Passing Operations on a Recreational Two-Lane, Two-Way Highway

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A study was conducted of passing maneuvers in selected passing zones over a 21-mi segment of a principal arterial, two-lane, two-way roadway in northern Wisconsin. Within the project, passing was restricted to 33 percent of the roadway length due to horizontal and vertical geometrics. Five independent sites were monitored using both field observers and directional speed and volume recorders. Timed video-recorders were also placed at two sites. The data were gathered on three peak summer weekends in 1988. Operational data, segregated into 15-min intervals, included information on directional flows, average speeds, and passing operations. The data conformed with AASHTO expectations and indicated that on recreational weekends with traffic volumes of 200 to 250 veh/hr in the major direction and 85 to 175 veh/hr in the minor direction, 25 to 35 percent of all passes were made in the presence of an opposing vehicle, an average of 21 passes per hour were completed with duration of time in the opposing lane (at 60 mph) of 12.2 sec, and pass aborts comprised 0.8 percent of all passes. Under higher flow levels of 330 to 420 veh/hr in the major direction and 70 to 170 veh/hr in the minor direction, 26 to 50 percent of all passes were made in the presence of an opposing vehicle, an average of 16 passes per hour were completed with duration of time in the opposing lane of 11.3 sec, and pass aborts comprised up to 7 percent of all passes where passing was restricted to 33 percent for a 10- to 15-mi segment. The data indicate that (a) the passing driver's decision threshold is negatively affected by the inability to pass, (b) this effect increases significantly at volume levels as low as 500 veh/hr two-way, and (c) passing drivers may be significantly overestimating their ability to complete passing maneuvers safely.

US-63 from Turtle Lake to Cumberland is an 11.1-mi principal arterial extending from the intersection with US-8 in Turtle Lake to the intersection with SH-48 west of Cumberland in Barron County, Wisconsin. Its location is approximately 1 hr northeast of the Minneapolis–St. Paul metropolitan area, and the route is a major recreational highway to northern Wisconsin and Lake Superior. The roadway was originally constructed in 1936 as a 20-ft-wide concrete pavement with 8-ft gravel shoulders. It was resurfaced and widened with bituminous in 1973 to a 24-ft pavement with 10-ft gravel shoulders.

The roadway geometrics are satisfactory for 60-mph horizontal operations, although several long horizontal curves limit passing sight distance. The vertical alignment has 52 vertical curves, of which 46 have stopping sight distance for 55 mph, 5 are adequate for 55-mph stopping sight distance, and 1 is marked for 45-mph stopping sight distance. In general, the combined geometrics offer an MUTCD marked passing opportunity of approximately 32 percent northbound and 33 percent southbound within the 11.1-mi segment.

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The traffic volume in 1985 was recorded as 2,530 veh/day with a peak-hour volume of 24.1 percent of average daily traffic (ADT). However, a nearby average annual daily traffic (AADT) station on US-8 reported that Sunday peak traffic in July was 235 percent in excess of the annual weekday ADT, with averaged summer (May to September) weekend volumes approximately 80 percent above the monthly AADT. In the peak direction on weekends, video-recorded data from this project revealed that passenger vehicles make up approximately 67 percent of the traffic flow, light trucks and vans 26 percent, vehicles with trailers 6 percent, and RVs and large trucks 1 percent of the average peak flow.

From 1978 to 1986, this segment experienced a total of 90 accidents—an average of approximately 11 accidents per year. These accidents resulted in 71 injuries and 6 fatalities, or about 1 fatality and 9 injuries per year. A review of the 1985 through 1987 accidents indicated that 67 percent of them were vehicle-vehicle and 22 percent were passing related. Although the average annual accident rate is reported as only 45 per 100 million vehicle-miles (mvm) for this segment compared with 220 for this roadway type statewide (indicating a safe roadway on average), a severity of 77 fatalities and injuries per 90 total accidents indicates the risk of substantial severity when an accident does occur.

A proposed project on this segment will reconstruct the entire 11.1-mi roadway by improving the substandard curves to a minimum 60-mph stopping sight distance, retaining the same two-way passing sight distances. The typical section will provide 12-ft lanes with 6-ft shoulders, of which 3 ft will be paved. Passing lanes approximately 1 mi long will be added at two locations in each direction, which will increase the passing opportunity to 67 percent northbound and 56 percent southbound. Neither of the passing lanes is adjacent to the other so that a driver will not perceive the presence of a four-lane roadway. To quantify the full effect of the new passing lanes, an in-depth collection of data related to the passing maneuver was performed (*1*).

