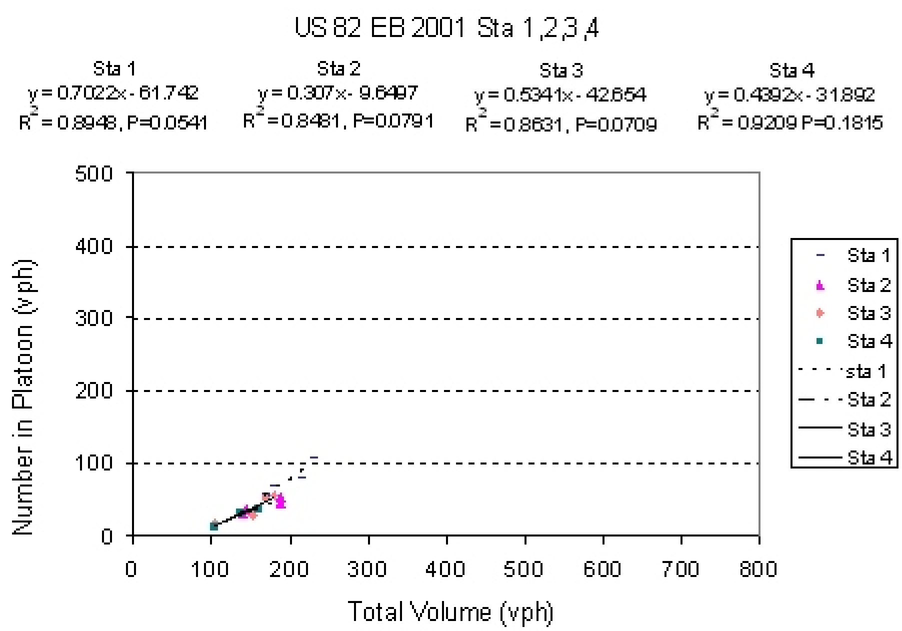


FIG. 4-12 Number of Vehicles in Platoon and Volume US 82 EB 2001

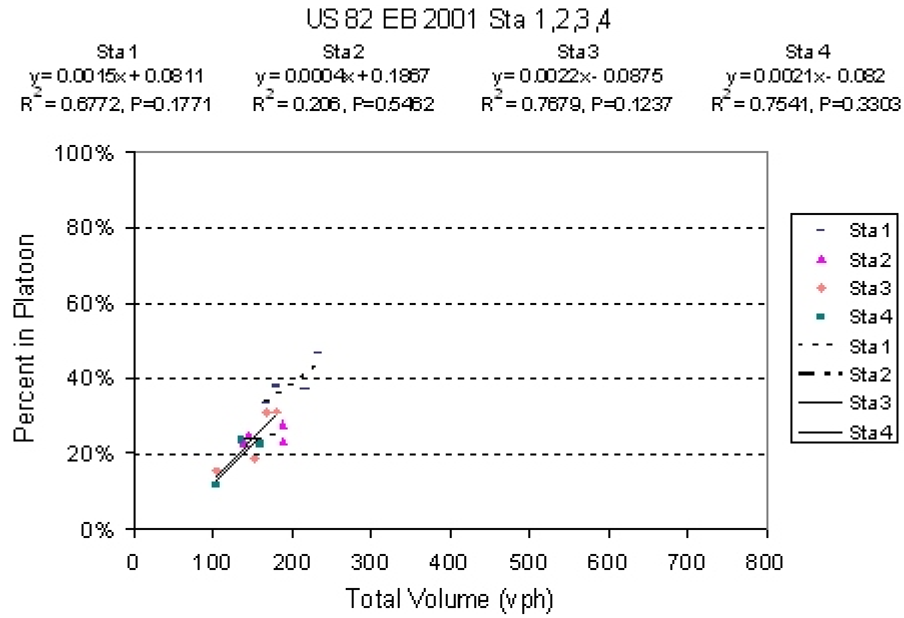


FIG. 4-13 Percent of Vehicles in Platoon and Volume US 82 EB 2001

US 70 WESTBOUND 2002

This site had four stations. The first and the fourth stations were two-lane sections. The second and the third stations had three lanes, one lane for eastbound traffic and two lanes for westbound traffic. This site had a wider volume range than some others. Due to equipment failure while collecting the data, there was less data for station 2. Platooning at station 1 was much higher than at the other stations.

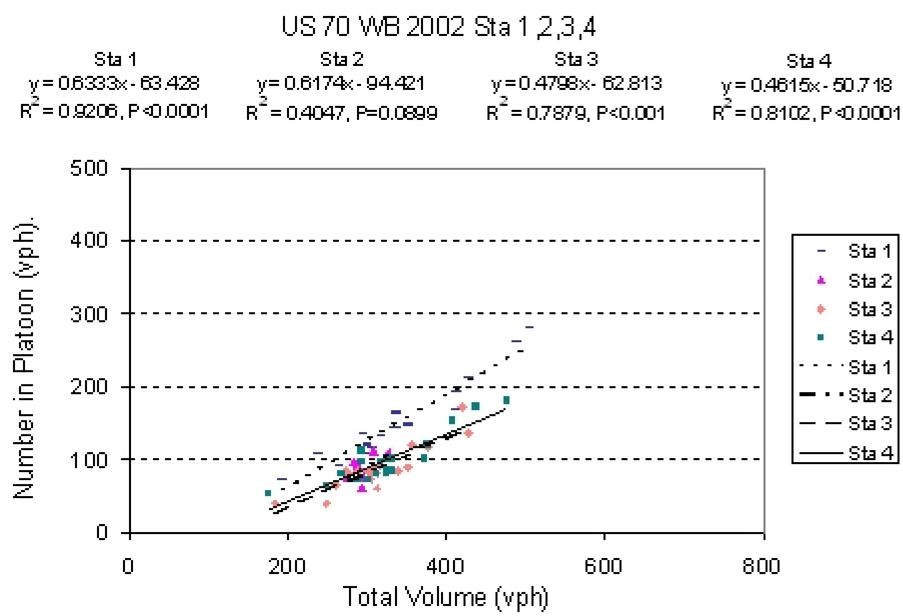


FIG. 4-14 Number of Vehicles in Platoon and Volume US 70 WB 2002

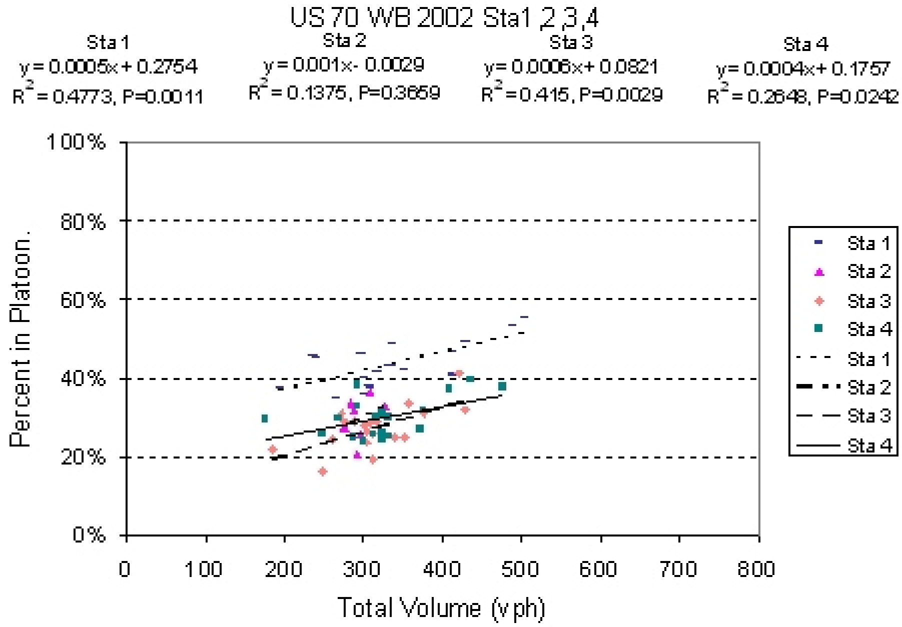


FIG. 4-15 Percent of Vehicles in Platoon and Volume US 70 WB 2002

Statistical Analysis of Platooning

From the study of all the plots, it could be observed that platooning decreased along the passing lane segment and in general the platooning at the end of passing lane segment was less than that at the beginning of the passing lane. The data were subjected to statistical analysis to find out if the reductions in platooning were significant. The null hypothesis was that significant reduction in the platooning occurred between two stations.

For the analysis, the response variable was the number of vehicles in the platoon and the independent variable was total traffic volume. The natural log of volume was used as an offset variable so that the final result could be reported in terms of platooning rate (number of vehicles in platoon per total number of vehicles).

Initially, the underlying distribution of the data was assumed to be Poisson. If over-dispersion was observed, i.e. variance found to be greater than mean (as indicated in the deviance and or Pearson chi-square goodness-of-fit statistics), a Negative Binomial model was used instead of Poisson.

Poisson and/or Negative Binomial regressions with repeated measures (Generalized Estimating Equations) were used to determine if and how the rate of platooning differed along the segment. As the same vehicles were observed going through each station, repeated measures were needed to account for possible correlations between observations.

The results of the statistical analysis are presented in the following discussion. The statistical analysis could not be performed on US 82 EB 2001 because the amount of data was not adequate.

US 70 WESTBOUND 1999

This site had only three stations. As mentioned earlier, initially the data were subjected to Poisson regression with repeated measures. The value for the deviance statistics was 5.3086, which indicated that there might be over-dispersion. A Negative Binomial regression model with repeated measures was fit for the data, and the value for the deviance statistic was 1.0835, which indicated that Negative Binomial model was appropriate.

Comparison of least square means indicated that the differences between platooning at stations 1 and 2, stations 1 and 3, and stations 2 and 3 were found to be statistically significant. Figure 4-16 is a graphical presentation of statistical analysis.

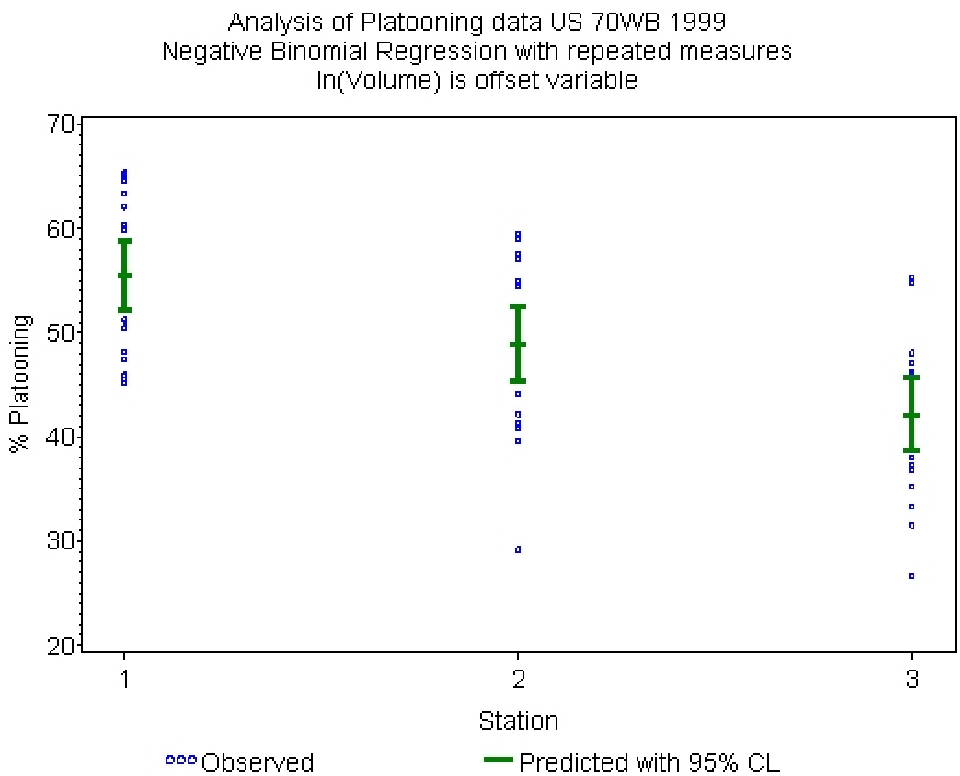


FIG. 4-16 Statistical Analysis for US 70 WB 1999

US 70 EASTBOUND 2000

This site had four stations. The data were subjected to Poisson regression with repeated measures. The value for the deviance statistics was 2.8096, which indicated that there might be over-dispersion. A Negative Binomial regression model with repeated measures was fit for the data, and the value for the deviance statistic was 1.0707, which indicated that Negative Binomial model was appropriate.

