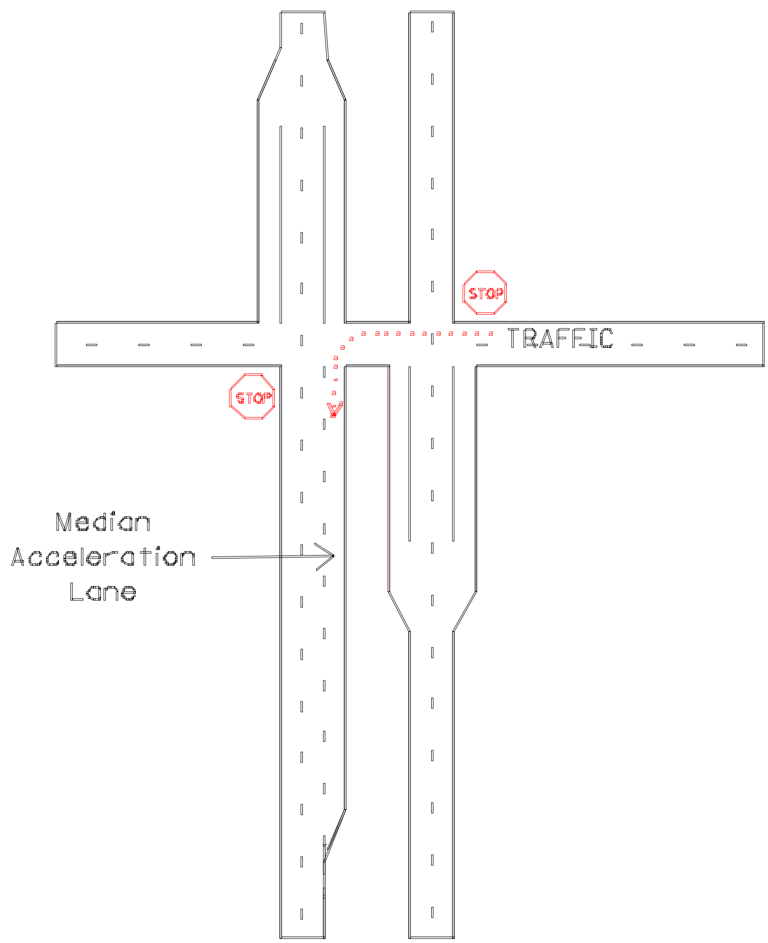
Median Acceleration Lane Study Report



Chad Hanson

Graduate Engineer

Mn/DOT District 6 Traffic Office

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I. Executive Summary

Median acceleration lanes (MALs) have been used at thru-stop intersections on four-lane divided highways in Minnesota for approximately 10 years. They were originally constructed in locations with high truck traffic to allow trucks a safer and easier opportunity at merging with mainline traffic. However, recently they have been looked at as a way to increase intersection safety and decrease delay time for all vehicle types. They are designed to provide benefits for vehicles making a left turning maneuver from a minor two-lane road onto a four-lane divided highway.

The theory behind MALs is that they allow left-turning vehicles to make the turn once there is a gap in the lanes on the near side of the median instead of a gap in the passing lane on the far side of the median and in the lanes on the near side of the median, without stopping in the median. Once vehicles cross the nearest lanes they can immediately make the left turn and begin to accelerate. This should allow vehicles to merge at higher speeds and reduce delay time at intersections.

Since the speed differential between the merging traffic and the mainline traffic is reduced, MALs should reduce the number of accidents near the intersections. Rear-end and sideswipe accidents should be reduced as a result of the higher merging speeds. As a result, MALs are typically used at unsignalized intersections where the volume of mainline traffic is relatively high or where insufficient gaps are available for entering traffic to merge with the mainline traffic. Other locations where MALs may be beneficial are at intersections where there is a high-volume of entering trucks or where there is limited sight distance for entering traffic.

While MALs may not immediately improve intersections as much as interchanges, they may provide many of the same benefits. The advantages of MALs are that they are relatively low-cost as compared to interchanges and they can be designed and constructed more quickly. One reason for this is because they do not typically require the purchase of any additional right-of-way and can be constructed on existing right-of-way, given the median is of ample width. For these reasons, MALs can be used at intersections as an interim measure before interchanges are constructed or when the future traffic characteristics of a highway are uncertain.

Median acceleration lanes will not provide any benefits unless they are properly used, however. Driver education and proper signage may be necessary to help facilitate their usage. It is also not certain how public opinion of the MALs affects their usage. Even if drivers know how to use the lanes properly, the lanes will not be effective unless drivers feel they are beneficial and use them when merging with mainline traffic.

The goals of this study were to investigate both qualitatively and quantitatively the effect of MALs on traffic. It aimed to study their operational effects and safety effects near intersections, along with attempting to measure user opinion of the lanes. The findings of the study will be used to make recommendations regarding the use of MALs.

II. Methodology

The Mn/DOT District 6 Traffic Office conducted this study. The study consisted of three basic components: operational effects, safety effects, and user characteristics. First, the operational effects of the acceleration lanes were studied by analyzing field data, such as traffic volume, merging speed, and delay time. Next, accident histories near the intersections were examined to study the safety effects of the lanes. Finally, a survey was conducted to attempt to measure the public's overall perception of the lanes. Data used for studying the operational effects was only collected from intersections in District 6, due to the close proximity of the intersections. However, data used to study the safety effects was collected from all of the intersections with MALs in Minnesota.

A total of ten MALs in Minnesota were analyzed during this study. Eleven MALs were known to exist in Minnesota at the time of this study; however, one in the metro district was not included because it is less than 400 feet in length. These ten intersections are summarized in Table 2.1. Four of these ten intersections either (a) did not exist or (b) were not 4-lane cross sections before the installation of an MAL. For this reason, "before" data for these four intersections was considered irrelevant for this study.

Table 2.1

Minnesota MAL Locations Included in Study

District	TH	Location	Intersection Ref. Point	Length (ft)	Year Built	Speed Limit	Previous Mainline
3	10 EB	South of Royalton	158+0.800	1080	1997	65	4-lane
	10 WB	East of St. Cloud	180+0.930	1150	1991	65	4-lane
	23 EB	76th Ave. - West of Waite Park	201+0.170	1000	1999	65	2-lane
	23 EB	72nd Ave. - West of Waite Park	201+0.830	1000	1999	60	2-lane
	371 SB	CSAH 46	3+0.490	980	1996	65	4-lane
6	52 SB	75th Street (CSAH 14)	61+0.704	1370	1999	65	4-lane
	52 SB	85th Street (CSAH 154)	62+0.711	1590	1999	65	4-lane
	61 SB	CSAH 18	98+0.929	690	1996	65	N/A
	61 SB	TH 316	104+0.489	1160	1997	65	2-lane
7	169 NB	TH 68	50+0.658	960	1994	65	4-lane

Operational Effects. Field data was collected at three intersections with MALs and two intersections without them. The intersections with MALs on Trunk Highway (TH) 52 at 75th Street NW and 85th Street NW are very similar in geometry and traffic characteristics. All of the data was analyzed based on the traffic volume in the passing lane, so the data should not be skewed just because one more intersection was included that had MALs. This simply creates a larger sample size for intersections that have MALs in place. The intersections where field data was collected are shown in Table 2.2.

Table 2.2

MAL Locations Where Field Data Was Collected					
	Mainline	**Mainline ADT**	**Minor Road**	**Minor Road ADT**	**County**
With MALs	TH 52	24000	75th Street NW	2800	Olmsted
	TH 52	24000	85th Street NW	2800	Olmsted
	TH 61	7000	TH 316	4700	Goodhue
Without MALs	TH 52	23500	CSAH 12	2500	Olmsted
	TH 61	16700	TH 19	3950	Goodhue

Along TH 52 the intersection with County State Aid Highway (CSAH) 12 was chosen due to its close proximity and because it has similar traffic volumes and characteristics to the intersections at 75th Street NW and 85th Street NW. Likewise, along TH 61 the intersection with TH 19 was chosen because of its close proximity and similar traffic volumes and characteristics to TH 316.