SITE LOCATIONS AND DATA COLLECTION

Collection of the roadway data was performed on three nonconcurrent weekends—July 4, 15, and 30, 1988. These particular dates were selected because the weekend of July 4 is the peak traffic weekend of the year, and by retaining the weekends in 1 month large shifts in driver population would be minimized. Also, by selecting nonconcurrent weekends, it was hoped that the driver population would not become sensitized to expectancies of traffic studies in progress on the roadway.

Five passing zone observation sites were selected to provide a depth and breadth to the data collection while maintaining control of the data. Sites 2, 3, and 4 were selected for observation within the 11.1-mi project limits, and Sites 1 and 5 were selected for observation significantly beyond the termini of the project at each end. The external sites were selected at a distance of approximately 5 mi from the termini of the project to establish if, as reported by Harwood (*2*), such passing lanes have an impact on operations a significant distance from the project. The external sites were selected as the closest, longest passing zones from each terminus in which passing is relatively easy and safe if flow levels are low. Both zones were about 1 mi in length with relatively flat, tangent geometrics. The internal observation sites were selected at approximately 2- to 3-mi intervals to provide data from the short 2,000-ft passing zones at Sites 2 and 4 to the longer 3,600-ft zone at Site 3. Sites 2 and 4 were selected for placement of the video-recorders because these sites offer a well-balanced perspective of traffic flow at a distance of about 2 mi from each terminus.

Roadside observers trained in the collection of passing data were placed at each site. To minimize disruption to the traffic stream and external influences on driver behavior caused by the presence of the observers, they were either sufficiently hidden from the drivers' view or were dressed as resting bicyclists (complete with easily observed bicycle). The intent of this strategy was to alleviate the threat of driver behavior modification due to the presence of an unusual observer at the roadside. Similarly, the observers were placed at roadside locations as far from the traveled roadway as possible, while retaining their visual capability, so their location would not interfere with driver performance by appearing as a roadside obstacle. Video-recorders with time (in minutes) imprinted on the image were stationed at two of the internal sites for two weekends and at the two external sites for one weekend. The video-recorders were wrapped in black or green plastic wrap, which blended into the natural background at the sites. In general, the bicycle and video-camera disguises appeared extremely effective in maintaining the integrity of the observers as a natural part of the roadway environment, thus preserving the drivers' existing operational and safety characteristics.

Pneumatic road-tubes were placed at each site to record flow and speed in the major direction of travel. On each weekend, the speed and volume recorders were set for the northbound (away from home) direction from noon on Friday to 3:00 p.m. on Saturday and were then transferred to the southbound (to home) direction from 3:00 p.m. on Saturday to 9:00 p.m. on Sunday (or Monday, July 4).

Following is a summary of the site locations and the type of data collected at each.

Site 1

Site 1 is an external location designed to provide stability to the data collection by the observation of substantial passing maneuvers and to measure the effect of passing lanes a significant distance from the termini of the lanes. The observer was located approximately midway within the passing zone, which begins about 4.5 mi west of the intersection of US-8 and US-63 in Turtle Lake. The passing zone, which is on a tangent alignment, is 1.25 mi long (6,600 ft), with a flat grade in both directions at the point of pass initiation. Speed and volume data were collected from road-tube counters on each weekend, and videotape data were recorded on the last weekend.

Site 2

Site 2 is an internal site, with the passing zone located approximately from Station 145 to Station 163 (1,800 ft). Observers were located at Station 158 northbound and Station 163 southbound. Both observation sites are approximately 2.0 mi from the beginning of the segment at US-8 in Turtle Lake, which is Station 56. The horizontal alignment is tangent in the northbound direction and has a slight curve to the right in the southbound direction. This passing zone has a downhill grade northbound (-1.5 percent at the pass initiation point) and a slight downhill grade southbound (-0.5 percent at the pass initiation point). Road-tube speed and volume data were recorded in 15-min increments on each of the three weekends, and videotape data were recorded on the first and second weekends.