Comparison of least square means indicated that the platooning rate at station 1 was significantly higher than at stations 2, 3 and 4. The platooning at station 2 was significantly higher than at stations 3 and 4. However, there was no significant reduction in platooning between stations 3 and 4. Figure 4-17 is a graphical presentation of the statistical analysis.

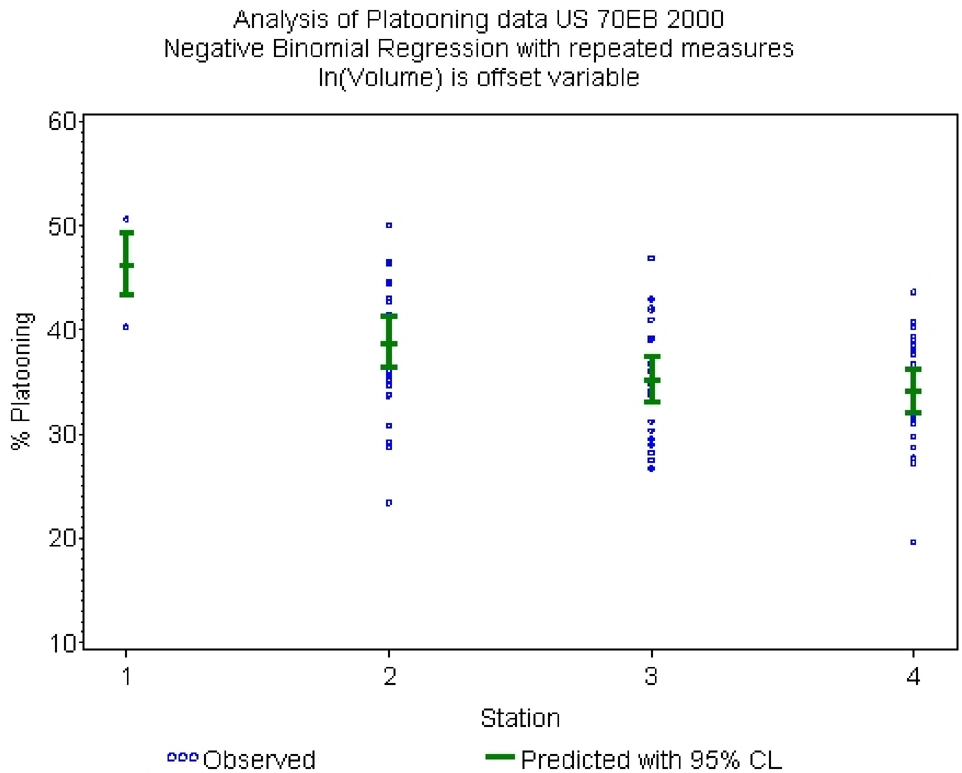


FIG. 4-17 Statistical Analysis for US 70 EB 2000

US 70 WESTBOUND 2002

This site had four stations. However, due to equipment failure at station 2, sufficient data could not be collected at that station. So station 2 was omitted from the statistical analysis. The data were subjected to Poisson regression with repeated measures. The value for the deviance statistics was 5.5439, which indicated that there might be over-dispersion. A Negative Binomial regression model with repeated measures was fit for the data, and the value for deviance statistic was 1.5299, which indicated that Negative Binomial model was appropriate.

Comparison of least square means indicated that the platooning rate at station 1 was significantly higher than at stations 3 and 4. However, there was no significant reduction in the platooning between stations 3 and 4. Figure 4-18 is a graphical presentation of statistical analysis.

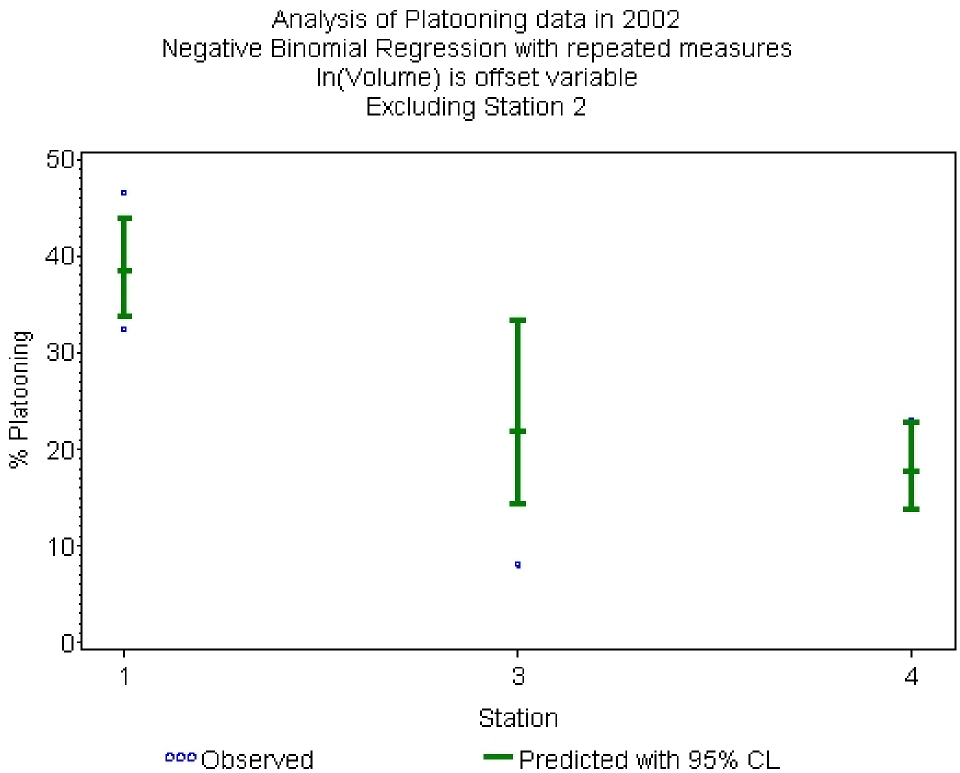


FIG. 4-18 Statistical Analysis for US 70 WB 2002

SUMMARY

Table 4-2 summarizes the statistical comparisons of platooning among the stations along a study segment. A "yes" indicates there was a statistical difference in platooning between the pair of stations indicated.

Table 4-2 Statistical Differences in Platooning

Study Site	Stations	1	2	3	4
US 70 WB 1999	1	-	Yes	Yes	
	2	Yes	-	Yes	
	3	Yes	Yes	-	
US 70 EB 2000	1	-	Yes	Yes	Yes
	2	Yes	-	Yes	Yes
	3	Yes	Yes	-	No
	4	Yes	Yes	No	-
US 70 WB 2002	1	-		Yes	Yes
	3	Yes		-	No
	4	Yes		No	-

Analysis of Influence of Volume and Passing Lane Length on Platooning

The researchers examined the effects of volume and passing lane length on platooning. The equations that were obtained from the platooning data analysis of each study site were used to calculate the number and percent of vehicles in platoon for volumes of 250, 350 and 450 vph (Table 4-3 and Table 4-4).

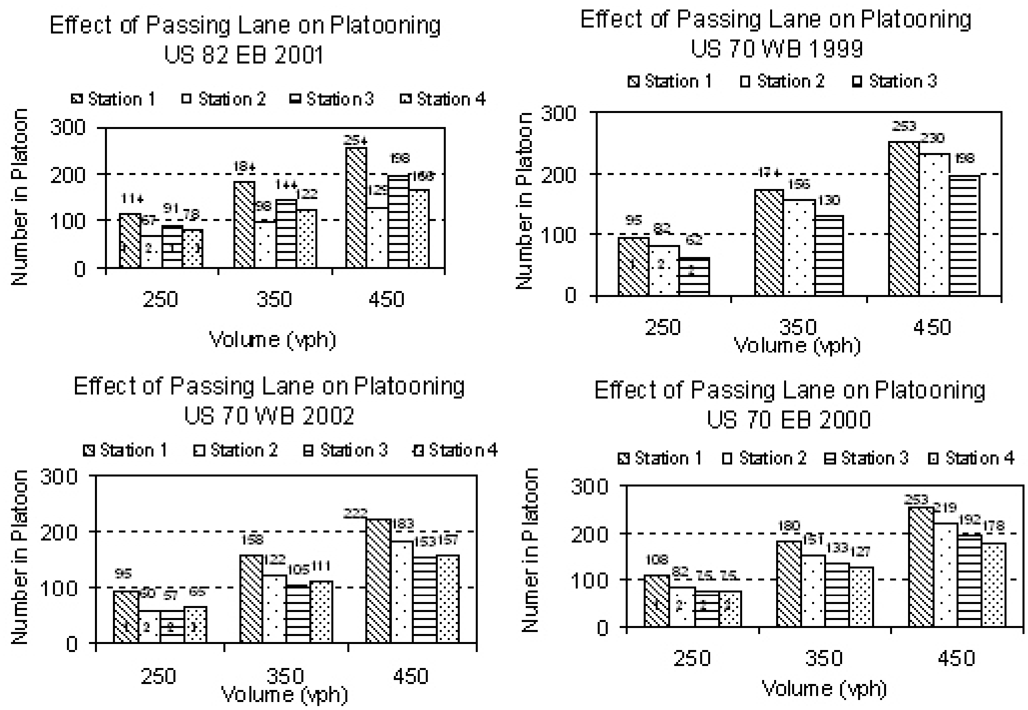
Table 4-3 Number of Vehicles in Platoon from Predictive Equations

Study Site	Volume	Station			
		1	2	3	4
US 82 EB	250	114	67	91	78
	350	184	98	144	122
	450	254	129	198	166
US 70 WB	250	95	82	62	--
	350	174	156	130	--
	450	253	230	198	--
US 70 WB	250	95	60	57	65
	350	158	122	105	111
	450	222	183	153	157
US 70 EB	250	108	82	75	75
	350	180	151	133	127
	450	253	219	192	178

Table 4-4 Percent of Vehicles in Platoon from Predictive Equations

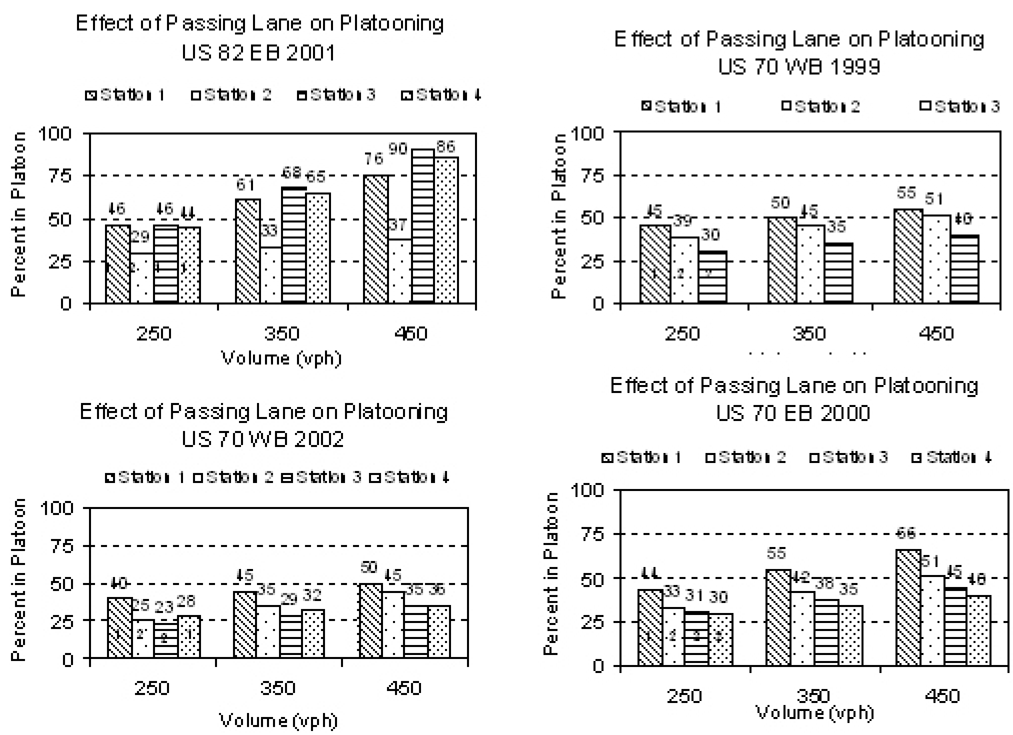
Study Site	Volume	Station			
		1	2	3	4
US 82 EB	250	46	29	46	44
	350	61	33	68	65
	450	76	37	90	86
US 70 WB	250	45	39	30	--
	350	50	45	35	--
	450	55	51	40	--
US 70 WB	250	40	25	23	28
	350	45	35	29	32
	450	50	45	35	36
US 70 EB	250	44	33	31	30
	350	55	42	38	35
	450	66	51	45	40

Figure 4-19 is a plot of the projected number of vehicles in platoon and respective volume. The following Figure 4-20 is a plot of the projected percent of vehicles in platoon and respective volume.