Traffic counting tubes were placed in several locations near each intersection. They were placed on the minor road approach to the intersection, on the major road approach on the lanes to be crossed by left turning traffic, and in the passing lane on the major road after the end of the MAL. The tubes were used to measure traffic volume, time, gap size, and gap frequency. See Figure A.1 in the appendix for the locations of the tubes.

Data was also collected at each intersection by observation and with a handheld laser gun. Data that was recorded included the time of day, vehicle type, duration of time that vehicles were delayed at the minor road stop sign, number of vehicles queued at the minor road stop sign, and duration of time that left turning vehicles waited in the median. The speed that vehicles were traveling when they merged from the acceleration lanes into mainline traffic and the distance from the intersection at which this occurred were also measured. See page A-3 in the appendix for a copy of the data sheet that was used to collect the field data.

Data was collected at each location during the peak two hour period and also for two hours at an off-peak time, with the exception of the TH 52/75th Street NW intersection, where it was collected during two peak periods and two off-peak periods. The reason that it was collected during twice as many time periods at 75th Street NW is because this is the first intersection at which data was collected. A few minor changes were made to the data collection methodology after the first two time periods were complete. More data was then collected at this location with the revised process; however, the original data sets were still included since the changes would not have affected the reliability of the data.

The peak period was assumed to be from 7 AM to 9 AM at all of the locations, except for the TH 61/TH 316 intersection, where it was taken to be from 3:30 PM to 5:30 PM. The peak period was assumed to be from 7 AM to 9 AM, since these are the two hours that have the largest number of the people commuting from home to work. The intersections on TH 52 are in locations where drivers would use MALs to travel toward Rochester and at TH 61/TH 19 where they would travel toward Hastings or the Twin Cities. The MAL at the TH 61/TH 316 intersection is in a location where drivers use it when traveling south from Hastings or the Twin

Cities, which is the reason that the peak two hours was assumed to be in afternoon when people are returning home from work.

After all of the data was collected, it was tabulated in spreadsheets. The data from the tube counters was coordinated with the data that was collected manually so that the volume of traffic and time could be matched with each of the vehicles that was observed. All of the traffic volumes were calculated in five-minute intervals. Each of these volumes was then adjusted to hourly volumes by multiplying each volume times 12. The data was then sorted and filtered. The results were put into tables and graphs.

Safety effects. The second part of the study was to analyze the effect MALs have on the safety of intersections by looking at accident histories near the intersections. A total of nine intersections that currently have MALs were studied. Only six of these intersections were studied before the MALs were constructed, because three of the mainlines were previously two-lane sections and one of the intersections did not exist before the MAL was constructed. Eight intersections that do not have MALs were also included in the study.

All of the actual accident reports from crashes that occurred within a minimum of 0.2 miles on either side of the each intersection were compiled. Each one was studied independently to determine if the crash was preventable. Preventable was taken to mean that the crash could have been prevented if an MAL had been in-place and properly used at the intersection. All crashes unrelated to MALs, such as deer hits or those not involving left turning traffic, were disregarded. Comparisons in crash rate were made between intersections before and after the construction of median acceleration lanes and also between intersections that currently have the lanes and those that do not.

The TH 52/75th Street NW and TH 52/85th Street NW intersections were compared to the TH 52/CSAH 12 and TH 52/CSAH 18 intersections in Olmsted County for the comparison between intersections currently with and without acceleration lanes. These intersections were chosen due to their close proximity to one another and similar traffic patterns. The time period of analysis was two years, since the acceleration lanes have only been in place that long. Comparisons were made between the intersection types based on crash rate and crash type.

Those intersections that were used for before and after analysis were the following:

- TH 371/CSAH 46 in District 3
- TH 10 - south of Royalton in District 3
- TH 10 - east of St. Cloud in District 3
- TH 52/75th Street NW in District 6
- TH 52/85th Street NW in District 6
- TH 169/TH 68 in District 7

The TH 61/CSAH 18 intersection in Goodhue County was excluded because it did not exist before the median acceleration lane was constructed. The two intersections west of Waite Park on TH 23 and the TH 61/TH 316 intersection were also excluded, because the highways were converted from two-lane to four-lane roads when the MALs were constructed. Five years of "before" data and as many years of "after" data as was available were used for the analysis. The number of years of "after" data ranged from 2 to 10 years, depending on the intersection. Comparisons were made between before and after construction based on crash rate and crash type.

User Characteristics. The final part of the study on median acceleration lanes was to gauge user opinion of the lanes. Surveys were mailed to households near the intersections being studied. They were mailed to households east of TH 52, near 75th Street NW and 85th Street NW. A database of addresses was searched for this geographic area to determine the best candidates for the survey. The surveys consisted of five simple questions along with ample room for any additional comments regarding the MALs. They were printed on pre-addressed, pre-stamped sheets of paper to make it simpler to respond. See page A-4 in the appendix for a copy of the survey that was mailed out.

200 surveys were mailed to households and approximately 35 of them were returned "undeliverable" due to an error in the address taken from the database. A total of 119 completed surveys were returned. This is a response rate of over 72% of the surveys that were delivered. The results were then tabulated and graphed.

III. Operational Effects

The four major factors that were analyzed to determine the operational characteristics of MALs were the delay time, the length of the acceleration lane used before merging, the speed of vehicles at the time of merging with mainline traffic, and vehicle type. The delay time refers to both the duration of time that vehicles were delayed at the minor road stop sign and the time they waited in the median. The factors were also used to determine if drivers know how to properly use MALs and if they are used as intended. Although these four factors are closely related, they were analyzed separately to examine the differences depending on traffic volume.

The data and figures summarizing the operational effects of MALs frequently relate the four operational factors to the volume of traffic. It should be noted that the factors are specifically related to the size and frequency of gaps in the mainline traffic. Then the acceptable gap, or gap size that drivers take to be acceptable for them to merge into, relates directly to the operational factors. Due to the difficulty in accurately measuring gap acceptance, the measurement of this parameter was not possible. Better data collection equipment is needed to measure this parameter.

It was possible to record the frequency and size of gaps in the passing lane, but it was not possible to determine the specific gap that a driver accepted. Table 3.1 summarizes the gap frequency depending on the volume of traffic in the passing lane. This table is a summary of all of the data collected at all of the intersections included in the study. It shows how the frequency of smaller gaps in traffic increases and the frequency of larger gaps decreases as the traffic volume increases. Figure A.2 in the appendix shows the gap frequency based on the specific traffic volumes in the passing lane. The ITE Traffic Engineering Handbook (TEH) suggests that the acceptable gap for left turning traffic entering a four-lane divided highway from a minor road is typically 7.5 seconds. Drivers would accept over 80% of the gaps when the traffic volume is a minimum (< 100 vehicles per hour). Whereas, drivers would only find 27% of the gaps acceptable when the traffic volume is significantly greater (500-600 vehicles per hour). A summary of the percent of total gaps that would likely be accepted (≥ 7.5 seconds) is shown in Table 3.2. Even though there are a larger number of total gaps, the percentage of these gaps that would be considered acceptable is much lower at higher traffic volumes.

Table 3.1

Gap Frequency vs. Traffic Volume in Passing Lane

	Volume (vph)							
Gap (s)	**0-100**	**100-200**	**200-300**	**300-400**	**400-500**	**500-600**	**600-700**	**700-800**
0-1.50	6%	11%	15%	18%	19%	27%	30%	35%
1.5-3.0	4%	8%	12%	15%	15%	20%	18%	20%
3.0-4.5	3%	6%	7%	8%	13%	10%	11%	9%
4.5-6.0	3%	6%	7%	8%	9%	10%	9%	7%
6.0-7.5	2%	4%	5%	6%	8%	6%	8%	8%
7.5-9.0	3%	4%	4%	5%	7%	3%	4%	6%
9.0-10.5	2%	4%	4%	4%	5%	3%	3%	3%
10.5-12.0	2%	3%	3%	5%	3%	3%	4%	2%
12.0+	75%	55%	42%	31%	22%	18%	12%	10%

Table 3.2

Acceptable Gap Frequency (≥ 7.5 sec.) vs. Traffic Volume in Passing Lane							
Volume (vph)							
0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800
81%	66%	54%	45%	37%	28%	24%	20%

Many of the data and figures relate the operational factors to the volume of traffic in the passing lane. It should be noted that the operational factors might also be related to the traffic volume in the driving lane, however this relationship was not analyzed independently. This relationship exists because a lower volume of traffic in the driving lane allows vehicles in the passing lane to change lanes more readily to give entering vehicles a larger gap with which to merge into. It was assumed that a reasonably uniform ratio of traffic volume in the passing lane to volume in the driving lane exists on the highways included in this study. Therefore, the relationship between the operational factors and total volume of traffic can be analyzed if the volume in the passing lane is known.