Site 3

The passing zone at Site 3, an internal site, is located approximately from Station 412 to Station 452 (3,600 ft). Observers were located at Station 429 northbound and Station 438 southbound. Both observation sites are located approximately 0.5 mi north of the northern limits of the village of Comstock, or 7.2 mi north of the intersection with US-8 in Turtle Lake. The horizontal alignment is tangent, with a downhill grade northbound (-2.0 percent at the pass initiation point) and a slight downhill grade southbound (-0.5 percent at the pass initiation point). Directional speed and volume data were collected on each of the three weekends using road-tubes. No video-recorded data were gathered for this site because it is midway between Sites 2 and 4, and data from those sites could be averaged to approximate the directional flows and vehicle classifications at Site 3.

Site 4

The passing zone at Site 4, an internal site, is located approximately from Station 550 to Station 571 (2,100 ft). The observer was located at Station 558 for both the northbound and southbound passing observations. The observer location was about 9.5 mi north of the intersection with US-8 in Turtle Lake. The horizontal alignment is tangent throughout this site, with an uphill grade northbound ($+1.8$ percent at the pass initiation point) and a downhill grade southbound (-3.0 percent at the pass initiation point). Directional speed and volume data were collected on three weekends, and video-recording data were taken on the first and second weekends.

Site 5

Site 5 is an external site. The passing zone is located approximately 7.1 mi north of the northern terminus of this project at SH-48, which is about 4.5 mi north of the northern limits of the village of Cumberland. This passing zone was selected for observation because, at approximately 1.1 mi (5,800 ft) in length, it is the first significantly long passing zone north of the project limits. This site is on a slight uphill grade northbound (+0.5 percent at the pass initiation point) and a downhill grade southbound (−1.5 percent at the pass initiation point). The horizontal alignment is essentially tangent throughout the passing zone. Three weekends of directional road-tube speed and volume data were collected, and videotape data were recorded on the last weekend.

PASSING DATA COLLECTION PROCEDURES

The field observers placed at the five sites over the three weekend periods were instructed to observe all passing maneuvers and record the following data.

Time in the Opposing Lane

This characteristic of the passing maneuver was estimated by using a stopwatch to record the elapsed time between the crossing of the centerline by the passing vehicle's left front tire and the return of the vehicle's left rear tire to the lane of origin. This time corresponds to the AASHTO definition of the time ($t2$) during which the driver occupies the left lane (*3*). Although it is often difficult to measure this event precisely because of the distance and skew between the vehicle and the observer, it becomes easier with experience to recognize which vehicles intend to pass and to record the event with relative precision.

Pass with No Opposition

This type of pass represented those completed with no opposition to the pass observed at the so-called "critical position" (alongside the passed vehicle) and with no difficulty or conflict encountered in the completion of the pass. The critical position is assumed to be the point at which the passing driver evaluates the outcome of the pass attempt and either proceeds or aborts the pass.

Pass with Opposition Greater than 10 sec

In this type of pass, the pass was completed with no conflict but with an opposing vehicle 10 sec or more from the completion of the pass (return of the left rear tire to the original lane) at the critical position. The time between the passing vehicle's return to the original lane and the point at which the vehicle trajectories would meet was estimated using verbal counting (i.e., "1001, 1002, 1003"). Although verbal counting is admittedly an inaccurate data collection technique, it does present a relative measure of the clearance time between vehicles, which is an estimate of the AASHTO $t3$ clearance interval. Funding constraints precluded a more refined measurement of the $t3$ characteristic.

Pass with Opposition Between 5 and 10 sec

This type of pass represented those completed with an opposing vehicle in sight at the critical position and with a vehicle clearance within the range of more than 5 sec but less than 10 sec from the completion of the pass to the opposing vehicle. This is referred to as a slight passing conflict because the passing driver is taking a greater risk than in other passing maneuvers.

Pass with Opposition Less than 5 sec

In this type of pass, the pass was completed with an opposing vehicle in sight at the critical position and with a vehicle clearance of less than 5 sec from completion of the pass to the opposing vehicle. This is referred to as a major conflict because these drivers are taking a significant risk with the potential of a severe outcome to themselves and their passengers should the pass attempt fail. Roadside observers were instructed to record as much detail as possible about the vehicles and character of this type of passing event.