Note: The number inside the histogram indicates the number of lanes at that station

FIG. 4-19 Number of Vehicles in Platoon from Predictive Equation



Note: The number inside the histogram indicates the number of lanes at that station

FIG. 4-20 Percent of Vehicles in Platoon from Predictive Equation

The following observations were drawn from Figures 4-19 and 4-20.

1. The reduction in the platooning was highest between stations 1 and 2 (i.e., up to 1.5 km or 0.9 mi). A smaller reduction in platooning or even some increases were observed between subsequent stations.
2. In some cases, platooning increased at the end of the passing lane segment. However, the platooning at the end of the passing lane was less than the platooning at the beginning.
3. There were insufficient data for flow rates above 450 vph.

ANALYSIS OF PASSING DATA

The study tried to find which portion of the passing lane accounts for majority of passing maneuvers. The passing data were analyzed for every five-minute interval. To determine the number of passes between any two stations, the sequence of vehicles at a station was compared with that of the previous station. As mentioned earlier, the slow moving vehicles and the vehicles that did not travel through the complete segment were excluded from the analysis; only the vehicles that traveled through the passing lane segment (i.e., through volume) were considered.

The order of the vehicles at station 1 was the initial order or sequence of vehicles. Then, the order of vehicles at station 2 was compared with that at station 1, the order of station 3 was compared to that at station 2, and so on. Whenever a change in the sequence of vehicles was observed between two successive stations, it was concluded that a passing maneuver had occurred. Each vehicle that was involved in passing was assigned a value "1" in a column in the spreadsheet, and each vehicle that was passed was also assigned a value of "1" in another column.

For each five-minute interval, the number of passing vehicles and the number of vehicles that were passed was counted. The procedure was repeated for all the stations except the first station. For each interval, the number of through vehicles, the number of vehicles that were involved in passing and the number of vehicles that were passed was calculated. Equivalent hourly volume was calculated based on fifteen minute data which in turn was obtained by adding volumes of three overlapping consecutive five minute intervals.

The following discussion presents the analysis of the passing data. First the data were analyzed for all the sites and stations combined. The analysis of individual sites is presented next.

Analysis of Passing Data Combined for all the Sites and all the Stations

The following Figures 4-21 and 4-22 are the plots of the percentage passing at each station for all the sites combined.

The graph shows that maximum passing occurred between stations 1 and 2. Also, for all the sites combined, the rate of passing increased with higher volume. However, some individual sites exhibited different trends.

Analysis of Passing Data for Individual Sites

The following Figures 4-23 through 4-30 are the plots showing the number and percentage of vehicles passing against through hourly traffic volumes along the passing lane segment.

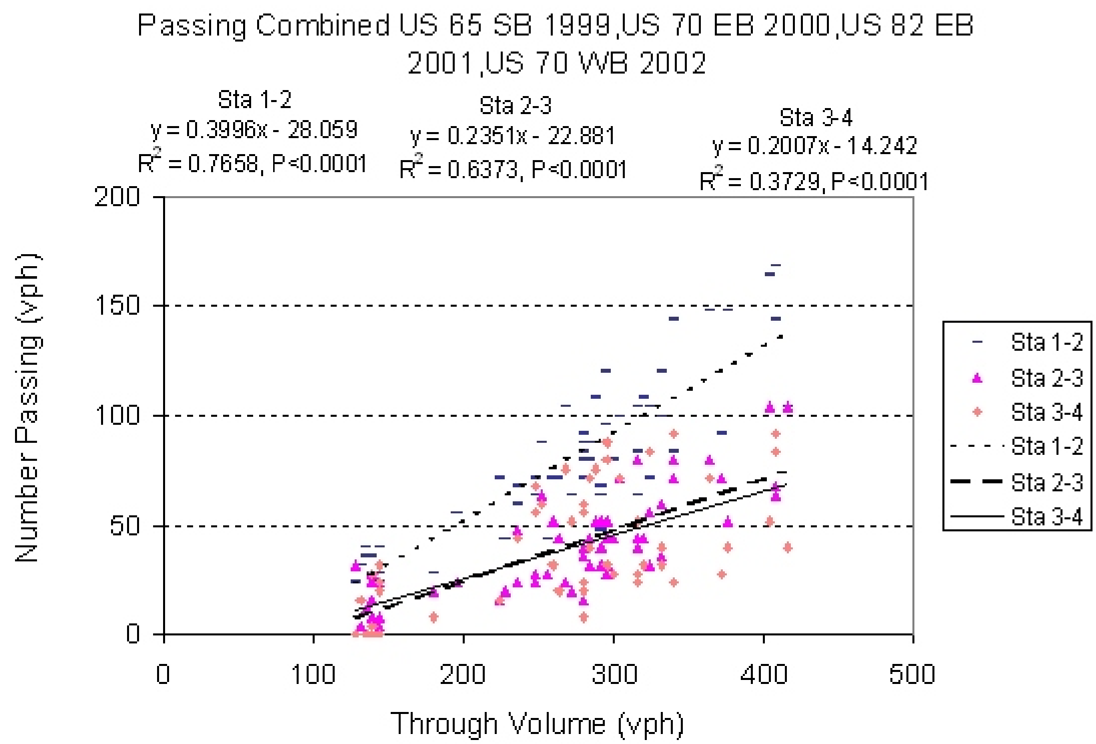


FIG. 4-21 Number of Vehicles Passing for All Sites Combined

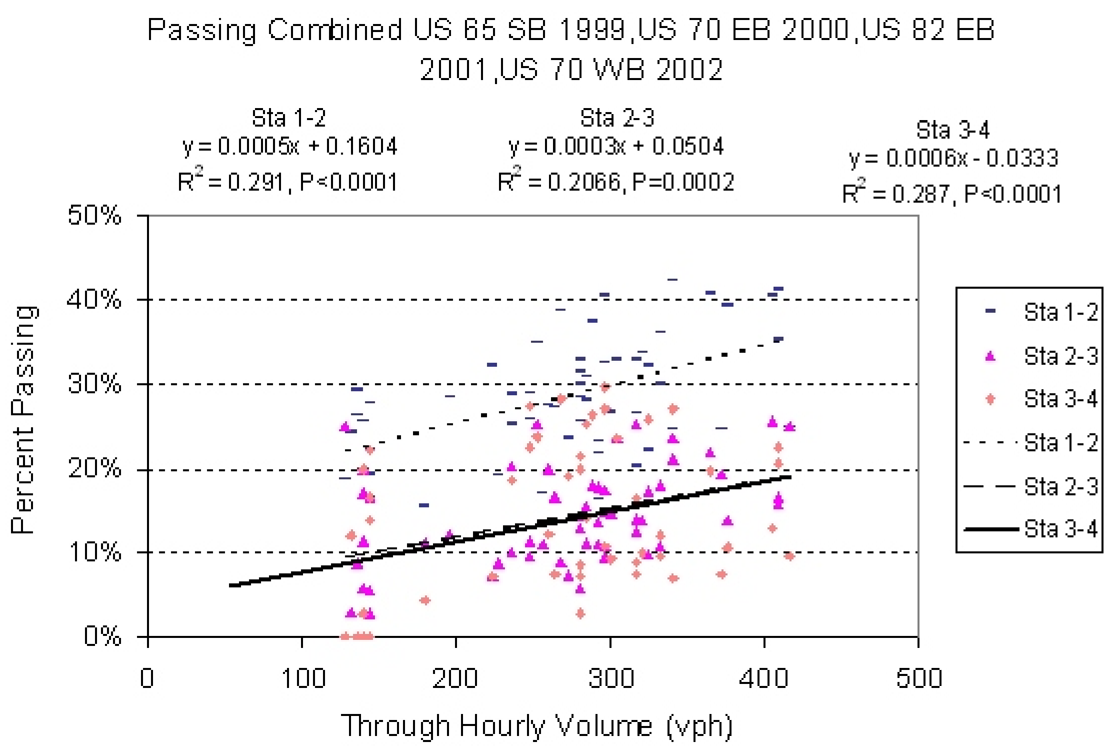


FIG. 4-22 Percent of Vehicles Passing for All Sites Combined

US 65 SB 1999

This site had three stations. The first station had two lanes, one lane for each direction of travel. The second and the third stations had three lanes each, one lane for northbound traffic and two lanes for southbound traffic. Passing maneuvers between stations 1 and 2 were much higher than that between stations 2 and 3.

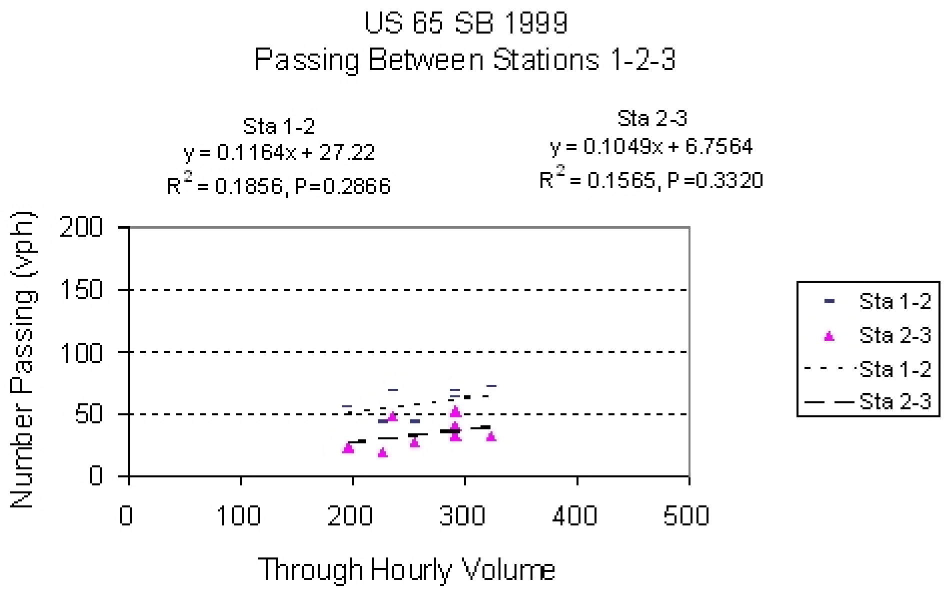


FIG. 4-23 Number Passing for US 65 SB 1999

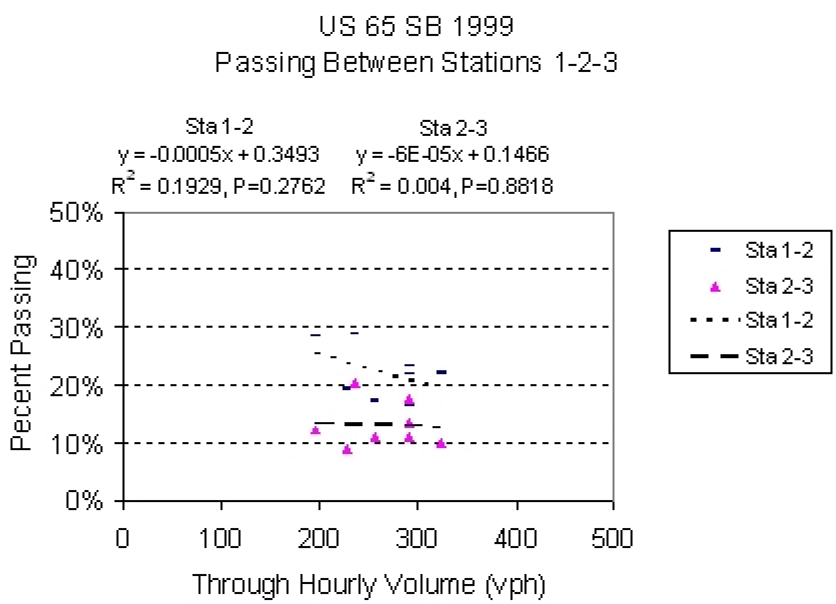


FIG. 4-24 Percent Passing for US 65 SB 1999

US 70 EASTBOUND 2000

This site had four stations. The first station had two lanes, one lane for each direction of travel. The second and the third stations had three lanes, one lane for westbound traffic and two lanes for eastbound traffic. Maximum passing occurred between stations 1 and 2 (see Figures 4-25 and 4-26).