The relationship between volume of traffic in the passing lane and in the driving lane was investigated to confirm this assumption. The results summary and standard deviation of the data are shown in Table 3.3. From this table it appears that the percent of total traffic that travels in the passing lane ranges between 10% and 20%, depending on the total traffic volume. It appears that a reasonably uniform ratio of traffic volume between the passing and driving lanes does exist, since the standard deviations are relatively low.

Table 3.3

Percent of Traffic in Passing Lane by Total One-way Traffic Volume		
Total One-way Traffic Volume (vph)	Percent of Traffic in Passing Lane	Standard Deviation of Traffic in Passing Lane
0 - 300	10%	5.6
300 - 600	16%	7.1
600 +	19%	6.4

Delay time. The greatest reduction in delay time can be attributed to the fact that left turning vehicles are not required to stop in the median before merging with through traffic. Of all of the vehicles observed in the study at intersections without MALs, approximately 74% stopped in the median. 17% waited in the median for greater than 10 seconds. Figures 3.1 and 3.2 show the relationship between the median delay time and the traffic volume in the passing lane at locations without MALs.

Theoretically, at locations with MALs there should be no median delay time if the lanes are used correctly. In this study, 4% of all the vehicles observed waited in the median and only 1% waited greater than 10 seconds in the median. From this data it appears that the majority of motorists know how to use MALs correctly, however there is a small percentage of drivers who either do not know how to properly use MALs or do not feel comfortable using them.

The study also looked at the total delay time experienced by left turning vehicles at both intersections with and without MALs. Total delay time refers to the sum of the time spent waiting at the stop sign of the minor road and the time spent waiting in the median. Total delay time was analyzed to determine if it is dependent on both the traffic volume in the lanes on the near side of the median and the traffic volume in the lanes on the opposite side.

The intersections studied that did not have MALs had a lower average two-way traffic volume than the intersections with them. Only the total delay times for similar two-way traffic volumes were used for comparison. Figures A.3 and A.4 in the appendix show the relationship between the total delay time and two-way traffic volumes at intersections with and without MALs. A best-fit line was inserted on the figures assuming that a linear relationship exists between the total wait time and the two-way traffic volume. The data shows that the intersections with MALs had a noticeably lower total average delay time than those without the lanes when the two-way traffic volume was 300-800 vehicles per hour. For this traffic volume, the average total delay time for intersections with MALs was 7.0 seconds and for intersections without MALs was 11.2 seconds. The total delay time was found to be greater at the intersections without MALs for all traffic volumes analyzed.

Figure 3.1
Median Delay Time
(Intersections Without MALs)

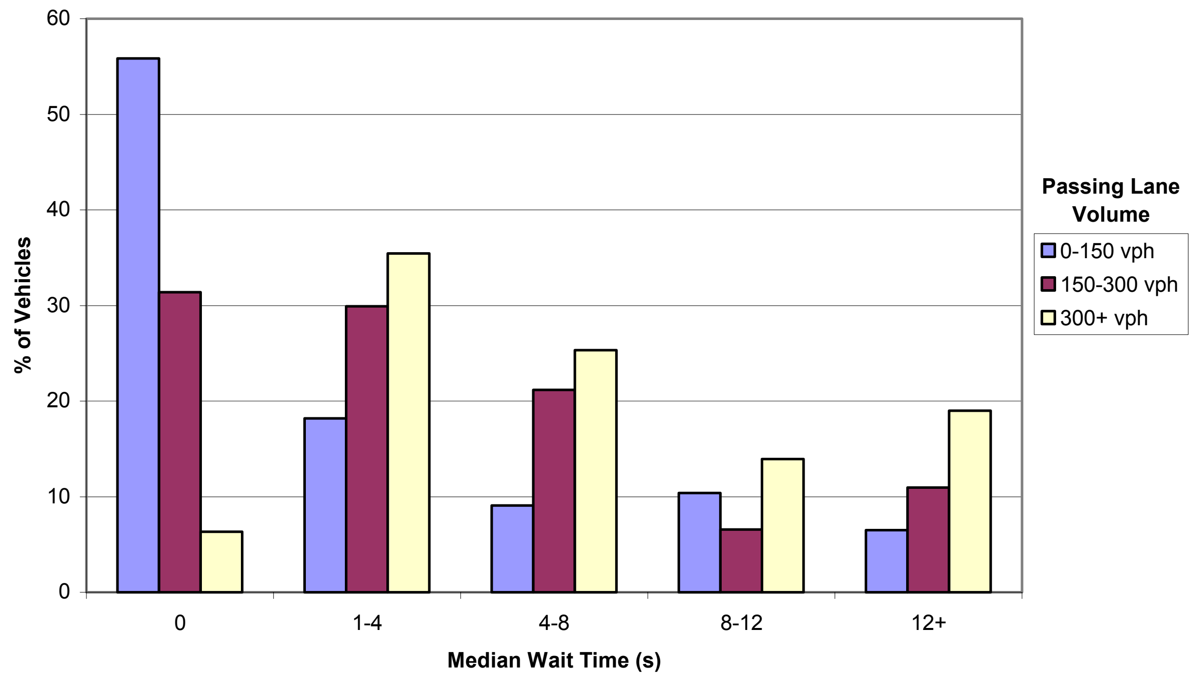
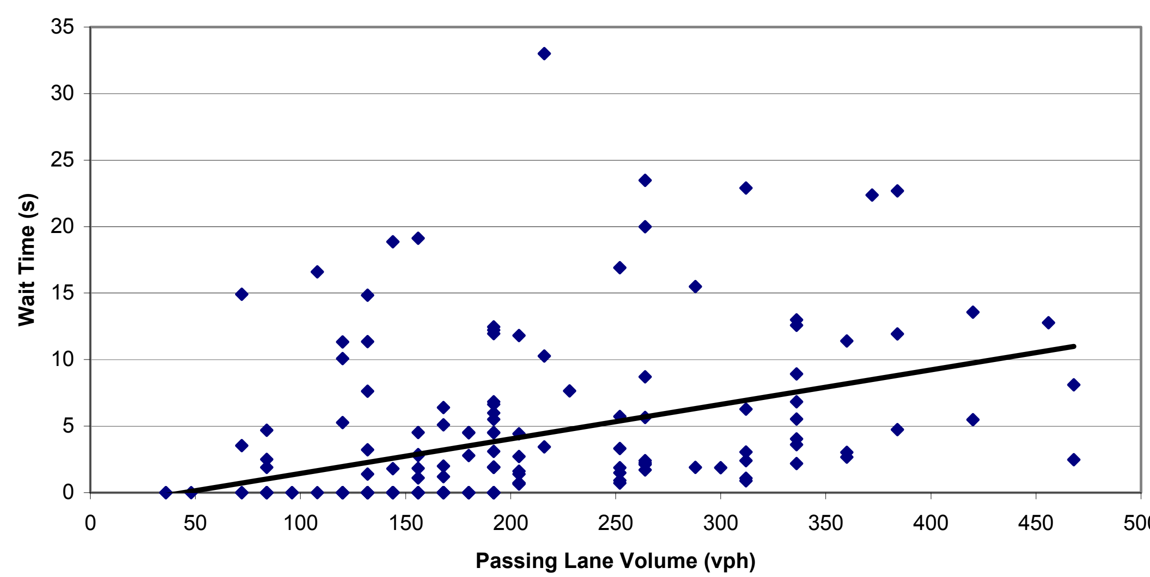


Figure 3.2
Median Delay Time by Traffic Volume in Passing Lane
(Intersections Without MALs)



Length. The length of the ten median acceleration lanes in Minnesota that were included in the study ranged in length from 690 to 1590 feet, with an average of 1098 feet. The study's goal was to analyze the relationship between traffic volume and the length of an MAL that is used by drivers. The study assumed that the relationship between the length of acceleration lane used and volume of traffic was linear.