Pass—Full Abort

This type of pass represented the most serious and life threatening of passing maneuvers with the vehicle completely entering the opposing lane and then retreating to the lane of origin after concluding (due to the presence of an opposing vehicle) that the pass could not be completed safely. This type of event is a clear indication of great risk taking on the part of the passing driver and indicates the trade-off between primacy (which accepts safety as the ultimate goal of driving) and the presence of overpowering delay (which alters the passing driver's disposition to pass from a normal risk-taking level to a level of significantly elevated risk).

Multiple Pass

This type of pass represented a pass extension, in which one vehicle passed two or more vehicles, two or more vehicles passed one or more vehicles, or any similar combination of passes occurred. It was assumed that multiple passes are an undesirable by-product of inefficient passing operations on two-lane roadways and that they indicate elevated risk taking on the part of the passing driver. Roadside observers were instructed to record the character of the multiple passes with as much detail as possible, including the number and character of vehicles involved.

PASSING DATA COLLECTION AND ANALYSIS

On the basis of the procedures described in the preceding section, passing, speed, and flow data were collected at 15-min intervals from each site as follows:

- *Site 1.* At this site, 135 intervals of data were developed and 391 passes were observed in the northbound direction.

In the southbound direction, 74 intervals of data were collected and 456 passes were observed.

- *Site 2*. At this site, 156 intervals of data were produced and 273 passes were observed in the northbound direction. In the southbound direction, 95 data intervals were recorded and 242 passes were observed.
- *Site 3*. At this site, 156 data intervals were recorded for the northbound direction, with 489 passes observed. In the southbound direction, 81 data intervals were recorded and 466 passes were observed.
- *Site 4*. At this site, 112 data intervals were developed northbound and 210 passes were observed. In the southbound direction, 96 data intervals were recorded along with 318 observed passes.
- *Site 5*. At this site, 175 data intervals were produced in the northbound direction and 578 passes were observed. In the southbound direction, 101 data intervals were recorded along with 730 observed passes.

In summary, the three internal sites (2, 3, and 4) produced 421 data intervals in the northbound direction, recording major direction flows, speeds, and observations of passing maneuvers for 970 completed or aborted passes. In the southbound direction, 276 data intervals were recorded at the internal sites, with 1,026 observations of completed and aborted passes. At the two external control sites (Sites 1 and 5), 310 data intervals were recorded in the northbound direction, with 969 observed passing maneuvers. In the southbound direction, 175 data intervals were recorded at the external sites, with 1,577 completed or aborted passes observed.

Table 1 presents an overall summary of the percentage of passes, cross-classified by the risk taking in the passing maneuver in the northbound and southbound directions. The data are based on 1,182 data intervals (obtained in the three weekend data collection periods) and on 4,153 observed passing maneuvers.

A comparison of the data gathered in this study with other research indicated conformance in the following:

- The overall number of passes with no opposition was recorded as 70 percent. The actual site conditions included variations from 50 to 81 percent, which may have been caused by the individual characteristics of the sites and the traffic flows experienced at the time of observation. Because previous passing research has found that 60 percent of all passes occur with no opposition in sight, it can be concluded that the passing data conform with previous results (*4*).
- The time in the opposing lane was recorded for each passing maneuver and averaged 10.6 sec over the 4,000+ passing observations at an average operating speed of approximately 59 mph. This finding conforms with AASHTO *t*2 results of 10.7 sec at 60-mph operating conditions.

Tables 2 and 3 present a summary of the data recorded at each site by direction in 15-min data intervals. The northbound data intervals included both Friday and Saturday peak and off-peak data records, with an average of approximately 150 to 180 data intervals at each site. The southbound data intervals included more highly peaked 15-min intervals recorded only on Sundays (or Monday, July 4), with an average of approximately 75 to 100 data intervals at each site. In general, the northbound data collected from each site can be compared directly with data from other northbound sites; however, caution must be used when comparing northbound and southbound data summaries because the quantity of off-peak data intervals in the northbound direction may tend to depress the mean values.