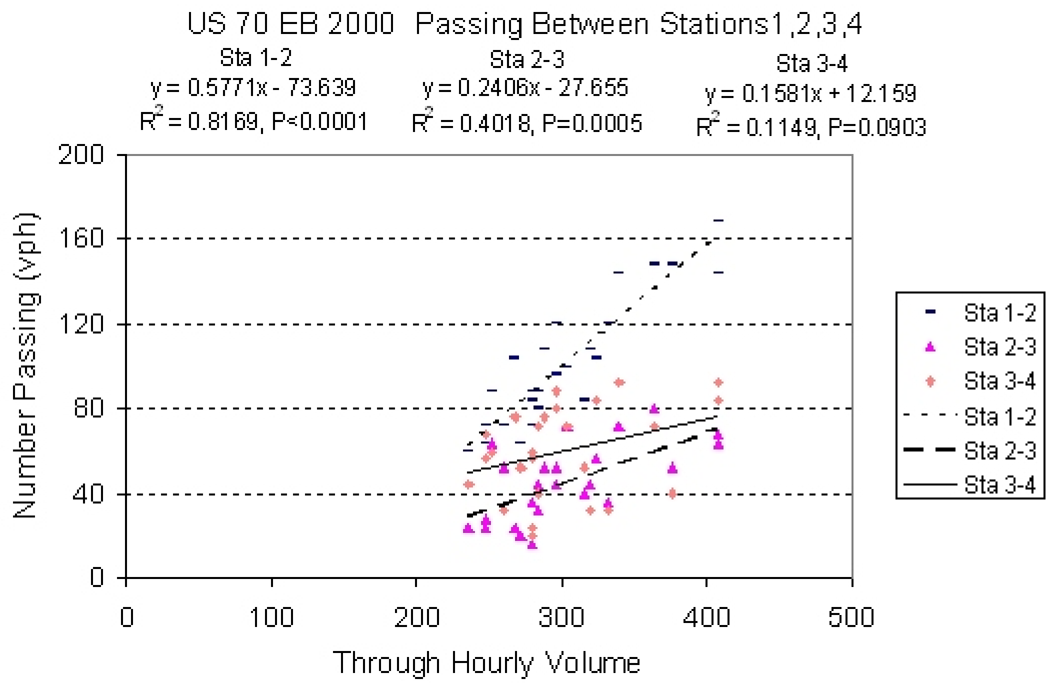


FIG. 4-25 Number Passing for US 70 EB 2000

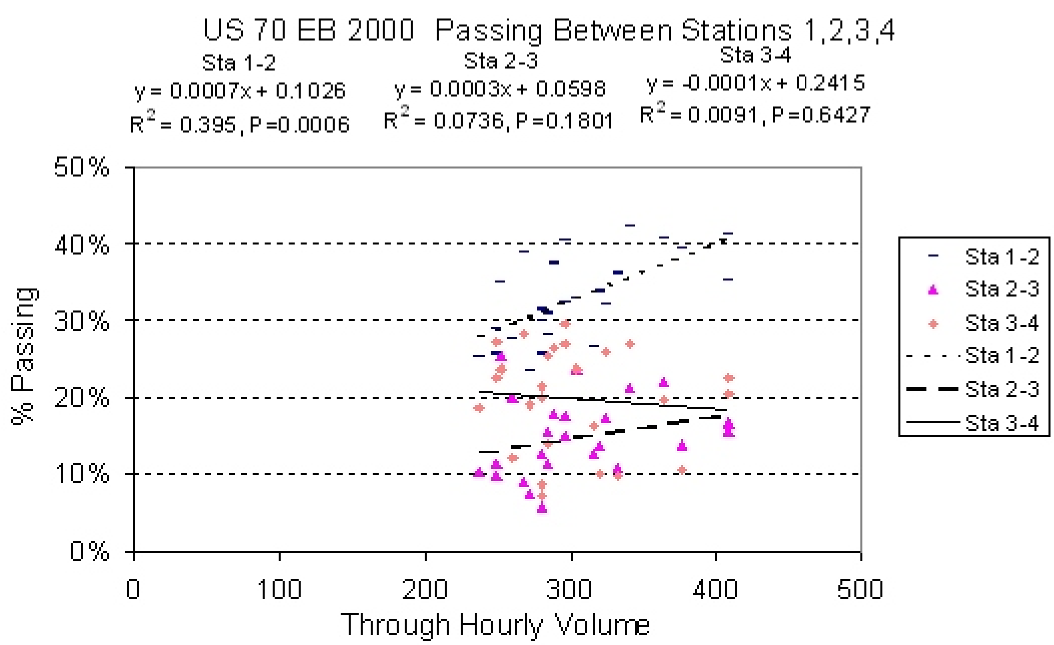


FIG. 4-26 Percent Passing for US 70 EB 2000

US 82 EASTBOUND 2001

This site had four stations. The first, the second and the fourth stations were located on two-lane section of the segment, having one lane for each direction of travel. The second station had three lanes, one lane for westbound traffic and two lanes for eastbound traffic. As shown in the Figures 4-27 and 4-28, maximum passing occurred between stations 1 and 2. However, at this site, the volumes were confined to a very narrow range.

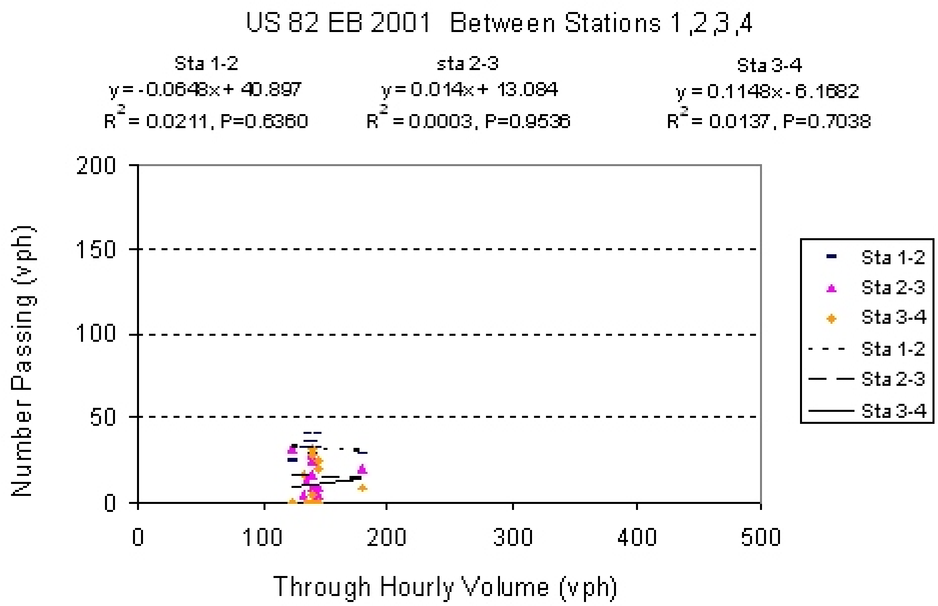


FIG. 4-27 Number Passing for US 82 EB 2001

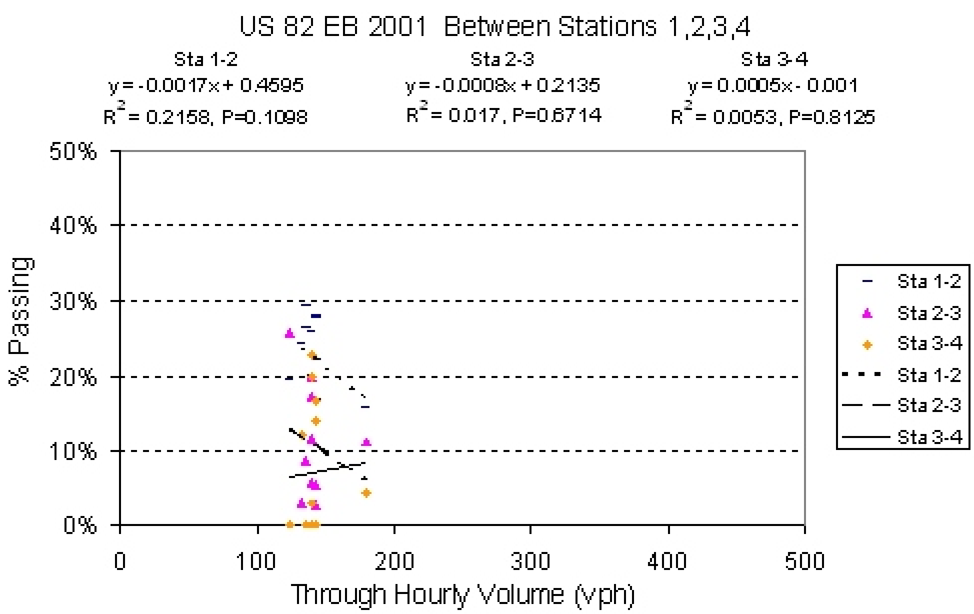


FIG. 4-28 Percent Passing for US 82 EB 2001

US 70 WESTBOUND 2002

This site had four stations. The first and the fourth stations were located on two-lane section of the segment, having one lane for each direction of travel. The second and the fourth stations had three lanes, one lane for eastbound traffic and two lanes for westbound traffic. The passing rate was highest between stations 1 and 2. The passing between stations 2 and 3 increased dramatically as volumes increased (see Figures 4-29 and 4-30).

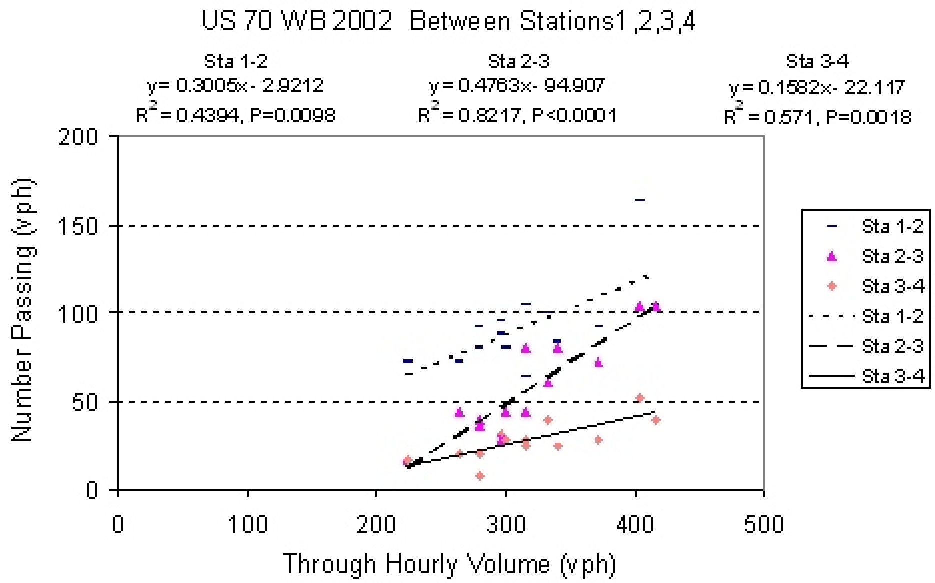


FIG. 4-29 Number Passing for US 70 WB 2002

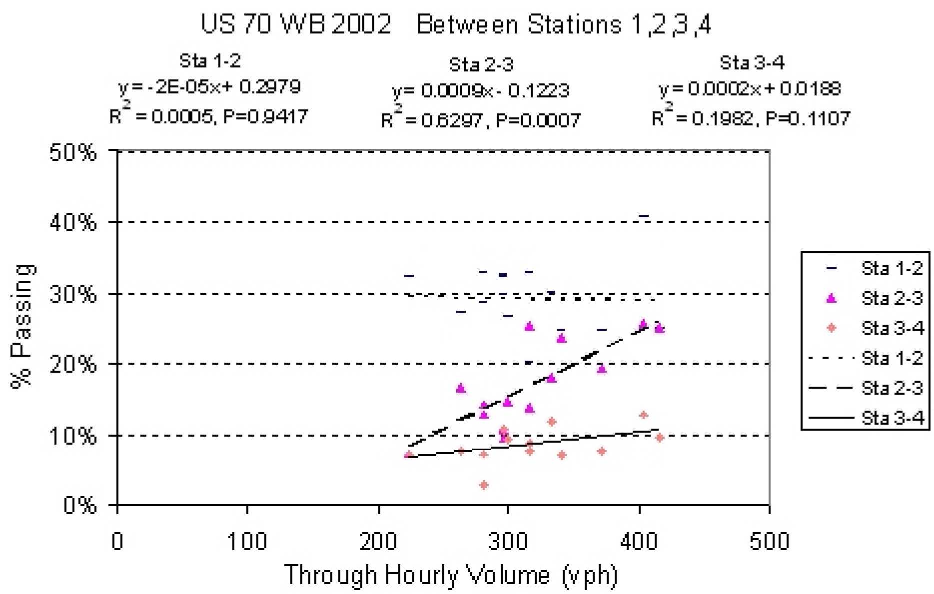


FIG. 4-30 Percent Passing for US 70 WB 2002

Analysis Passing Lane Influence on Passing Maneuvers

The researchers explored the effects of volume and the length of the passing lane on the passing maneuvers. The equations that were obtained from the passing data analysis of each study site were used to calculate the number (Table 4-5) of vehicles and percent (Table 4-6) of vehicles passing for 250, 350 and 450 vph volumes.