Figures 3.3 and 3.4 show the relationship between traffic volume in the passing lane and length of MAL used. As expected, they show that as the traffic volume increases in the passing lane, the length of MAL used also increases. When the volume is low, less than 100 vehicles per hour, nearly 43% of the vehicles merge within the first 200 feet of the acceleration lane. This shows that when the volume is low, and it should be easy for drivers to find acceptable gaps in the mainline traffic, a large percentage of the vehicles are using the lanes very minimally or not at all. However, for the same volume of traffic, approximately 15% of vehicles use over 800 feet of the lane. An assumption can be made that there should be sufficient gaps in the mainline traffic to allow vehicles to merge within the first 800 feet of the MALs with this volume of traffic. Therefore, regardless of the length of the lanes, a certain percentage of drivers will use a majority of MALs before merging.

The length of MAL used vs. traffic volume relationship can be further investigated by analyzing Figures 3.5 and 3.6. They take the length of the acceleration lane into account and show the percentage of MAL that is used depending on the traffic volume in the passing lane. Figure 3.5 illustrates that when less than 150 vehicles per hour are in the passing lane, nearly 20% of the vehicles use greater than 60% of the MALs. Furthermore, regardless of the volume of traffic in the passing lane, over 10% of the vehicles use over 80% of the MALs. Figure 3.6 shows that even though the percent of MAL used increases, as one would expect with the traffic volume, the data is highly variable. These figures show that many drivers use more length of the acceleration lanes than they actually should need in order to find an acceptable gap in the mainline traffic.

On the other hand, when traffic volumes in the passing lane are significantly high and fewer gaps are available in the mainline traffic, a greater length of the acceleration lanes may be required for drivers to merge safely. From Figure 3.3 it appears that the majority of all drivers use a minimum of 500 feet, or an average of approximately 40% of the MALs, when the traffic volume exceeds 400 vehicles per hour in the passing lane. For this same volume, approximately 55% of drivers use over 800 feet of the MALs and nearly 35% use in excess of 1000 feet.

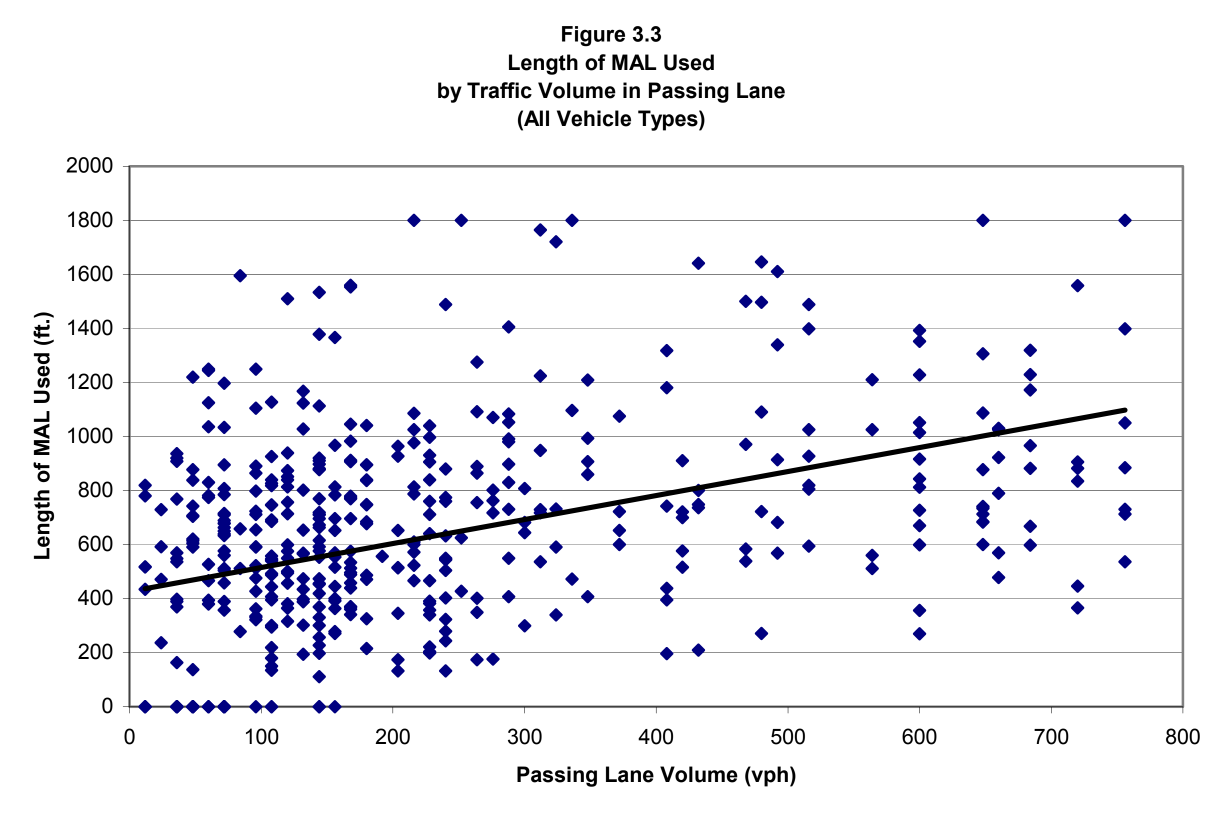


Figure 3.3
Length of MAL Used
by Traffic Volume in Passing Lane
(All Vehicle Types)
Length of MAL Used (ft.)
Passing Lane Volume (vph)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
100
200
300
400
500
600
700
800