TABLE 1 RISK TAKING IN PASSING MANEUVER (PERCENTAGE OF ALL PASSES BY DIRECTION)

	NO OPPOSITION		TIME TO OPPOSING VEHICLE IN PASSING >10 sec.		5<10 sec.		< 5 sec.		PASS ABORTS	
	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
SITE 1	76	50	6.1	17.8	9.2	12.9	7.7	11.4	1.3	7.9
SITE 2	81	76	4.0	0.4	6.2	9.9	8.1	7.0	1.1	6.6
SITE 3	63	69	14.1	11.6	10.6	11.6	9.8	6.9	2.0	1.1
SITE 4	64	81	26.2	13.2	5.7	1.6	1.0	2.8	3.3	1.6
SITE 5	65	75	19.4	7.3	9.5	9.7	5.4	7.3	0.7	0.8
AVERAGE	70	70	14.0	10.1	8.2	9.1	6.4	7.1	1.7	3.6

A comparison of the northbound average flow rates suggests that Sites 1 through 4 are not significantly different from one another, but the northbound average flow levels at Site 5 are significantly lower than those at Sites 1 through 4. This suggests that the northbound flows within Sites 1 through 4 develop from the same parent population and are maintained throughout the project, but the northbound flow at Site 5 represents a distinctly lower population. A statistical comparison of the flow levels in the southbound direction suggests the same conclusion; i.e., Sites 1 through 4 have similar flow levels, whereas Site 5 has significantly lower flow levels than Sites 1 through 4.

From the data, three distinct passing relationships were noted, as discussed in the following paragraphs.

Low-Flow-Level-Passing Characteristics

The northbound and southbound data shown in Tables 2 and 3 from Site 5 can be examined to help determine the expected characteristics of passing operations in reduced flow levels and less pressured passing operations than those found in Sites 1 through 4. Although these data compare two differently collected data sets, they do indicate that both flow rates are statistically similar in the major direction of passing operations and slightly different in the minor direction. A summation of the last three passing types from Table 1 is 15.6 and 17.8 percent, respectively, for the northbound and southbound directions. This result indicates the stability of the first three passing characteristics as a whole at this site. It also indicates that, if the major direction flow remained constant and more vehicles were added to the opposing flow at Site 5, the first two passing characteristics might be the only ones significantly altered because sufficient major direction volume may not exist to create a severe passing hazard (such as more pass aborts).

TABLE 2 NORTHBOUND PASSING DATA SUMMARY

VARIABLE	15 MINUTE INTERVAL MEAN INDIVIDUAL SITES				
	1	2	3	4	5
NORTHBOUND FLOW (veh/15-minutcs)	71.70	74.80	77.72	81.53	54.82
SOUTHBOUND FLOW (veh/15-minutes)	50.70	25.91	28.07	29.31	38.97
TOTAL FLOW (veh/15-minutes)	121.20	107.20	112.60	110.84	93.79
TOTAL NUMBER OF PASSES (15 minutes NB)	3.00	1.81	3.33	2.04	3.27
t2 (average time in opposing lane)	10.45	10.93	9.40	7.98	11.63
PASS WITH NO OPPOSITION	2.26	1.47	2.10	1.34	2.14
PASS WITH OPPOSITION > 10 SEC.	0.18	0.07	0.47	0.55	0.64
PASS WITH OPPOSITION 5 - 10 SEC.	0.27	0.11	0.35	0.12	0.31
PASS WITH OPPOSITION < 5 SEC.	0.23	0.14	0.32	0.02	0.17
PASS ABORTS	0.04	0.02	0.07	0.07	0.02
MULTIPLE PASSES	0.66	0.28	0.56	0.13	0.63

Given this apparent stability in the sum of the most critical of passing events at the Site 5 flow rates and directional splits, the directional passing characteristics at Site 5 can be averaged to present a picture of low-flow-level recreational weekend passing operations as follows:

Where the major directional flow is in the range of 200 to 250 veh/hr, with the minor flow in the range of 85 to 175 veh/hr,

1. Approximately 21 passes occur each hour.
2. The time spent in the opposing lane passing the lead vehicle is approximately 12.2 sec at an operating speed of approximately 60 mph.
3. Passes aborted after the passing vehicle fully enters the opposing lane are approximately 0.75 percent of all passing operations.
4. Passes in which the pass completion is less than 5 sec from the opposing vehicle are approximately 6.3 percent of all passes.
5. Passes in which the pass completion is approximately 5 to 10 sec from the opposing vehicle are approximately 9.6 percent of all passes.
6. Although the extent of passing with no opposition in sight or with opposition greater than 10 sec from pass completion appears to be a function of the flow rate in each direction of travel, the average percent of passes completed in the presence of no opposition is 65.1 to 74.9 percent.