Table 4-5 Number of Vehicles Passing Predicted from Equations

Study Site	Volume	Station 1-2	2-3	3-4
US 82 EB 2001	250	25	17	23
	350	*	*	*
	450	*	*	*
US 65 SB 1999	250	56	33	
	350	68	43	
	450	80	54	
US 70 WB 2002	250	72	24	17
	350	102	72	33
	450	132	119	49
US 70 EB 2000	250	69	32	52
	350	126	57	67
	450	183	81	83

Note: The entries marked * were out of range of the volume range of the data.

Table 4-6 Percent of Vehicles Passing Predicted from Equations

Study Site	Volume	Station 1-2	2-3	3-4
US 82 EB 2001	250	3.5	1.4	12.4
	350	*	*	*
	450	*	*	*
US 65 SB 1999	250	22.4	12.9	na
	350	17.4	12.3	na
	450	12.4	11.7	na
US 70 WB 2002	250	29.3	10.3	6.9
	350	29.1	19.3	8.9
	450	28.9	28.3	10.9
US 70 EB 1999	250	27.8	13.5	21.7
	350	34.8	16.5	20.7
	450	41.8	19.5	19.7

Note: The entries marked * were out of range of the volume range of the data.

Figure 4-31 is a plot of projected number of vehicles passing and volume. The following Figure 4-32 is a plot of projected percent of vehicles passing and volume.

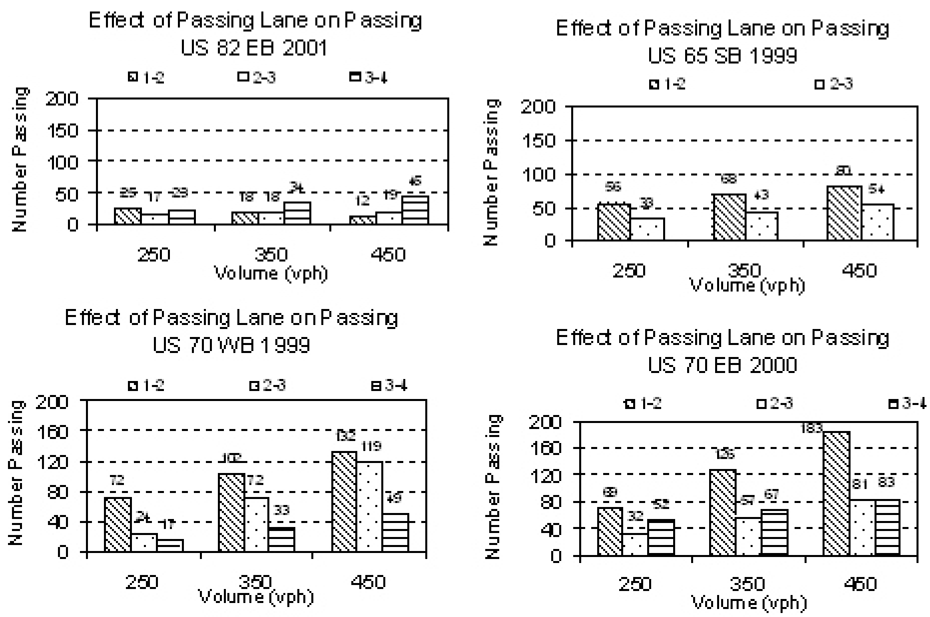


FIG. 4-31 Number of Vehicles Passing

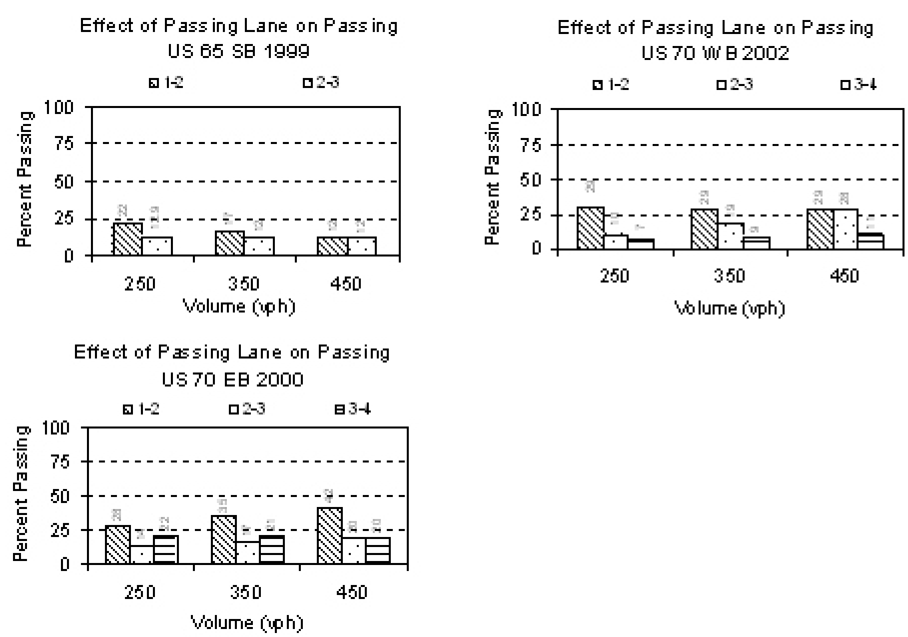


FIG. 4-32 Percent of Vehicles Passing

The following observations could be drawn from above plots.

1. For a passing lane segment, highest passing occurred between stations 1 and 2.
2. Past station 2 (1.5 km, or 0.9 mi), the amount of passing seemed to stabilize or decline.
3. Higher volumes resulted in increased passing maneuvers.

ANALYSIS OF CRASH DATA

The crash attributes such as severity and type of collision were compared with corresponding statewide crash attributes to find out if the presence of passing lane influenced any parameters. The crashes in the transition zones and in the segments were analyzed separately.

Crashes in Transition Zones

As previously illustrated in Figure 3-8, the passing lane segments studied had five different types of transition zones: Enter-Inside, Enter-Outside, End-Outside, End-No head-on left turning lane, End-Head-on with buffer, and End-Head-on without buffer.

To calculate crash rates in the transition zones, instead of using length, the total number of transitions encountered within the respective passing segment was incorporated into the formula. Thus the crash rate obtained was per million vehicles per transition.

From the analysis of the AHTD crash data, it was found that 77 crashes took place in the transition zones. For whatever type of transition zone, the crash could have occurred either in the Enter (diverge) taper or in the End (merge) taper. Table 4-7 lists crash rates at various types of transition zones.

Table 4-7 Crash Rate in Transition Zones

Type of Taper	Transition Zone Type and Number	Average Daily Volume	Total Number of Crashes	Crash Rate per 10^6 Vehicles
Enter	Inside (8)	3320	3	0.06920
Enter	Outside (46)	5118	25	0.08053
End	No Head-on Outside (28)	4305	23	0.17294
End	No Head-on Left Turn (1)	4980	2	0.23561
End	Head-on without Buffer (6)	3099	1	0.04310
End	Head-on with Buffer (17)	5419	23	0.14259

Note: The number in the bracket indicates the number of transitions encountered on the passing lanes under study.

There were too few instances of three types of tapers -- Enter-Inside, End-Head-on without buffer, and End-No head-on left turn lane -- to perform any meaningful analyses. It could be observed from the table that the crash rates of enter tapers were lower than that of end tapers. The crashes were analyzed by crash severity and type of collision.

END: HEAD-ON WITH BUFFER

As shown in Figure 3-1d, the merging maneuver involved merging of fast moving vehicles in the inside lane with the slow moving vehicles in the outside lane. This type of transition was provided at 18 locations on the passing lane segments under study. During the previous five years, 23 crashes occurred within these transition zones. The following Table 4-8 describes these crashes as per crash severity.

Table 4-8 End Head-on with Buffer Crashes by Severity

Crash Severity Code	Description of Injury	Number of Crashes
1	Fatal	1
2	Injury Severe	10
3	Injury Moderate	0
4	Injury Possible	3
5	Property Damage	9

The following Figure 4-33 shows crash severity types as a percentage of total number of crashes.

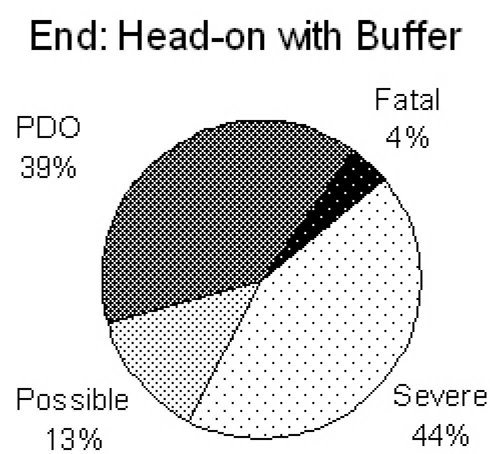


FIG. 4-33 End Head-on with Buffer Crashes by Severity

Among the types of severity, it could be seen from the plot that severe injury was the highest category. Table 4-9 describes these crashes as per the type of collision.

Table 4-9 End Head-on with Buffer Crashes by Type of Collision

Collision Code	Description	Number of Crashes
0	Single Vehicle	16
9	Head-on	2
17	Right Angle	5

Most of the crashes were single vehicle type. These may not be related to the presence of a passing lane.

END: OUTSIDE

As shown in Figure 3-1a, the merging maneuver involved merging of slow moving vehicles in the outside lane with fast moving vehicles in the inside lane. This type of transition was provided at 27 locations on the passing lane segments studied. During the previous five years, a total of 23 crashes occurred within these transition zones. Table 4-10 describes these crashes as per crash severity. Figure 4-34 shows crash severity types as a percentage of total number of crashes.

Table 4-10 End Outside Crashes by Severity

Crash Severity Code	Description	Number of Crashes
1	Fatal	0
2	Severe Injury	7
3	Moderate Injury	0
4	Possible Injury	4
5	Property Damage	12

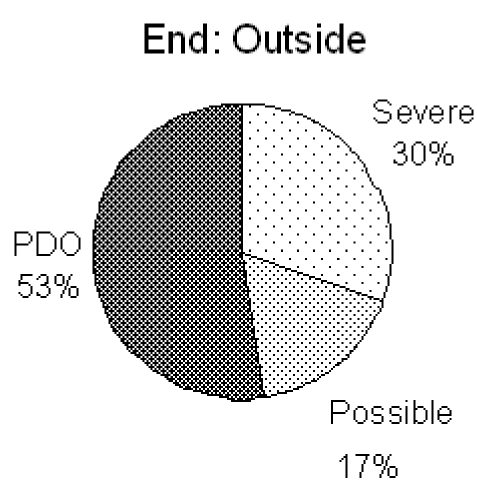


FIG. 4-34 End Outside Crashes by Severity

The pie chart shows that excluding PDO crashes, more were categorized as severe. The following Table 4-11 describes these crashes as per the type of collision.

Table 4-11 End Outside Crashes by Type of Collision

Collision Code	Description	Number of Crashes
0	Single Vehicle	11
9	Head-on	1
16	Rear End	3
17	Right Angle	4
18	Sideswipe S.D.	1
99	Unknown	3

For this analysis, single vehicle crashes could be attributed solely to the driver's mistake. Among the other collision types, it can be seen that right angle and rear end collisions were more common than any other type. The proportions of head-on and of sideswipe same direction collisions were small.