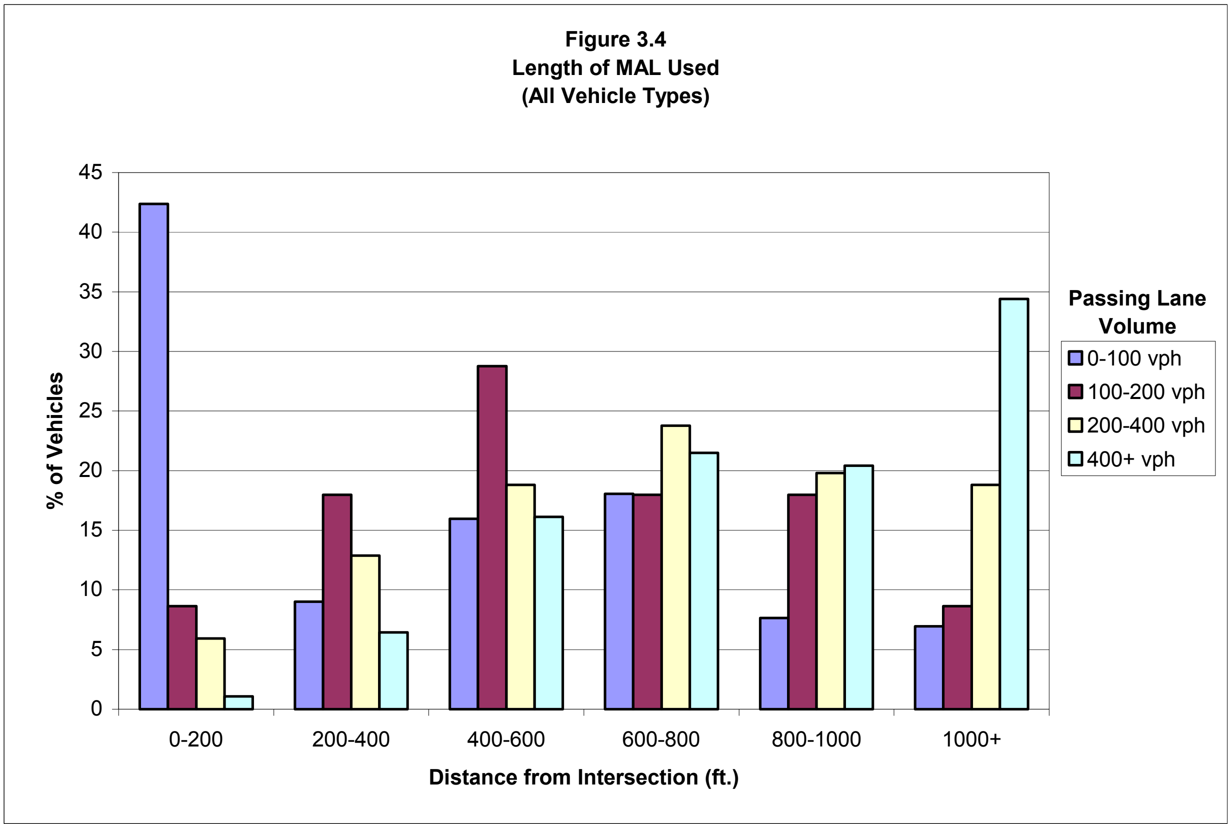


Figure 3.4
Length of MAL Used
(All Vehicle Types)
% of Vehicles
0
5
10
15
20
25
30
35
40
45
0-200
200-400
400-600
600-800
800-1000
1000+
Distance from Intersection (ft.)
Passing Lane Volume
0-100 vph
100-200 vph
200-400 vph
400+ vph

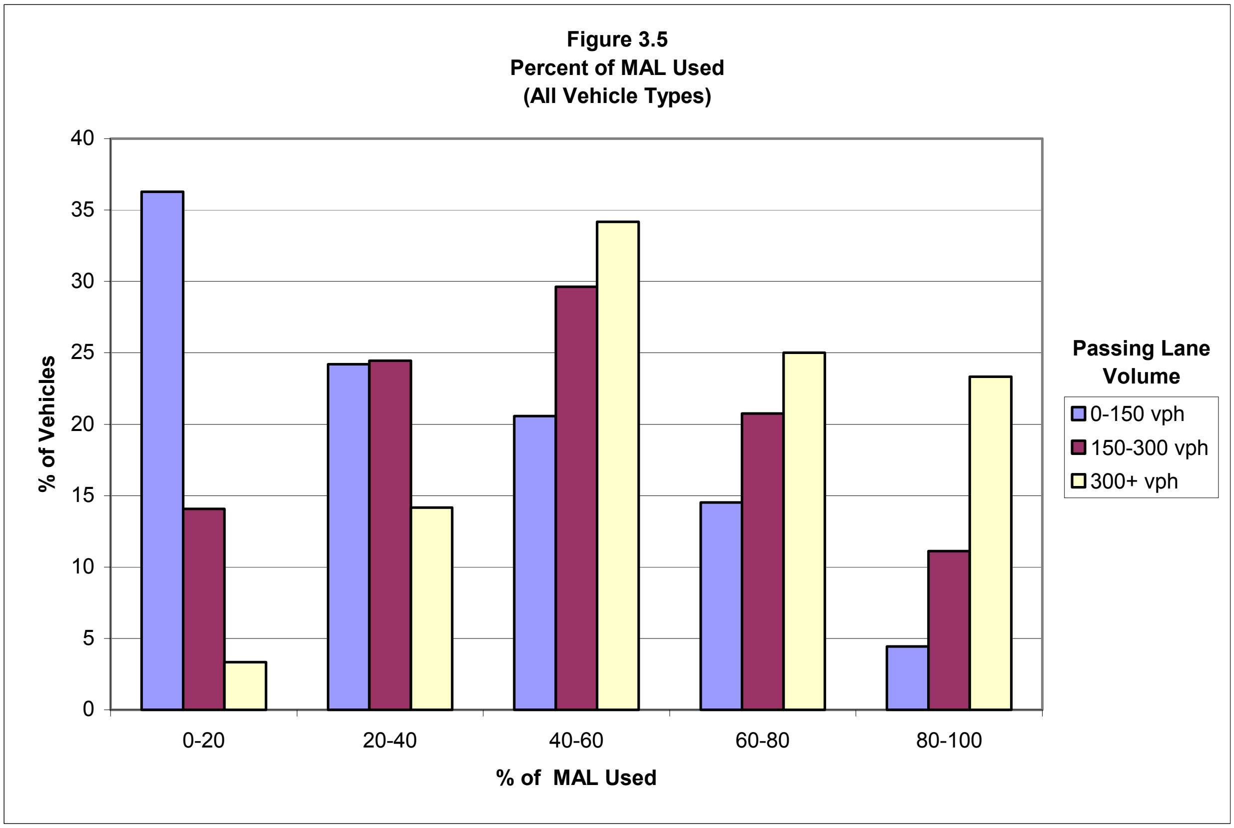


Figure 3.5
Percent of MAL Used
(All Vehicle Types)
% of Vehicles
40
35
30
25
20
15
10
5
0
0-20
20-40
40-60
60-80
80-100
% of MAL Used
Passing Lane Volume
0-150 vph
150-300 vph
300+ vph

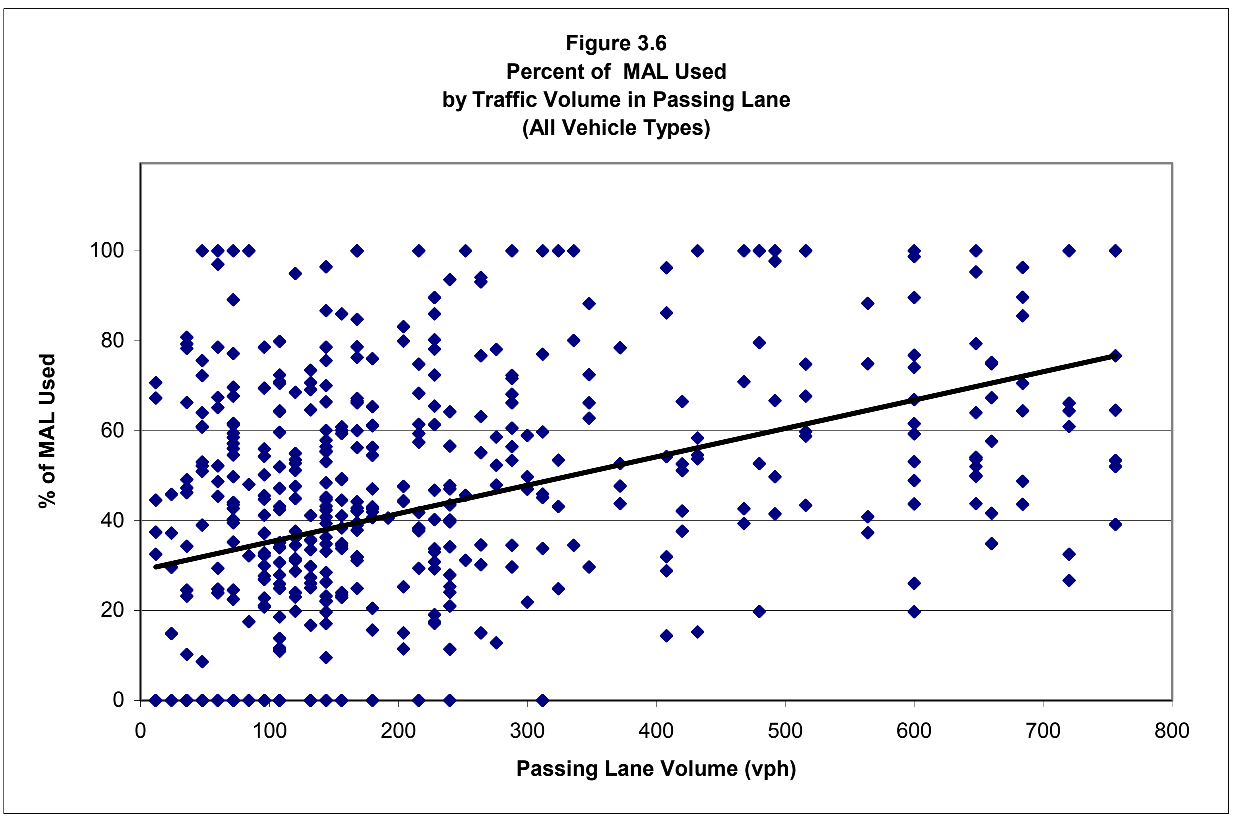


Figure 3.6
Percent of MAL Used
by Traffic Volume in Passing Lane
(All Vehicle Types)
% of MAL Used
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Passing Lane Volume (vph)

Speed. The study also analyzed the relationship between the speed that vehicles are traveling upon merging into the MALs and the volume of traffic in the passing lane. When the mainline volume of traffic is higher, merging vehicles must be traveling closer to the speed of the mainline vehicles in order to merge safely with traffic, without causing excessive deceleration of vehicles already in the passing lane. The lanes must therefore be long enough to allow drivers to reach their desired speed when merging.