TABLE 3 SOUTHBOUND PASSING DATA SUMMARY

VARIABLE	15 MINUTE INTERVAL MEAN INDIVIDUAL SITES				
	1	2	3	4	5
SOUTHBOUND FLOW (veh/15-minutes)	92.00	98.40	86.06	88.41	56.10
NORTHBOUND FLOW (veh/15-minutes)	41.80	19.40	25.17	22.73	23.22
TOTAL FLOW (veh/15-minutes)	133.80	117.80	112.48	111.14	79.32
TOTAL NUMBER OF PASSES (15 minutes NB)	5.55	2.39	4.86	3.23	7.17
t2 (average time in opposing lane)	12.00	10.71	11.45	10.06	12.87
PASS WITH NO OPPOSITION	3.08	1.94	3.38	2.65	5.42
PASS WITH OPPOSITION > 10 SEC.	1.10	0.01	0.57	0.43	0.52
PASS WITH OPPOSITION 5 - 10 SEC.	0.80	0.25	0.57	0.05	0.70
PASS WITH OPPOSITION < 5 SEC.	0.70	0.18	0.34	0.09	0.52
PASS ABORTS	0.49	0.17	0.05	0.05	0.06
MULTIPLE PASSES	0.93	0.39	1.00	0.23	1.42

These conclusions represent the conditions under which passing operations occur on an apparently typical summer recreational weekend within the volume levels observed.

High-Flow-Level Passing Characteristics

It is also useful to examine the operational and passing characteristics of the higher volume sites (Sites 1 through 4). A comparison of sites in Table 3 shows that the best indicator of the effect of the inability to pass in the presence of higher flow levels occurs at Sites 2 and 1 southbound. Although the volume levels in the opposing direction at these two sites are different, their passing percentages can be averaged to present a picture of high-flow-level recreational weekend passing operations as follows:

Where the major directional flow is in the range of 330 to 420 veh/hr, with the minor flow in the range of 70 to 170 veh/hr,

1. Approximately 10 to 22 passing operations will occur each hour.
2. The time spent in the opposing lane passing the lead vehicle is approximately 11.3 sec at an operating speed of 60 mph.
3. Passes aborted after the passing vehicle fully enters the opposing lane are approximately 7.2 percent of all passing operations.
4. Passes in which the pass completion is less than 5 sec from the opposing vehicle are approximately 9.2 percent of all passes.
5. Passes in which the pass completion is 5 to 10 sec from the opposing vehicle are approximately 11.4 percent of all passing operations.
6. Although the extent of passing with no opposition in sight or with opposition greater than 10 sec from pass completion appears to be a function of the flow rate in each direction of travel, the average percent of passes completed in the presence of no opposition is 50.0 to 75.7 percent.

TABLE 4 MULTIPLE-PASS PERCENTAGE OF TOTAL PASSES

	NORTHBOUND(%)	SOUTHBOUND(%)	TOTAL(%)
SITE 1	21.8	16.8	19.3
SITE 2	15.2	16.3	15.7
SITE 3	16.8	20.6	18.6
SITE 4	6.4	7.0	6.8
SITE 5	19.3	19.8	19.6
AVERAGE	15.9	16.1	16.0

These conclusions represent the conditions under which passing operations occur on a typical high-peak-volume recreational weekend in the summer. The conclusions, especially with regard to abort passes and hazardous passes, can be expected to exceed those to be found under nonrecreational conditions of a similar volume in which passing is restricted to 33 percent in both directions.

ANALYSIS OF MULTIPLE PASSES

As explained previously, multiple passes are an undesirable by-product of inefficient passing operations in which one vehicle passes two or more vehicles or two or more vehicles pass one or more vehicles. Although the level of risk varies among multiple passes, all of these maneuvers may be a surrogate measure for the pressure to pass exerted in each individual passing zone. Table 4 presents the multiple pass percentage of total passes occurring at each site by direction. Ideally, no multiple passes should occur; however, a range of multiples from 6 to 21 percent indicates substantial passing pressure in the passing zones.