ENTER: OUTSIDE

This diverging maneuver required slow moving vehicles to shift to the outside lane so that the fast moving vehicles can continue their travel in the same lane and perform the passing maneuver. This type of transition was provided at 46 locations on the passing lane segments studied. During 5 years, a total of 25 crashes occurred within these transition zones. Table 4-12 presents the severity for this type of transition.

Table 4-12 Enter Outside Crashes by Severity

Crash Severity Code	Description of severity	Number of Crashes
1	Fatal	0
2	Severe Injury	10
3	Moderate Injury	3
4	Possible Injury	4
5	Property Damage	8

The following Figure 4-35 shows crash severity types as a percentage of total number of crashes.

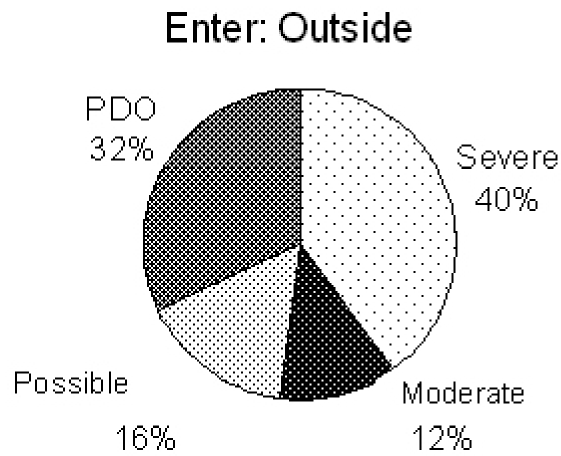


FIG. 4-35 Enter Outside Crashes by Severity

More enter-outside crashes resulted in severe injury than any other outcome. The following Table 4-13 describes these crashes as per the type of collision.

Table 4-13 Enter Outside Crashes by Type of Collision

Type of Collision Code	Description	Number of Crashes
0	Single Vehicle	13
9	Head-on	1
16	Rear End	5
17	Right Angle	2
18	Sideswipe S.D.	1
19	Sideswipe O.D	1
99	Other	2

Single vehicle crashes could be attributed solely to the driver's mistake. Among other collision types, the rear end collisions were prominent. This might be because of failure of the slow moving vehicle to shift to the outside lane. Thus, because of higher speed differential between the slow moving vehicle and the vehicle that was intending to pass the slow moving vehicle, rear end crash might result. The proportion of head-on collisions was also very small.

TRANSITION CRASH SUMMARY

Taken as a whole, the Enter tapers had a lower crash than did the End tapers. The samples of the two End types with the greater sample sizes, End-Outside and End- Head-on with buffer, had similar average volumes. End-Outside has a slightly higher crash rate, but less severe injury than did End-Head-on with buffer.

Crashes in Segments

The analysis of crashes in segments involved comparison of crash rates in passing lane segments with the statewide average crash rates observed on the rural two-lane highways. The analysis also attempted to determine if the crashes followed any typical trend with respect to crash attributes such as crash severity and type of collision. The calculated crash rates are in Table 4-14.

The crash rates were plotted against their respective traffic volumes to examine the relationship between crash rate and AADT. Figure 4-36 is a plot of crash rates in the segment against corresponding traffic volumes.

The statewide crash rates on rural two-lane highways for years 1995 through 1999 were obtained from the AHTD database. The results are presented in Table 4-15. The statewide average AADT and average crash rates were marked on the plot of passing lane crashes.

Table 4-14 Crash Rates on Road Segments with Passing Lane

Route	Section	AADT (vpd)	Length of Segment (miles)	Number of Crashes	Number of Usable Years	Crash Rate per MVM
1	13	6955	1.11	31	5.0000	2.2003
15	3	1800	2.87	2	1.5833	0.6699
15	5	2650	2.21	2	2.2500	0.4158
15	6	2450	1.9	4	2.1667	1.0865
62	8	4100	2.44	8	4.4167	0.4961
62	12	3340	5.83	38	4.6667	1.1457
63	1	4980	4.60	47	4.6667	1.2045
65	1	7180	5.32	123	5.0000	1.7644
69	2	3340	3.36	7	5.0000	0.3418
70	9	7750	10.4	133	5.0000	0.9042
70	10	9210	5.32	93	5.0000	1.0400
82	1 a	8300	1.20	2	1.1667	0.4715
82	1 b	8300	1.27	2	1.1667	0.4455
82	1 c	4350	1.21	2	3.0000	0.3470
82	1 d	3640	1.20	5	5.0000	0.6272
82	1 e	1642	1.18	5	5.0000	1.4140
82	4	4300	4.67	12	2.2500	0.7276
82	5	4525	5.24	17	2.2500	0.8730
82	7	3400	2.80	2	1.8333	0.3140

Table 4-15 Statewide Crash Rates on Two-Lane Rural Highways

	Year				
	1995	1996	1997	1998	1999
Number of crashes	14705	14410	13392	13235	12923
Average crash rate	1.49	1.50	1.38	1.36	1.33
Average AADT	1879	1815	1854	1859	1879

NOTE: Average AADT for 5 years = 1857 vpd
Average crash rate for 5 years = 1.41 MVM

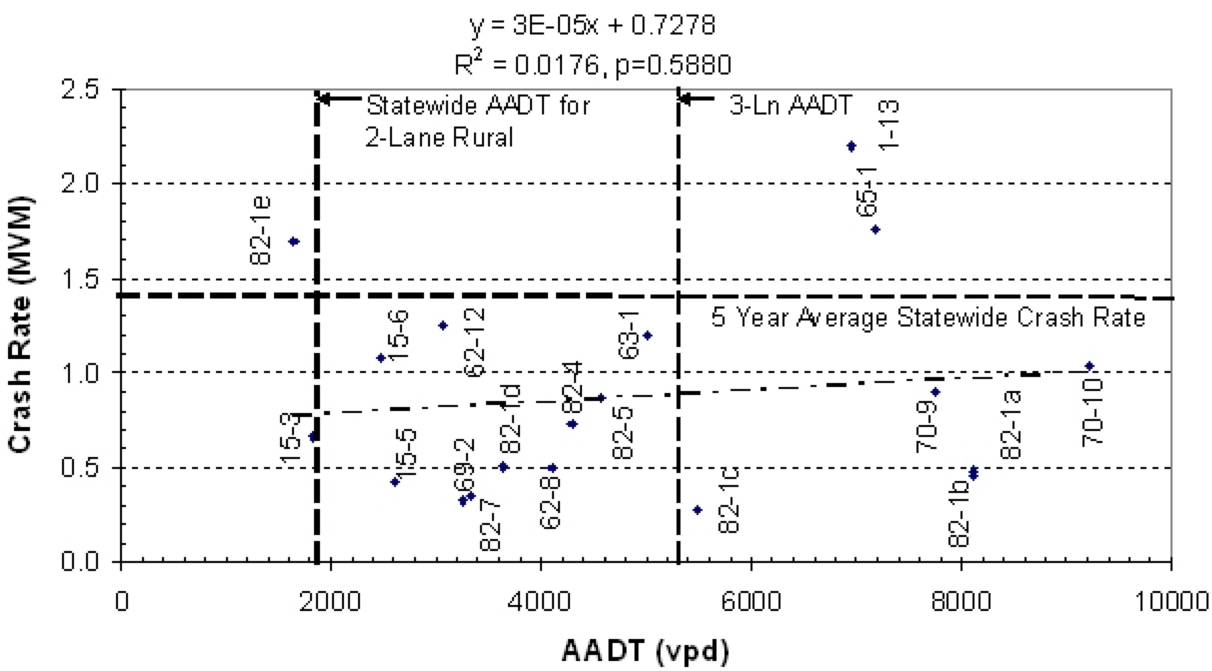


FIG. 4-36 Crash Rates in Segments

The following observations were made.

1. Even though most of the passing lane segments had AADT higher than the statewide average for two-lane rural roads, the crash rates of passing lane segments were usually less than the statewide average for two-lane rural roads.
2. The crash rate of the passing lane segments exhibited a weak trend of increasing with volume. If the trend line were extended, the passing lane crash rate would exceed the statewide average at higher volumes. The projected crash rate trend line would cross the statewide crash rate at an AADT of 22,740 vpd.
3. The crash rates of three passing lane segments (1-13, 65-1 and 82-1e) exceeded the state average. The researchers did not identify any obvious reasons for this.

COMPARISON WITH STATEWIDE CRASH TOTALS BY SEVERITY

The AHTD crash database was queried using the following criteria.

Number of lanes =2

Crash in construction zone= 2 (no)

Crash in city = 2 (no)

Crash severity codes = 1, 2, 3, 4, and 5

These criteria helped eliminate the crashes occurring on highways having a number of lanes other than two, crashes in construction zones; and crashes in city limits. The results are listed in Table 4-16.

Comparing crash severity attributes of the crashes that took place in passing lanes with the statewide crash averages, it could be seen that the percentages were somewhat similar. The passing lane severe injury rate was slightly higher than the statewide average, and the PDO rate was slightly lower.

Table 4-16 Passing Lane and Overall Crash Rates per Severity

	Fatal	Severe Injury	Moderate Injury	Possible Injury	Property Damage Only
AHTD Crash Severity Code	1	2	3	4	5
Passing Lane					
Number	14	128	65	72	256
Percentage	2.62	23.93	12.15	13.46	47.85
Statewide Rural 2-Lane					
Percentage	2.23	17.82	12.93	14.98	52.04

COMPARISON WITH STATEWIDE CRASH TOTALS BY THE TYPE OF COLLISION

The AHTD crash data were sorted using the following criteria.

Number of lanes =2

Crash in construction zone= 2 (no)

Crash in city = 2 (no)

Type of collision codes = 0, 9, 16, 17, 18, 19, 24, 98, and 99

These criteria helped eliminate the crashes occurring on highways having a number of lanes other than two, crashes in construction zones; and crashes in city limits. The results are listed in Table 4-17.

Comparing collision type attributes of the crashes that took place in passing lanes with the statewide crashes averages, it could be seen that the percentages were similar.

Table 4-17 Passing Lane and Overall Crash Rates per Type of Collision

	Single vehicle	Head on	Rear end	Right angle	Sideswipe same direction	Sideswipe opposite direction	Backing	Other	Unknown
AHTD Crash Codes	0	9	16	17	18	19	24	98	99
Passing Lane									
Number	276	16	84	62	31	24	0	11	31
%	51.59	2.99	15.70	11.59	5.79	4.49	0	2.06	5.79
Statewide Rural 2-Lane									
%	54.13	3.33	15.54	10.68	4.47	4.66	0.23	0.95	6.00

ANALYSIS OF SEGMENT CRASHES BY LOW AND HIGH VOLUME GROUP

The passing lane segments were arranged in ascending order of AADT and plotted by the magnitude of the volume. The passing lane segments were divided in to higher and lower volume groups. Figure 4-37 shows how the grouping was done. A sizeable break in the distribution was identified between routes 82-1c and 1-13. Thus, all the routes that had AADT of 5483 vpd or less were classified in to the lower volume group, and all the routes that had AADT of 6955 vpd or more were classified in to the higher volume group. Table 4-18 illustrates comparison of crashes as per crash severity.

