Alternating Passing Lane Lengths

J. L. Gatzis, Ranjit Bhave, and Lynette K. Duncan

This paper reports on a study of passing lane operations, with a focus on continuous three-lane cross sections with alternating passing lanes (three-lane alternate passing or 3LP) in Arkansas. The examined aspects include effective geometric design, the effect on platooning, passing speed, and passing lane crash rates. Five sets of field data were collected at four rural sites. After a vehicle entered the passing lane, platooning decreased and eventually stabilized. Passing activity was greatest at the beginning of the segments. Speed patterns were found to vary among sites, but average speed rose when a vehicle entered the passing lane section. Five years of crash data from 19 sites were used. Even though the volumes for the passing lane segments were higher than the state average volume for rural two-lane roads, the passing lane crash rates were generally lower than the statewide average crash rate for rural two-lane roads.

As traffic volumes continue to grow, rural two-lane roadway users are experiencing increasing delay, frustration, and accidents. One response to these problems is the construction of passing lanes, which allow faster drivers to get around slower vehicles without encroaching into the lane for oncoming traffic.

Passing lanes can be provided in a number of ways. Roadways constructed with a continuous three-lane cross section and alternating passing lanes (three-lane alternating passing or 2+1 road) have been viewed as an "alternative to two- or four-lane roads." For situations in which a two-lane road is not providing the desired level of safety or mobility and expansion to a four-lane roadway seems unjustified or prohibitively expensive, widening to a two-lane section can be an economical alternative. Figure 1 is a schematic of a three-lane alternate passing section.

The Arkansas State Highway and Transportation Department (AHTD) has upgraded some two-lane highways to continuous three-lane cross sections and marked them for alternating passing lanes. AHTD sponsored research to examine the operation of these 2+1 passing lane sections. Research objectives included quantifying the following variables: passing rates, the percentage of vehicles in platoons, and changes in speed within the passing lanes. Aggregate crash data were also examined.

LITERATURE REVIEW

The following passing lane literature was reviewed.

Platooning

Vehicle platooning was a more sensitive measure of traffic service than mean speed (2). The authors concluded that the percentage of vehicles in platoons decreased from an average of 35.1% immediately upstream of a passing lane to 20.7% within the passing lane. Immediately downstream of the passing lane, vehicles in the platoon rose to 29.2% on average, still 5.9% less than the upstream percentage.

In another paper, Harwood et al. (5) 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. Enberg and Pursula (4) conducted simulation studies to evaluate the effect of passing lanes on platooning. (Those authors considered the vehicles to be in a platoon if the headway between two successive vehicles was less than 5 s.) They concluded that passing lane sections had a smaller percentage of platoons than did two-lane sections.

Passing

The passing rate was strongly related to traffic flow and passing lane length (2). The passing rate decreased with increasing passing lane length and increased with increasing vehicular flow and increasing upstream percentage of vehicles in platoon. May found that the number of platoons increased with vehicular flow (5). Enberg and Pursula (4) found that the passing rate increased with increasing traffic flow. However, these authors also found that the passing lane length had a negligible effect on the passing rate.

Speed

Enberg and Pursula (4) found a statistically significant increase in the speed of traffic in the passing lane section but that the passing lane had no significant effect on downstream speeds. Harwood et al. (2) noted that the effect of passing lanes on traffic speeds varied widely from site to site and that the vehicle speeds were influenced more strongly by local geometrics than by the presence of passing lanes.

Length

Harwood et al. (5) calculated, on the basis of traffic flow rates, needed length of a passing lane. As the flow rate increased, optimum length of the passing lane also increased. For flow rates up to 200 vehicles per hour (vph) in one direction of travel, passing lane lengths between 0.4 and 1.2 km (0.25 and 0.75 mi) were most efficient. For flow rates of 700 vph in one direction of travel, the required length of passing lanes appeared to be from 1.0 to 2.0 km. However, passing lanes longer than 1.0 mi may not be desirable because the length is not needed during the remainder of the time, when traffic volumes are low. The authors suggested that more short passing lanes would be more effective than fewer long passing lanes.