Figure 3.7, taken from the TEH, shows the average acceleration of a passenger vehicle from rest. Figure 3.8, based on field data, shows that approximately 60% of all merging vehicles merge at speeds between 40 mph and 60 mph, with the highest percentage merging at speeds between 51 mph and 55 mph. Assuming that 55 mph is a desirable speed for vehicles to merge at, Figure 3.7 shows that a passenger vehicle would need approximately 1000 feet of acceleration lane before merging with mainline traffic. Therefore, to allow vehicles to accelerate to 55 mph without requiring them to use the through lanes as speed change lanes, the MALs would need to be a minimum of 1000 feet in length.

The relationship between merging speed and traffic volume in the passing lane is shown in Figures 3.9 and 3.10. This shows that as the mainline traffic volume in the passing lane increases from zero to approximately 700 vehicles per hour, the average speed at which vehicles merge at increases from 30 mph to over 60 mph. This helps to confirm the assumption that as the volume on the mainline increases and the available gap size decreases, drivers accelerate to higher speeds before merging.

Figure 3.7
Acceleration of Vehicle from Rest
(Taken from ITE Traffic Engineering Handbook)

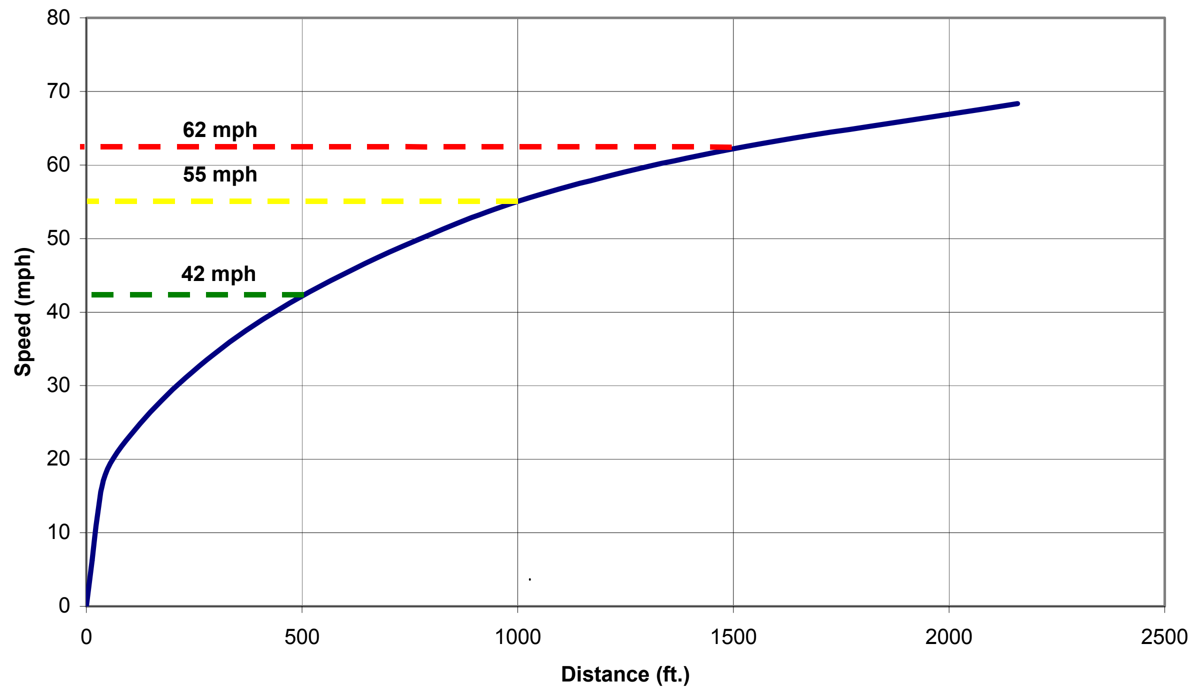


Figure 3.8
Merging Speed of Vehicles Entering Highway
(Locations with MALs)

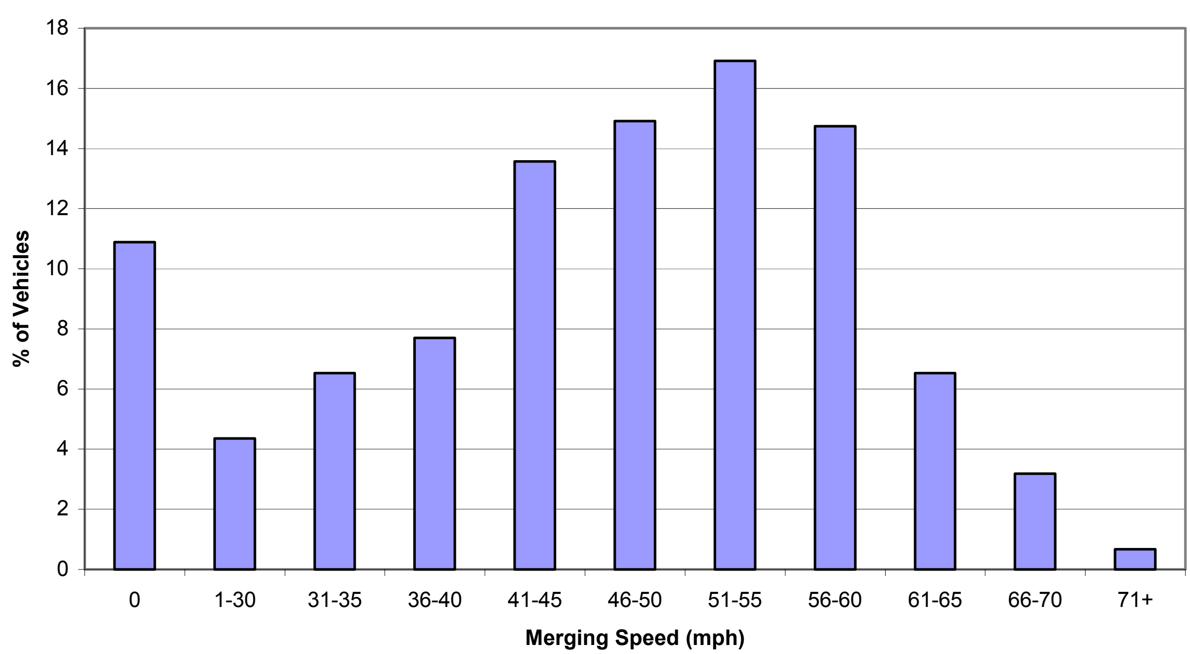


Figure 3.9
Merging Speed of Vehicles
(All Vehicle Types)