SUMMARY

Although internal spot speeds were not collected at all sites, they were recorded as 58.1 mph northbound and 59.9 mph southbound with floating-car travel times of 12.14 and 11.87 min, respectively. Table 5 presents a summary of the change in passing operations over the lower and higher flow levels. These data indicate that, where flow levels are sufficiently elevated, the passing driver's risk-taking decision threshold may increase by up to 100 percent; in other words, the passing driver is twice as willing to accept risk when the opportunity to pass is restricted to 33 percent of normal operating conditions. In the more typical recreational weekend passing operations, only 25 to 35 percent of all passes are made with an opposing-lane vehicle in sight. However, when the volume levels increase by only another 100 to 125 veh/hr in the major direction, and with the opposing flow approximately the same, passing drivers accept up to 50 percent of passing operations in the presence of an opposing vehicle.

Within this additional risk-taking event, the data also indicate that the passing driver accepts an approximate 2 percent increase in less significant passing conflicts (in which the opposing vehicle is 5 to 10 sec from the pass completion) and a 3 percent increase in more significant pass conflicts (in which the opposing vehicle is less than 5 sec from the pass completion). Most surprising, the incidence of pass aborts increased approximately 7 percent from its original condition of approximately 1 percent of all passes.

Passing drivers appear to be creating a far greater change in the primacy associated with passing aborts than with the less hazardous maneuvers. This suggests that passing drivers may be significantly overestimating their ability to complete passing maneuvers safely, which may be causing the inordinate

TABLE 5 COMPARISON OF PASSING OPERATIONS AT OBSERVED FLOW LEVELS

MAJOR FLOW (vph)	200 - 250	330 - 420
MINOR FLOW (vph)	85 - 175	70 - 170
PASSES/HR	21	16
TIME t2 IN OPPOSING LANE (seconds @ 60 mph)	12.2	11.3
VEHICLE OPPOSITION TO PASS (percent of total passes)	65 - 75	50 - 76
PASS COMPLETION 5-10 SEC. FROM OPPOSITION (percent of total passes)	9.6	11.4
PASS COMPLETION LESS THAN 5 SEC. FROM OPPOSITION (percent of total passes)	6.3	9.2
PASS ABORTS (percent of total passes)	0.8	7.2

increase in passing aborts compared to the less serious conflicts at higher flow levels.

CONCLUSIONS

Over 4,000 normally occurring passing operations were observed in this research, which conformed with both AASHTO and previous research results relating to passing maneuvers. The volumes observed are not significant in terms of the capacity of a two-lane, two-way roadway because the major direction carries only 200 to 420 veh/hr, with a minor direction volume in the range of 70 to 175 veh/hr, or a total two-way maximum flow of only 500 to 550 veh/hr. However, even at these relatively low flow levels, passing operations were observed to be negatively affected by the absence of passing opportunity when contrasted to normal passing zones, and this negative effect increased significantly as the traffic flow levels increased.

A reduced passing opportunity to only 33 percent also appears to have a significant effect on the passing driver's delay tolerance and the relationship with primacy, which presumes that drivers value safety above all other driving goals. The shift in primacy for a variety of passing characteristics (including aborts) from less than 1 percent to 6 and 7 percent of all passes at two individual sites indicates that the passing driver's decision threshold can be significantly altered by the previous inability to pass as volume levels increase and that passing opportunity at flow levels of only 400 to 500 veh/hr appears to be an integral part of the safe operation of two-lane, two-way rural highways.

RECOMMENDATIONS FOR FUTURE RESEARCH

This effort has developed a significant amount of data related to the operation and safety characteristics of rural two-lane, two-way roadways in peak and off-peak flow conditions. Due to the volume of both field-observed and video-recorded data, the following issues deserve more detailed attention:

1. What type of lead vehicle is causing passing to occur?
2. Are peak and off-peak passing operations similar, or do passing characteristics follow an exponential distribution as traffic flows increase such that increased flows add substantially to degraded passing operations and safety?
3. How do the passing data from this study correspond to data generated by the two-lane traffic simulation model ROADSIM?
4. The significance of close-following platoons should be compared to the *Highway Capacity Manual* (HCM) rural capacity procedures in a before-and-after study of the passing lanes to establish a relationship between the HCM and the safety risk-taking effects observed in this study. This relationship, along with a peaking-sensitive economic analysis procedure, may aid in the determination of need for passing lanes on rural two-lane, two-way roadways.

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