<table>
<thead>
<tr>
<th>Table 1: Geometric Features of Data Collection Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site</strong></td>
</tr>
<tr>
<td><strong>US-65 SB</strong></td>
</tr>
<tr>
<td><strong>US-70 WB (Sec. 9 &amp; 10)</strong></td>
</tr>
<tr>
<td><strong>US-70 WB (Sec. 10 &amp; 11)</strong></td>
</tr>
<tr>
<td><strong>US-82 EB</strong></td>
</tr>
</tbody>
</table>

- **US-65 SB**: 920 m (2,865 ft), Upper end of grade: 2.78%
- **US-70 WB**: 861 m (2,825 ft), Upper end of grade: 6.70%
- **US-70 WB (Sec. 10 & 11)**: 598 m (1,960 ft), Upper end of grade: 5.35%
- **US-82 EB**: 589 m (1,930 ft), Upper end of grade: 2.40%

<table>
<thead>
<tr>
<th>Table 1: Geometric Features of Data Collection Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site</strong></td>
</tr>
<tr>
<td><strong>US-65 SB</strong></td>
</tr>
<tr>
<td><strong>US-70 WB (Sec. 9 &amp; 10)</strong></td>
</tr>
<tr>
<td><strong>US-70 WB (Sec. 10 &amp; 11)</strong></td>
</tr>
<tr>
<td><strong>US-82 EB</strong></td>
</tr>
</tbody>
</table>

- **US-65 SB**: 920 m (2,865 ft), Upper end of grade: 2.78%
- **US-70 WB**: 861 m (2,825 ft), Upper end of grade: 6.70%
- **US-70 WB (Sec. 10 & 11)**: 598 m (1,960 ft), Upper end of grade: 5.35%
- **US-82 EB**: 589 m (1,930 ft), Upper end of grade: 2.40%
that horizontal alignment would be expected to have no effect on speed, but at some locations, the vertical alignment might affect speed.

**DATA COLLECTION AND REDUCTION**

For this study, crash data and traffic flow data in passing lanes were collected. Field data were collected for many hours at each site, doing so yielded traffic flow data over a range of volumes.

**Traffic Operation Field Data**

Classifiers, lidar and radar guns, and video cameras were used to collect speed, passing, and passing attribute data in the field. Figure 2 shows a typical classifier setup. The classifiers recorded not only the speed and number of axles but also the time at which an axle passed. After the traffic behavior was studied, it was decided that the vehicles traveling at speeds less than 35 mph probably represented either entering or leaving vehicles or an anomaly. These vehicles were atypical, and hence all vehicles traveling at speeds less than 35 mph were discarded from the analysis.

The data from video tapes were reduced for each 5-minute interval for each station and entered into a spreadsheet. The sequence of vehicles was observed, and all 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 the through volume (i.e., the volume of traffic that traversed all the data collection stations).

**Crash Data**

The AHTF furnished 5 years of crash data and a schedule of road construction during that time. The crashes that were coded as having occurred in a work zone were excluded from the analysis.

**DATA ANALYSIS AND RESULTS**

The data collection studies were 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 volume 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 the data collection stations (i.e., the entire passing lane segment). For speed and passing analysis, total volume was used. For passing analysis, through volume was used. All 15-min flow rates were expressed as equivalent hourly volumes. Table 2 lists ranges of one-direction hourly flow rates during data collection.

**Analysis of Passing Data**

The project considered the effects of passing lane length and traffic volume on passing, according to the Highway Capacity Manual (HCM). Two vehicles are said to be in a platoon if the headway between the two successive vehicles is less than 3 s. A study by Gattis et al. (19) had concluded that, for speeds higher than 80 km/h (50 mph), headways more than 3 s did not encourage drivers to undertake passing maneuvers. In other words, for high speed—speeds more than 80 km/h (50 mph), as defined in the

**TABLE 2 One-Direction Flow Rates**

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Minimum</th>
<th>Average</th>
<th>50th %</th>
<th>90th %</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-70 WB 1999</td>
<td>260</td>
<td>445</td>
<td>396</td>
<td>608</td>
<td>724</td>
</tr>
<tr>
<td>US-70 EB 2000</td>
<td>216</td>
<td>397</td>
<td>300</td>
<td>360</td>
<td>428</td>
</tr>
<tr>
<td>US-82 EB 2001</td>
<td>104</td>
<td>164</td>
<td>168</td>
<td>216</td>
<td>232</td>
</tr>
<tr>
<td>US-70 WB 2002</td>
<td>176</td>
<td>322</td>
<td>312</td>
<td>420</td>
<td>504</td>
</tr>
</tbody>
</table>

*Note: Volumes are expressed in vehicles per hour (vph)*

**FIGURE 3** Number of vehicles in platoon for Studies US-70 WB 1999, US-70 EB 2000, US-82 EB 2001, and US-70 WB 2000. (Sta. 1, \( y = 0.7491x - 69.751, R^2 = 0.9927, P < 0.0001; \) Sta. 2, \( y = 0.7249x + 101.72, R^2 = 0.9908, P < 0.0001; \) Sta. 3, \( y = 0.6195x - 87.568, R^2 = 0.9111, P < 0.0001; \) Sta. 4, \( y = 0.4465x - 28.122, R^2 = 0.8049, P < 0.0001).**