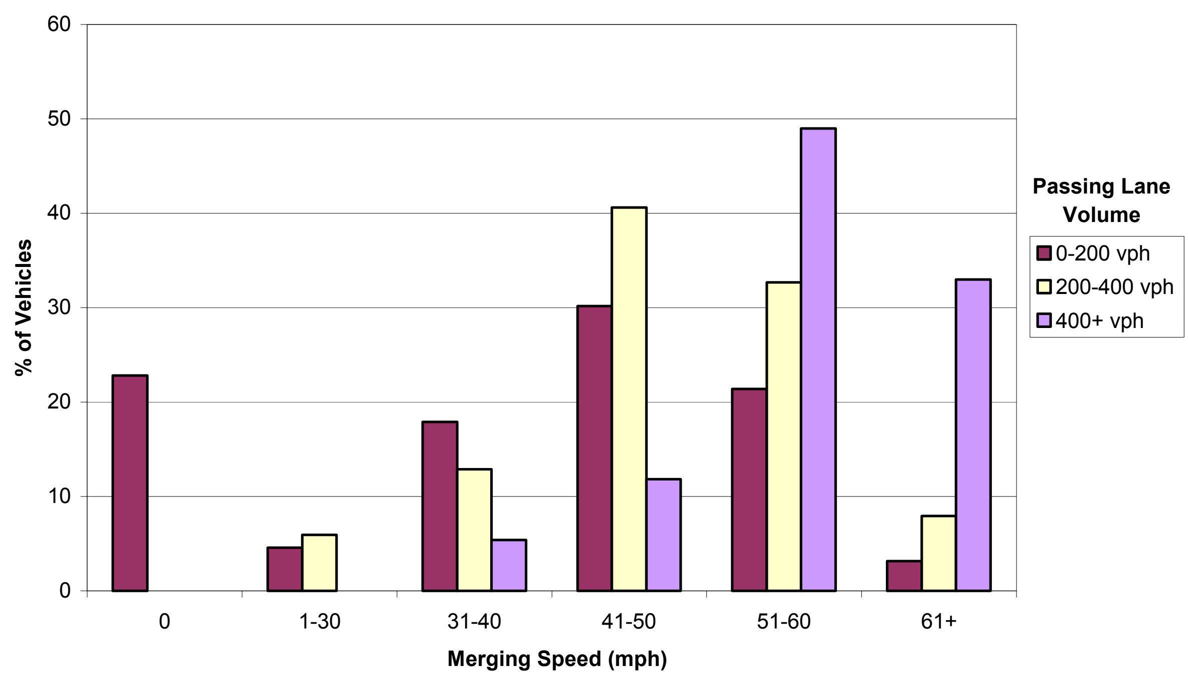
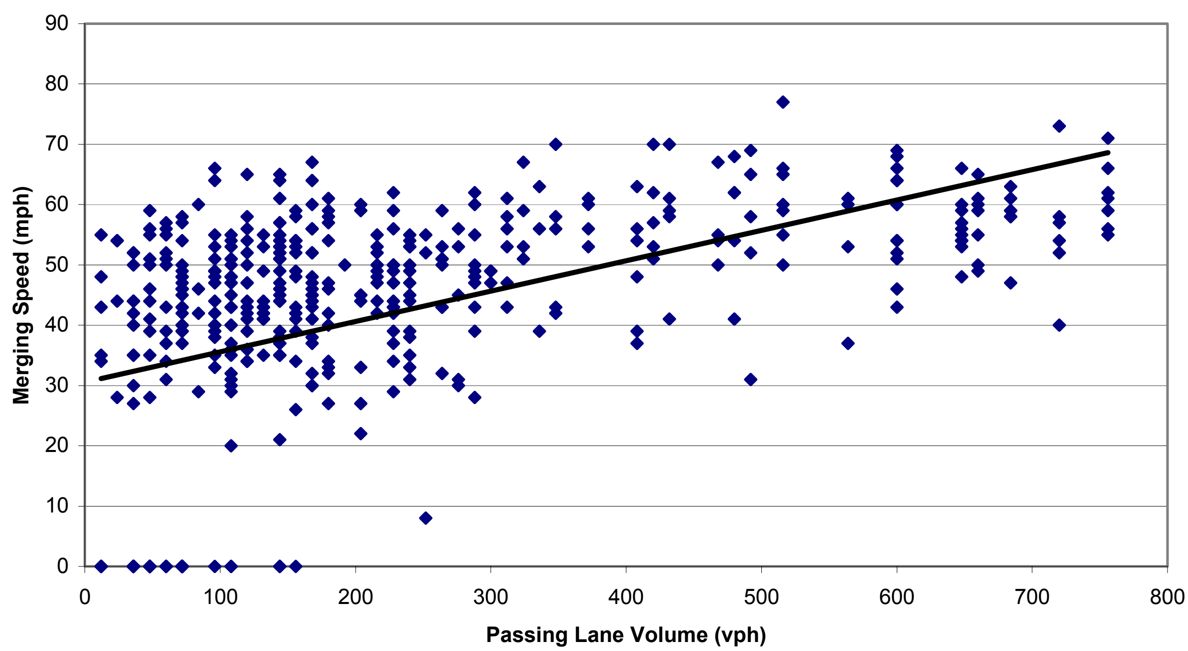


Figure 3.10
Merging Speed by Traffic Volume in Passing Lane
(All Vehicle Types)



Vehicle Type. The study analyzed the effect that vehicle type has on the use of the MALs. Passenger cars, single-unit trucks, and semi tractor-trailers were all studied independently. Specifically, the length of the MALs that are used by each vehicle type and the speed that vehicles are traveling upon merging into the MALs were studied. The sample size of each vehicle type studied is the following:

- Passenger cars = 398 vehicles
- Single-unit trucks = 46 vehicles
- Semi tractor-trailers = 33 vehicles

The acceleration characteristics of each vehicle type included in the survey are shown in Figures A.5, A.6, and A.7 in the appendix.

The length of acceleration lane used by each vehicle type was studied based on the volume of traffic in the passing lane. Table 3.4, which shows the average length of MAL used by vehicle type, was taken from Figures A.8, A.9, and A.10 in the appendix. Passenger cars most likely use the least length of the MALs, because they are able to achieve a desirable speed much quicker and do not need as much length of acceleration lane. The length of MAL used most likely converges between the vehicle types as the volume increases, because all vehicles have more difficulty finding an acceptable gap and need more of the MALs.

Semi tractor-trailers use the greatest length of MALs, on average, because their acceleration characteristics are typically the lowest. Therefore, it takes them a greater distance to reach an acceptable merging speed. However, looking more closely at Figure A.10 in the appendix shows that even though the averages are near what is expected, there is a high variability in the length of MAL used. Several trucks used a very minimal amount of the lanes (less than 400 feet) and several used a great deal of them (over 800 feet), however few of them are near the average.

Some trucks seem to merge into the mainline as soon as there is a gap, even if they are not near the speed of mainline traffic, whereas trucks that both accelerate to speeds near that of the mainline and then look for an acceptable gap use nearly the full length of the MALs. It is presumed that since trucks require a larger acceptable gap, many of them merge as soon as a suitable gap is available. These trucks then attempt to merge into the passing lane and continue their acceleration. A larger sample size is needed in order to make any concrete conclusions.

Single-unit trucks seem to show the least variability in length of MAL used, depending on the traffic volume in the passing lane. One reason for this could be due in part to the broad definition of single-unit trucks. Vehicle length and power/mass ratio may vary greatly among the many different types of single-unit trucks. For example, longer vehicles need a larger gap and may use more of the MALs when merging. Another reason for the lack of variability dependent on the volume in the passing lane could be due to the relatively small sample size.

Table 3.4

Average Length of MAL Used			
Average Traffic Volume in Passing Lane (vph)	**Passenger Cars**	**Single-unit Trucks**	**Semi Tractor-Trailers**
0	390	781	457
100	477	796	562
200	563	811	668
300	649	826	774
400	735	841	879
500	821	856	985
600	907	871	1090

The values in Table 3.5 were taken directly from Figures A.8, A.9, and A.10 in the appendix. It appears that the average merging speed is very similar between passenger cars and single-unit trucks, while semi tractor-trailers have the lowest merging speed. One reason for the large merging speed differential in passenger cars is because when the traffic volume is low, a large percentage of passenger cars do not use the MALs at all. Therefore, when the traffic volume is low, the average merging speed of passenger cars actually using the MALs is significantly higher than is shown in Table 3.5.