Table 4-18 Analysis of Low and High Volume Group Segments by Crash Severity

	Fatal	Severe Injury	Moderate Injury	Possible Injury	Property Damage	Total
AHTD Crash Severity Code	1	2	3	4	5	
Low Volume						
Total	6	37	31	13	64	151
Proportion	0.040	0.245	0.205	0.086	0.424	1.00
High Volume						
Total	8	91	34	59	192	384
Proportion	0.021	0.237	0.089	0.154	0.500	1.00

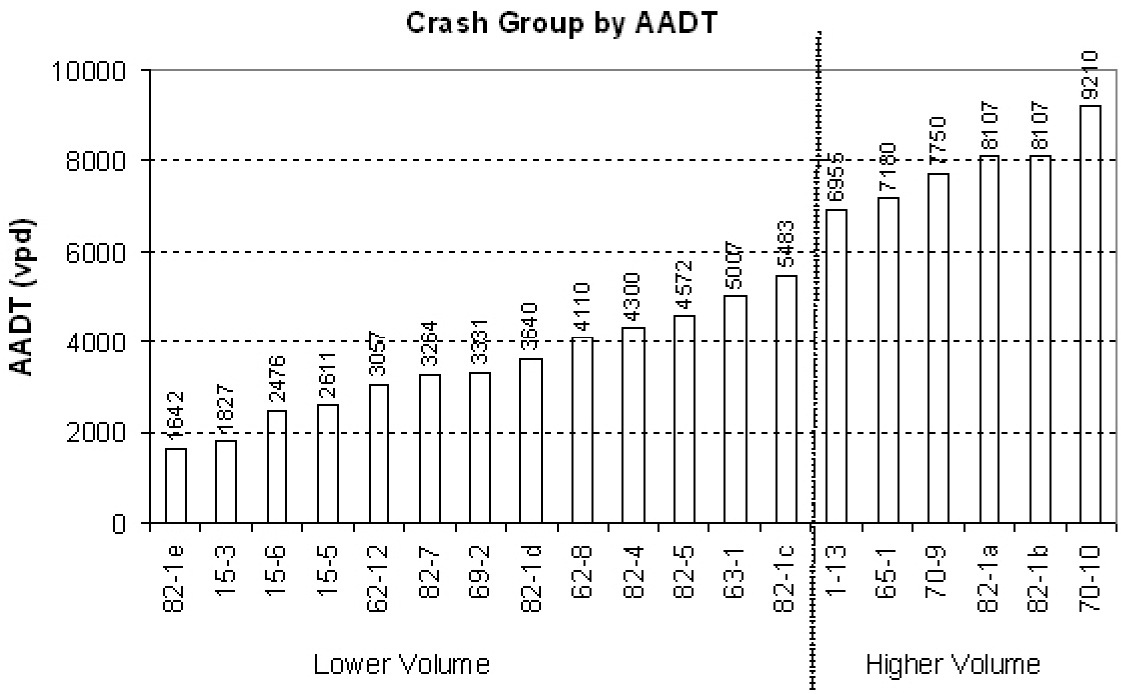


FIG. 4-37 Analysis by Low and High Volume Group Segments

The following could be observed from the comparison of low volume and high volume by crash severity.

1. The lower volume group had higher moderate injury rate.
2. The higher volume group had higher rate of possible injury and PDO.

Table 4-19 illustrates comparison of crashes as per the type of collision.

Table 4-19 Analysis of Low and High Volume Group Segments by Type of Collision

	Single vehicle	Head on	Rear end	Right angle	Sideswipe same direction	Sideswipe opposite direction	Backing	Other	unknown
AHTD Crash Code	0	9	16	17	18	19	24	98	99
Low Volume									
Total	91	3	15	17	8	7	0	2	8
Proportions	0.603	0.02	0.099	0.113	0.053	0.046	0.0	0.013	0.053
Sum of all crashes = 151									
High Volume									
Total	185	13	69	45	23	17	0	9	23
Proportions	0.482	0.034	0.18	0.117	0.06	0.044	0.0	0.023	0.06
Sum of all crashes = 384									

The following could be observed from the comparison of low volume and high volume by crash severity.

1. The lower volume group had higher proportion of single vehicle collisions.
2. The higher volume group had higher proportion of rear end collisions.
3. The proportion of right angle and sideswipe (both same and opposite directions) was almost similar in the both the crash groups.

ANALYSIS OF SEGMENT CRASHES BY CRASH RATE GROUP

The passing lane segments were divided in to low, medium, and high crash rate groups. Figure 4-38 illustrates how the classification was done.

The passing lane segments were arranged in ascending order of the crash rate and plotted. The sizeable breaks in the distribution were identified between 82-1d and 15-3, and 62-12 and 82-1e. Thus, all the routes that had the crash rate less than 0.5018 were classified in to lower crash rare group; all the routes that had the crash rate from 0.66 to 1.2517 were classified in to medium rate group, and all the routes that had crash rates greater than 1.6968 were classified in to higher crash rate group. Table 4-20 illustrates comparison of crashes as per crash severity.

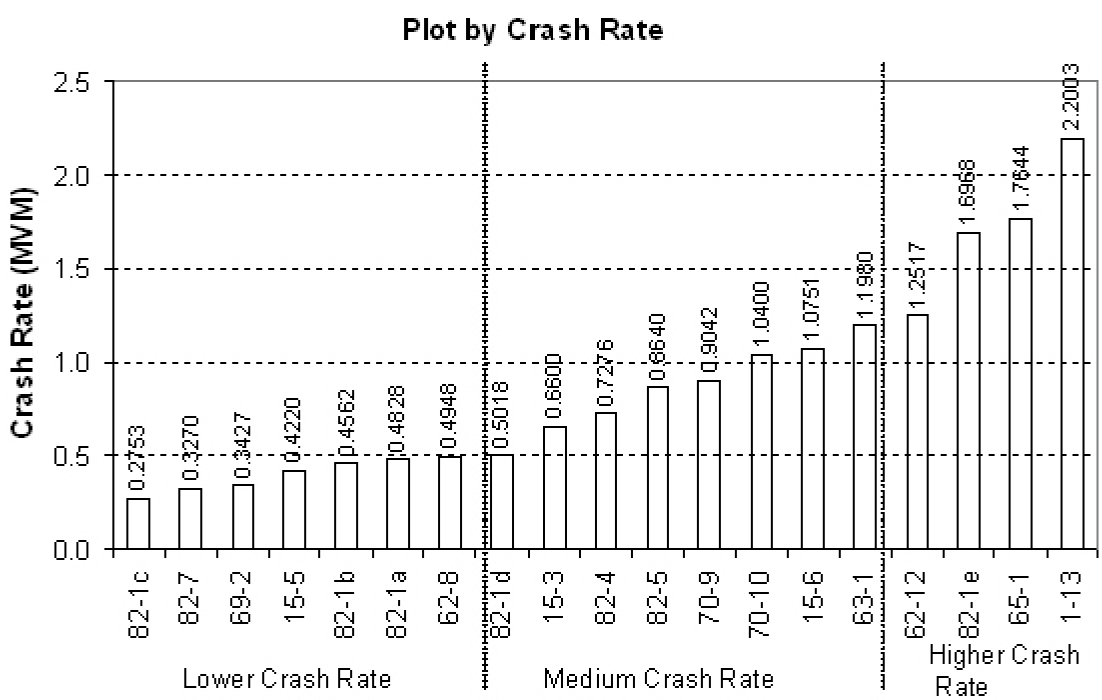


FIG. 4-38 Classification in to Low, Medium, and High Crash Rate Groups

Table 4-20 Analysis of Segment Crash Rate Group by Crash Severity

	Fatal	Severe Injury	Moderate Injury	Possible Injury	Property Damage	Total
AHTD Crash Severity Code	1	2	3	4	5	
Low Crash Rate						
Total	0	9	4	2	14	29
Proportions	0.0	0.31	0.138	0.069	0.483	1.0
Medium Crash Rate						
Total	10	79	46	46	165	346
Proportions	0.029	0.228	0.133	0.133	0.477	1.0
High Crash Rate						
Total	4	40	15	24	77	160
Proportions	0.025	0.250	0.094	0.150	0.481	1.0

The following could be observed from the comparison of low volume and high volume by crash severity.

1. The low crash rate group had no fatalities and lowest rate possible injuries.
2. The high crash rate group had lowest proportion of moderate injuries.
3. The proportion of property damage and severe injury was almost the same in all the crash rate groups.

The following Table 4-21 illustrates comparison of crashes as per the type of collision.

Table 4-21 Analysis of Segment Crash Rate Group by Type of Collision

	Single vehicle	Head on	Rear end	Right angle	Sideswipe same direction	Sideswipe opposite direction	Backing	Other	unknown
AHTD Crash Codes	0	9	16	17	18	19	24	98	99
Low Crash Rate									
Total	16	1	4	5	2	0	0	0	1
Proportions	0.552	0.034	0.138	0.172	0.069	0.0	0.0	0	0.034
Sum of all crashes = 29									
Medium Crash Rate									
Total	183	11	53	37	19	19	0	7	17
Proportions	0.529	0.032	0.153	0.107	0.055	0.055	0	0.02	0.049
Sum of all crashes = 346									
High Crash Rate									
Total	77	4	27	20	10	5	0	4	13
Proportions	0.481	0.025	0.169	0.125	0.063	0.031	0	0.025	0.081
Sum of all crashes = 160									

The following could be observed from the comparison of low volume and high volume by crash severity.

1. The proportion of single vehicle crashes, head-on, rear end and right angle collisions was almost the same in all the three groups.
2. The lower crash rate group had no sideswipe opposite direction type of collisions.

CRASH SUMMARY

A number of queries were conducted to determine if there were differing crash attributes among different subclasses of passing lane roadways. No significant differences were apparent, other than the passing lane segments as a group had lower crash rates than did rural two-lane highways in Arkansas.

CHAPTER 5
SUMMARY AND CONCLUSION

Passing lanes are provided on two-lane rural highways to mitigate congestion by providing increased passing opportunities. This study examined traffic on rural passing lane segments in Arkansas, with a particular but not exclusive emphasis on 3-lane alternate passing designs.

Although a number of 3-lane alternate passing lane segments were identified in Arkansas, attributes peculiar to each of the sites restricted the ability to obtain quality data. The available sites did not have the needed combinations of geometric and traffic characteristics. Nevertheless, some results were obtained.

FINDINGS SUMMARIZED

This research studied the following operational parameters of passing lanes, attempting to focus on three-lane alternating sections.

1. Speed
2. Platooning
3. Passing
4. Safety
5. Transition design

Speed

Studies cited in the literature review had some conflicting conclusions. The study by Enberg and Pursula concluded that the passing lanes allow an increase in traffic speed. However, the study conducted by Harwood et al. noted that the effect of passing lanes on the traffic speeds varies widely from site to site, and the study concluded that the vehicle speeds were more strongly influenced by local geometrics (grade, alignment, curvature) of the road than by presence of passing lane.

The speed data were analyzed for US 70 WB 1999, US 70 EB 2000, US 82 EB 2001 and US 70 WB 2002. The study sites generally exhibited a modest increase in average speed immediately after entering the passing lane segment. After proceeding past the 1.5 km (0.9 mi.) data collection station, the speed trends at different study sites varied. Since speed patterns varied among the sites studied, it was hypothesized that factors such as grade, traffic volume, and curvature possibly masked the effect of a passing lane on the speed of the traffic. Thus, the results obtained from this study seemed to concur with the findings of Harwood et al.

Platooning

The amount of platooning of the vehicles was quantified over the entire length of the passing lane segments studied. The researchers tried to determine the relationship between the traffic volume and the platooning that occurred between successive pairs of stations.

A study by Harwood et al. concluded that passing lanes with lengths between 0.25 to 0.75 miles are most effective for flow rates up to 200 vph in one direction of travel. For very high flow rates such as 700 vph in one direction of travel, the design length of passing lanes ranges from 1.0 to 2.0 miles. The authors also stated that the passing lanes longer than 1.0 mile might not be desirable. A simulation study by Enberg and Pursula found that optimal passing length varied from 1 km (0.62 miles) for a one-direction flow rate of 500 vph to 2 km (1.24 miles) for a 2000 vph flow rate. In general, the effective length of a passing lane segment increases somewhat as volume increases.

The platooning data were studied for US 70 WB 1999, US 70 EB 2000, US 82 EB 2001 and US 70 WB 2002. As the data for US 82 EB 2001 were limited, the statistical analysis was conducted only on the other three study sites. The following discussion presents the observations obtained from the analysis of the platooning data.

Passing lanes reduced the platooning as the traffic entered the passing lane segment. The percentage of vehicles in platoon decreased on an average from 48% immediately upstream of a passing lane to 34% within passing lane. The reduction in the platooning continued even downstream of passing lane segment; however, the rate of reduction was very low.

The statistical tests concluded that the platooning at station 1 (the beginning of the passing lane) was significantly higher than the platooning at the other stations located downstream. The platooning at stations 3 and 4, located 3 km (1.9 miles) and 4.5 km (2.8 miles) respectively downstream of station 1, was not found to be statistically significant from each other. Thus, it could be concluded that a significant reduction in the platooning occurred within first 1.5 km (0.9 miles) length of the passing lanes. For lower volumes, decreases in platooning diminished after that. For higher volumes, platooning tended to stabilize after about 3.0 km (1.9 miles), and for the range of volumes observed, platooning did not decrease significantly even if a longer passing lane were provided.

The effects of volume on platooning was studied, with the help of trend line equations obtained from the plot of platooning and respective volume for each individual site. For all the sites, the platooning increased with an increase in volume.