**FIGURE 4** Percentage of vehicles in platoon for Studies US-70 WB 1999, US-70 EB 2000, US-82 EB 2001, US-70 WB 2000. (Sta. 1, \( y = 0.0005x + 0.2179, R^2 = 0.7405, P < 0.0001; \) Sta. 2, \( y = 0.0006x + 0.1413, R^2 = 0.7017, P < 0.0001; \) Sta. 3, \( y = 0.0005x + 0.1297, R^2 = 0.0047, P = 0.0001; \) Sta. 4, \( y = 0.0005x + 0.1290, R^2 = 0.3812, P < 0.0001).**

**AASHO Green Book (J0)—drivers are more likely to feel that their trip is being impeded and are more inclined to pass if headways are less than 3 s.**

To be consistent in comparisons of platooning between stations having passing lanes and those not having passing lanes, it was assumed that two vehicles traveling in adjacent lanes were in a platoon if the headway between them was less than 3 s. This assumption was based on the fact that vehicles in adjacent lanes eventually have to merge into one lane at the end of the passing lane segment.

The data were analyzed in 15-min intervals. Figures 3 and 4 are plots of the number and the percentage of vehicles in platoon at each station. There were fewer data points for Station 4 than for the other three stations because only three studies (US-70 EB 2000, US-82 EB 2001, and US-70 WB 2002) had four stations. Equivalent volume is the 15-min flow rate multiplied by four.

The plots show that, for the same volume, platooning at Station 1 (immediately before 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 1 and 2. Platooning at the end of passing lanes was less than that at the beginning.

**Statistical Analysis of Platooning**

The data were subjected to statistical analysis to determine whether the reductions in platooning between stations were significant. The null hypothesis was that there was no significant reduction in platooning occurred between two stations.

For the analysis, the independent variable was total traffic volume, and the response variable was the number of vehicles in the platoon. The natural log of volume was used as an offset variable so that the final result could be reported as the 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 overdispersion was observed—that is, variance found to be greater than mean (as indicated in the deviance or Pearson chi-square goodness-of-fit statistics)—the negative binomial model was used instead of the Poisson.

Poisson regressions, negative binomial regressions, or both with repeated measures (generalized estimating equations) were used to determine whether 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 statistical analysis could not be performed on US-82 EB 2001 because the amount of data was not adequate. There were insufficient data for flow rates above 450 vph.

Table 3 summarizes the statistical comparisons of platooning among the stations along a study segment. A smaller interval indicates that there was a statistical difference in platooning between the pair of stations indicated. The following observations were made during the analysis:

1. The reduction in platooning was highest between Stations 1 and 2 (i.e., up to 1.5 km (0.9 mi)). A smaller reduction in platoon- ing or even some increases were observed between subsequent stations.
2. In some cases, platooning increased at the end of the passing lane segment. However, platooning at the end of the passing lane was less than that at the beginning.
TABLE 3 Statistical Differences in Platooning

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Station</th>
<th>Sta. 1</th>
<th>Sta. 2</th>
<th>Sta. 3</th>
<th>Sta. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-70 WB 2000</td>
<td>1</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>na</td>
</tr>
<tr>
<td>US-70 EB 2001</td>
<td>1</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Na</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Na</td>
</tr>
<tr>
<td>US-70 WB 2002</td>
<td>1</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Na</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Yes</td>
<td>No</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Yes</td>
<td>No</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Yes</td>
<td>No</td>
<td>Na</td>
<td>Na</td>
</tr>
</tbody>
</table>

- na = not applicable; Sta. = station; dashes indicate missing data.

Analysis of Platoning Data

Because individual vehicles were identified during the data reduction, the number of passing vehicles and the number of vehicles that were passed could be counted. Figures 5 and 6 are the plots, for all the sites combined, of the number and the percentage passing at each station. The graphs show that maximum passing occurred between Stations 1 and 2. Past Station 21.5 km (0.9 mi), the amount of passing seemed to stabilize or decline. In addition, the rate of passing increased with higher volume. However, some individual sites exhibited different trends.

Analysis of Speed Data

Speed data were studied to ascertain what change in the traffic speed occurred through the passing lane segment. Figure 7 shows that the speed trends across the passing lane segments were not uniform for all study sites. As stated earlier, the traffic speeds could have been influenced by many factors, such as traffic volumes, geometric features of the road segment, and the like.

Average speed increased between Stations 1 and 2. Previously constrained drivers were free to select their own speed upon entering the passing lane section.

Analysis of Crash Data

The crash rates from 19 passing lane sites were contrasted with the statewide average crash rates for rural two-lane highways. Figure 8 is a plot of crash rates for each passing lane site against the corresponding traffic volume for that site. Lines for the statewide average AADT and average crash rates were also drawn. Figure 9 shows crashes per mile/year against volume.

The following observations were made:

1. Even though most of the passing lane sites had volumes higher than the statewide average for two-lane rural roads, the crash rates of passing lane sites were usually less than the statewide average crash rate for two-lane rural roads.

2. The crash rates of the passing lane sites exhibited a weak trend of increasing with volume. If the trend line were extended, the projected crash rate trend line would cross the statewide crash rate at a volume of 22,740 vpd.

3. The crash rates of three passing lane sites (1-13, 65-1, and 82-1e) exceeded the state average. The researchers did not identify any obvious reasons for this.

4. Comparison of crash severity attributes of the crashes that took place in passing lanes with the statewide crash averages showed that the percent severe was somewhat similar. The passing lane severe injury rate was slightly higher than the statewide average, and the property-damage-only rate was slightly lower.

5. The percentages by crash type (such as head-on, right angle, etc.) for the passing lane sites were not greatly different from the rural two-lane percentages. The greatest difference was for the single vehicle type: 51.6% of passing lane crashes were this type versus 54.2% for rural two-lane roads.

SUMMARY

This study examined the following operational parameters of rural three-lane alternating passing lanes in Arkansas.

1. Platooning.
2. Passing.
3. Speed, and
4. Safety.

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

Platooning

An earlier study by Horwood et al. (3) concluded that passing lanes with lengths between 0.25 and 0.75 mi were 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 ranged from 1.0 to 2.0 mi. The authors also stated that passing lanes longer than 1.0 mi might not be desirable. A simulation study by Ehrig and Purdula found that optimal passing lane varied from 1 km (0.62 mi) for a one-direction flow rate of 500 vph to 2 km (1.24 mi) for a 2,000 vph flow rate. In general, the effective length of a passing lane segment increased somewhat as volume increased. The researchers used data from US-70 WB 1999, US-70 EB 2000, and US-70 WB 2002 to determine relationships between traffic volume and platooning that occurred between successive pairs of stations. For all sites, platooning increased with an increase in volume. When vehicles entered the passing lane segments, the percentage of vehicles in platoons dropped from an average of 48% immediately upstream of a passing lane to 34%. The reduction in platooning continued even downstream of a passing lane segment; however, the rate of reduction was very low.

For the range of volumes encountered in this study, platooning at Station 1 (the beginning of the passing lane) was statistically significantly higher than platooning at the other stations located downstream. The percentages in a platoon at Stations 3 and 4, located 3 km (1.9 mi) and 4.5 km (2.8 mi), respectively, downstream of Station 1, were not statistically different from each other. Thus, it could be concluded that a significant reduction in platooning occurred within the first 1.5 km (0.9 mi) 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 mi), and for the range of volumes observed, platooning did not decrease significantly, even if a longer passing lane was provided.

Passing Maneuvers

Horwood et al. (2) had proposed that the passing rate decreases further into the passing lane. However, Ehrig and Purdula (4) found that passing lane length had a negligible effect on passing maneuvers. In the current study, the highest number of passing maneuvers took place between Stations 1 and 2 (within the first 1.5 km (0.9 mi)). Passing maneuvers decreased between successive stations located downstream. It is not known what effect, if any, roadway gradients played in this.

This study considered the relationships between the amount of passing and both passing lane length and traffic volume. It was found that passing maneuvers increased as volume increased. The model predicted that, as volumes increase, higher numbers of passing maneuvers would occur further into the passing lane. Then, it could be inferred that higher-volume roads could use longer passing lanes.
be considered when agencies are determining locations for and how to set lengths of passing lanes.

In addition, practical factors such as the locations of narrow bridges, uphill grades, and higher-volume driveways or crossroads have to be considered when the length of a passing lane and its termination point are being established.

ACKNOWLEDGMENT
The support of the Arkansas State Highway and Transportation Department (AHTD) made this research possible.

REFERENCES


The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented here.

The Operational Effects of Geometric Committee sponsored publication of this paper.