Passing Maneuvers

Passing lanes provide additional opportunities for passing slow moving vehicles. This study tried to determine the relationship between the length of passing lane and the passing maneuvers undertaken. The study also tried to find out the relationship between the traffic volume and the passing maneuvers.

Harwood et al. (TRR 1026, pp 31-39) proposed that the passing rate decreases further into the passing lane. However, Enberg and Pursula (TRR 1572, pp 33-42) found that the passing lane length had a negligible effect on the passing maneuvers. In this study, the highest number of passing maneuvers took place between stations 1 and 2 (within first 1.5 km or 0.9 mi). The passing maneuvers decreased between successive stations located downstream.

The effect of volume on the passing was studied with the help of trend line equations obtained from the plot of passing and respective volume for each individual site. Passing maneuvers increased with the increase in the volume. The model predicted that as volumes increase, higher numbers of passing maneuvers continue to occur further into the passing lane. Thus it could be concluded that higher volume roads need longer passing lanes.

Safety

One of the objectives of providing passing lanes is to improve safety. The study analyzed the crash and volume data. The AADT (weighted by VMT) of all the passing lane segments (5293 veh/day) was higher than the statewide average AADT (1857 veh/day) of rural two-lane, undivided (no control of access) highways. However, the crash rates on most passing lane segments were lower than statewide average for rural two-lane highways. Only three of the passing lane segments studied (Ark 1, section 13; US 65, section 1; and US 82, section 1e) had higher crash rates.

The crash rate on the passing lanes weakly trended upward as volume increased. If the trend line of the passing lane crash rates were projected, it would cross the statewide rural two-lane average rate at an AADT of 22,740 vpd.

When the statewide crashes and the passing lane crashes were compared by crash severity type and collision type, it was found that both the statewide crashes and the passing lane crashes had similar percentages of various severity types and collision types.

The passing lane crashes were divided as per high (> 6900 veh/day) and low (< 5500 veh/day) volume groups to identify if the two groups exhibited different crash patterns. The two groups were compared by crash severity and collision type. The researchers found that the two groups had almost similar crash severity and the type collision patterns.

The passing lane crashes were divided as per high, medium and low crash rate groups to identify if these groups exhibited different crash patterns. The researchers found that these three groups had almost similar crash severity and the type collision patterns.

Thus, it could be concluded that at lower volumes, most of the passing lane segments had lower crash rates than did the average rural two-lane highway. At higher volumes the passing lanes seemed to be somewhat less effective in reducing the crash rate. Therefore, other alternatives such as expansion to a four-lane highway need to be explored.

Transition Design

This study examined a number of variations of transition zone designs. Small sample sizes excluded all but three transition types from analysis and comparisons. The inquiry did not find any notable differences among the performance of the three different transition types.

The reviewed literature included a study that concluded that, depending on downstream design and traffic conditions, passing lanes of 0.4 km to 1.21 km (0.25 miles to 0.75 miles) lengths provide effective downstream distances of 0.32 km to 1.21 km (0.2 miles to 0.5 miles) before percent time delay increases to its original higher value.

CONCLUSION

Findings from this research in part confirmed findings from previous studies conducted elsewhere. The three-lane alternate passing segments studies did seem to provide benefits to the motoring public. Some short term increase in speed and amount of passing was exhibited. The greater benefits seemed to be in the form of decreased platooning and increased safety.

The following observations related to this study were made.

1. Where daily volumes are low, passing lanes may yield a relatively small benefit. Although outside the scope of this study, it may be that for the same volume, a passing lane would

provide more benefits in rugged terrain than on a flat and straight alignment.

2. Where alternating segments truly are present, re-examine the need for any passing lane that continues in excess of approximately 3.0 km (1.9 mi) of length. This study suggests that a rather high volume is needed before extra length produces any great notable degree of extra benefits. It may be that the other direction of travel would benefit more from an earlier termination and "switch" of the direction having the additional lane for passing.
3. Based on experiences during this and other studies that involved crash data analysis, it is suspected that the precision of locating crashes in the state database is currently not adequate to confidently examine transition zone crashes. Given the relatively short length of a transition, it is likely that erroneous location coding caused some crashes which actually occurred in a transition zone to be coded outside of it, and some crashes outside of a transition to be coded within one. If actual crash sites were logged with a global positioning system (GPS), or some other method to achieve higher precision were employed, the resulting precision would allow more confident analyses of crash data for situations where high precision of location is imperative.
4. The study of transitions and passing lane segments would be enhanced by having a larger sample size to control for type of roadside development. If development changed along a segment, it would also be necessary to have more precise recording of crash locations.

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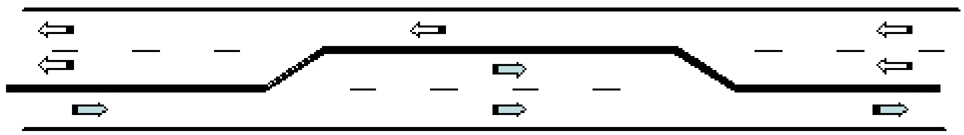
APPENDIX A: Survey Form

SURVEY OF RURAL TWO-LANE HIGHWAY INCREMENTAL IMPROVEMENTS

please respond with checkmarks or short answers

NOTE: The term "3-lane alternate passing design" means a highway which is striped for 2 lanes of travel in one direction and 1 lane in the opposite direction for a certain distance. This segment is immediately followed by another length in which the direction of travel that did have 1 lane is now striped for 2 lanes, and the direction that did have 2 lanes is now striped only for 1 lane.



YES **NO** **1. Does your state/province currently have ...**

☐ ☐ 3-lane alternate passing designs planned or under construction, but not yet open for traffic?

☐ ☐ 3-lane alternate passing designs currently in operation?

2. **What criteria do your agency currently use to justify the following 2-lane rural highway improvements? If you have a certain volume that may trigger the decision, please state it.**

(2a) We consider expanding to a rural 3-lane section when ...

☐ Our agency does not use this type of rural section.

☐ A certain volume is reached; this volume is ____________________

☐ A certain crash rate is reached; this rate is ____________________

☐ Other:

(2b) We consider expanding to a rural 4-lane undivided section when ...

☐ Our agency does not use this type of rural section.

☐ A certain volume is reached; this volume is ____________________

☐ A certain crash rate is reached; this rate is ____________________

☐ Other:

(2c) We consider expanding to a rural 4-lane section (with continuous center turn lane) when ...

☐ Our agency does not use this type of rural section.

☐ A certain volume is reached; this volume is ____________________

☐ A certain crash rate is reached; this rate is ____________________

☐ Other:

(2d) We consider expanding to a rural 4-lane section with a non-traversable median when ...

- ☐ Our agency does not use this type of rural section.
- ☐ A certain volume is reached; this volume is ____________________
- ☐ A certain crash rate is reached; this rate is ____________________
- ☐ Other:

3. Are there any other factors that affect your decision to expand a 2-lane rural highway to 3-lane alternate passing, 4-lane undivided, 4-lane with continuous center turn lane, or 4-lane divided with non-traversable median?

4. If your agency DOES use the 3-lane alternate passing design, then do you have ...

(4a) a general rule or practice for the length of transition when changing from 2-1 lane to 1-2 lane ?

NO☐ **YES**☐ If "yes", then what is it? _____________________

(4b) a general rule or practice for minimum length of a section before transitioning or "switching sides"?

NO☐ **YES**☐ If "yes", then what is it? _____________________

(4c) a general rule or practice for maximum length of a section before transitioning or "switching sides"?

NO☐ **YES**☐ If "yes", then what is it? _____________________

(4d) studies of accidents on or the safety of three-lane alternate passing design highways?

NO☐ **YES**☐ If "yes", then please send us a copy.

(4e) information about the capacity of three-lane alternate passing design rural highways?

NO☐ **YES**☐ If "yes", then please send us a copy.

===

Your name ____________________________ Title __________________

Agency/Dept. ____

Your address ____

____

____

Phone number _________________ Fax number __________________

PLEASE MAIL YOUR SURVEY, WITH ANY ENCLOSURES, TO

J. L. Gattis
Mack-Blackwell Transportation Center
4190 Bell Engineering Center
Fayetteville, AR 72701

thank you for your help THE END

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APPENDIX B: Potential Data Collection Sites

Note: End mile points include transition zone

row #	County Number	County	Di	Ro	Se	Between what 2 cities	Preliminary Begin-End MP (may be wrong !)	#	Comments 11/15/2003	Overall Begin MP	End MP	LENGTH of 3 Ln (mi)	# OF CRASH not in trans.
168	68	St.Francis	1	1	12	north edge of county		3	NO - lacks transition	9.49	10.36	0.87	
57	19	Cross	1	1	13	south of Wynne	not listed	3	YES for S end - lacks transition on N	0.00	1.72	1.11	31
169	69	Stone	5	14	7	east of Mtn View		3	NO - is 2 climbing lanes				
23	6	Bradley	7	15	3	south of US 278 (Warren bypass)	0.00 - 3.21	3	NO - (now US 63, sec 17)				
24	6	Bradley	7	15	3	S of Warren @ Jct. SH 8 (NB accel lan	0.00 - 3.21	3	NO - (now US 63, sec 17)				
25	6	Bradley	7	15	3	north of Hermitage	8.20 - 11.40	3	YES - (now US 63, sec 17); found	18.62	21.94	2.87	2
21	6	Bradley	7	15	4	north of Warren	1.07 - 4.19	3	NO - MP difference on map (now 63, 16)	5.27	7.81	2.56	
35	13	Cleveland	7	15	5	Rye and Pansy (south end)	17.2 for 2.1 mi	3	YES - (now US 63, sec 15); found	5.19	8.40	2.21	2
36	13	Cleveland	7	15	6	Pansy and Calmer (middle section)	11.33 for 3.07 mi	3	YES - (now US 63, sec 15); found	2.64	5.72	1.9	4
33	12	Cleburne	5	25	2	Heber Springs	Not listed	3	NO - only 1 direction				
34	12	Cleburne	5	25	3	Heber Springs	0.0 - 5.67	3	NO - is a SB climbing lane				
8	4	Benton	9	62	2	Avoca	7.70 - 9.95	3	NO - is 2 climbing lanes				
109	45	Marion	9	62	8	west of Yellville	Not listed	3	YES; found const May-Nov 1995	2.11	10.62	2.44	8
66	25	Fulton	5	62	12	Viola to Salem		3	YES; found const Jun-Sep 1997	11.58	19.62	5.83	38
68	25	Fulton	5	63	1	Mammoth Spg to Hardy	2.0 - 9.0	3	YES	2.02	8.71	4.6	47
37	13	Cleveland	7	63	15	north of Calmer (north end)	Not listed	3	NO - under cons't on vid tape				
26	6	Bradley	7	63	17	southwest of Hermitage	Not listed	3	NO - under cons't (SH 15, 3)				
18	5	Boone	9	65	1	jct US 62 to Burlington		3	YES (change MP Nov 1999)	7.91	14.84	5.32	123
179	71	Van Buren	8	65	8	Choctow and Bee Branch		3	NO - has 45 MPH speed limit				
90	33	Izard	5	69	1	nw of Batesville, Mt. Pleasant area		3	NO - under cons't on video tape				
87	32	Independence	5	69	2	northwest of Batesville		3	YES - can use part; part under const;	0	7.5	3.36	7
72	26	Garland	6	70	9	Lonsdale to west	Not listed	3	YES - found no const 1995-1999	4.89	17.30	10.40	137
152	62	Saline	6	70	10	Lonsdale to Benton	Not listed	3	YES - inc'l E end of Garland; found no	0.00	6.43	5.32	93
113	46	Miller	3	82	1	east of Texarkana		3	YES - high vol, flat section; found	3.64	18.68	6.04	15
										3.72	4.92	1.20	
										5.9	7.17	1.27	
										9.53	10.74	1.21	
										13.6	14.80	1.20	
										17.47	18.65	1.18	
38	14	Columbia	7	82	4	east part of county	5.8-13.96	3	YES - found const before Oct 1997	5.78	14.19	4.67	12
173	70	Union	7	82	5	Marysville to east	Not listed	3	YES - found const before Oct 1997	2.16	14.47	5.24	18
176	70	Union	7	82	7	east of Strong	Not listed	3	YES - found const before Mar 1998	6.85	10.06	2.80	2
		LaFayette		82		west of Lewisville	new	3	NO - new ~ MP 3, 2 ln EB; 2 ln WB near Lewisville				
136	58	Pope	8	7T	14T	south of Russellville	Not listed	3	NO - is 3 Ln, TWLTL				