It can be seen from Table 3.5 that passenger cars merge at average speeds ranging in mph from the low 30s to the low 60s depending on the traffic volume. Semi tractor-trailers merge at average speeds ranging in mph from the low 20s to the middle 40s. Therefore, even though semi tractor-trailers use considerably more of the MALs, they still do not reach speeds comparable to those of passenger cars upon merging from the MALs into the through lanes.

Table 3.5

Average Merging Speed of Vehicles			
Average Traffic Volume in Passing Lane (vph)	**Passenger Cars**	**Single-unit Trucks**	**Semi Tractor-Trailers**
0	31	36	22
100	36	39	26
200	42	43	30
300	47	46	34
400	52	49	38
500	57	53	42
600	63	56	46

IV. Safety Effects

Several intersections were analyzed for the effect that the MALs have on safety. The following results were found:

- 9 crashes were deemed preventable at the 9 intersections that currently have MALs (MAL intersections).
- 8 crashes that occurred before the MALs were constructed were considered preventable at 6 of those same intersections (pre-MAL intersections). Three intersections were not included in the pre-MAL intersection calculations, because the mainline was upgraded from two to four lanes at the same time that the MALs were constructed.
- 21 crashes were deemed preventable at the 8 intersections that have never had MALs, but have similar traffic volumes and geometries to the MAL intersections that do have MALs (non-MAL intersections).

Accident rates were calculated for non-MAL, pre-MAL, and MAL intersections. Accident rates were calculated based on the number of preventable crashes per ten million entering vehicles. The rates will be numerically low due to the fact that they only take into account crashes related to MALs, however they are still relevant for comparison purposes.

Tables 4.1 and 4.2 show the crash comparisons of non-MAL, pre-MAL, and MAL intersections in Minnesota. The non-MAL intersections that were used for comparison purposes were selected based on several criteria. They were taken from nearby intersections on the same four-lane divided highways that currently have MALs that were included in the study. Two unsignalized intersections were chosen from each of the following highways: TH 10, TH 52, TH 61, and TH 169. All of the intersections had a minimum 1998 ADT of 9000 vehicles on the mainline and a minimum of 2000 vehicles on the minor road approach.

The average crash rates shown in Table 4.1 support the theory that MALs increase the safety at certain intersections. More data should be collected at intersections with and without MALs to further prove this theory, due to the variability in the existing data. However, this is difficult since all of the MAL intersections in Minnesota have already been included in this study.

Table 4.1

Overall Intersection Preventable Crash Rates (Per 10 million entering vehicles)		
Non-MAL Intersections	**Pre-MAL Intersections**	**MAL Intersections**
0.67	0.40	0.34

Table 4.2 compares the type of accident depending on the type of intersection that it occurred at. There clearly seems to be a reduction in rear-end accidents at MAL intersections. There also seems to be a slight reduction in "sideswipe same direction" crashes between non-MAL and MAL intersections. They may be listed as sideswipe crashes, because one of the vehicles may have swerved to avoid a rear-end crash. No other types of accidents show any other significant

differences between the different intersection types. Once again a larger sample of intersections with and without MALs would help to draw more definite conclusions.

Table 4.2

Preventable Crashes/Year/Intersection			
ACCIDENT TYPE	**Non-MAL Intersections**	**Pre-MAL Intersections**	**MAL Intersections**
REAR-END	0.28	0.13	0.08
SIDESWIPE SAME DIRECTION	0.13	0.03	0.03
LEFT TURN	0.00	0.00	0.00
RUN OFF ROAD LEFT	0.00	0.03	0.00
RIGHT ANGLE	0.13	0.07	0.11

Four intersections on TH 52 in Olmsted County were examined more closely based on the number and type of preventable crashes. These four intersections were studied more closely due to their close proximity and the fact that their traffic volumes and intersection geometries are very similar. For several years these four intersections have had above-average crash rates, especially those related to left turning traffic entering TH 52. Median acceleration lanes were constructed at two of the intersections (75th Street NW and 85th Street NW) in 1999 and the other two (CSAH 18 and CSAH 12) do not have MALs. The crash data was analyzed for the two years since the acceleration lanes have been in place. Tables 4.3 and 4.4 summarize this data.

Table 4.3 shows the comparison of the overall intersection preventable crash rates between the intersections with and without MALs. The intersections without the MALs had approximately 80% more preventable crashes than the intersections without them. These results are quite convincing due to the similarities in traffic volumes and intersection geometries between the four intersections, even though the time period of analysis was only two years.

Table 4.3

Overall Intersection Preventable Crash Rates (per 10 million entering vehicles)	
TH 52 Intersections	
CSAH 12 & CSAH 18 (w/o MAL)	**75th St. NW & 85th St. NW (Has MAL)**
1.81	1.04

The comparison of the frequency of each accident type between intersections with MALs and those without them is shown in Table 4.4. Once again, the rate of preventable rear-end accidents occurring is four times greater at the two intersections without MALs. Furthermore, there were no accidents classified as “sideswipe same direction” at the two intersections with MALs while there were approximately 0.40 preventable crashes of that type at the intersections without

MALs. The data also shows that there was a slight increase in the number of right angle crashes at the two intersections with MALs.

Table 4.4

Preventable Crashes/Year/Intersection		
	TH 52 Intersections	
ACCIDENT TYPE	**CSAH 12 & CSAH 18 (w/o MAL)**	**75th St. NW & 85th St. NW (Has MAL)**
REAR-END	1.00	0.25
SIDESWIPE SAME DIRECTION	0.40	0.00
LEFT TURN	0.00	0.00
RUN OFF ROAD LEFT	0.00	0.00
RIGHT ANGLE	0.30	0.50

Crash severity data was also collected for all of the preventable crashes included in the study. This data was not included in this report. See the Mn/DOT District 6 Traffic Office for this data.

V. User Characteristics

The goal of the survey was to get input on MALs from drivers that frequently use intersections where they are in place. The surveys were mailed to residences east of TH 52 near 75th Street NW (CSAH 14) and 85th Street NW (CSAH 154) in Olmsted County. The five basic questions that were asked tried to measure public perception of MALs, including the benefits of them and potential improvements/changes that can be made to them. Of the 119 surveys that were returned, over 50% of them were completed by drivers that use them at least once per day and nearly 85% were completed by those using MALs at least once weekly. See Figure 5.1 for the average intersection usage of the people that completed the survey.

Nearly 90% of respondents indicated that they always use the acceleration lanes when merging with mainline traffic. See Figure 5.2 for the average MAL usage of the survey respondents. This clearly shows that almost all drivers regularly use the lanes. However, the respondents to the survey were mainly drivers that regularly use the lanes and the results may be different for drivers who are unfamiliar with them.

From Figures 5.3, 5.4, and 5.5 it can be seen that the majority of drivers feel MALs improve the safety of intersections, decrease the intersection delay time, and make it easier to merge with mainline traffic at intersections where they are used compared to those where they are not. The public perception of MALs is clearly favorable. Drivers are more apt to use MALs since they feel that the lanes provide many benefits. As a result of the regular usage of the lanes, the overall safety of the intersections should increase.

A majority of the surveys included positive comments regarding MALs. Most comments expressed the many benefits that MALs provide at intersections. A few concerns and recommendations were common on many of the surveys. The most frequent ones being:

- Many drivers do not know how to properly use the acceleration lanes. They either wait at the side road or in the median until a gap is available in the traffic that they are attempting to merge with.

- Mainline traffic is too often not aware of the MALs. Mainline traffic approaching the intersections sees traffic from the minor road turn left immediately without stopping in the median and assumes that the vehicles are in the through lanes. The mainline traffic often decelerates unnecessarily because of this.

- More signing is necessary at these intersections to make both mainline traffic and left turning traffic more aware of the acceleration lanes.

- A larger radius is needed at the intersection in the median to allow drivers easier access to the MALs. It was suggested that a larger radius would eliminate the need for larger trucks to encroach on the through lanes when using the acceleration lanes.

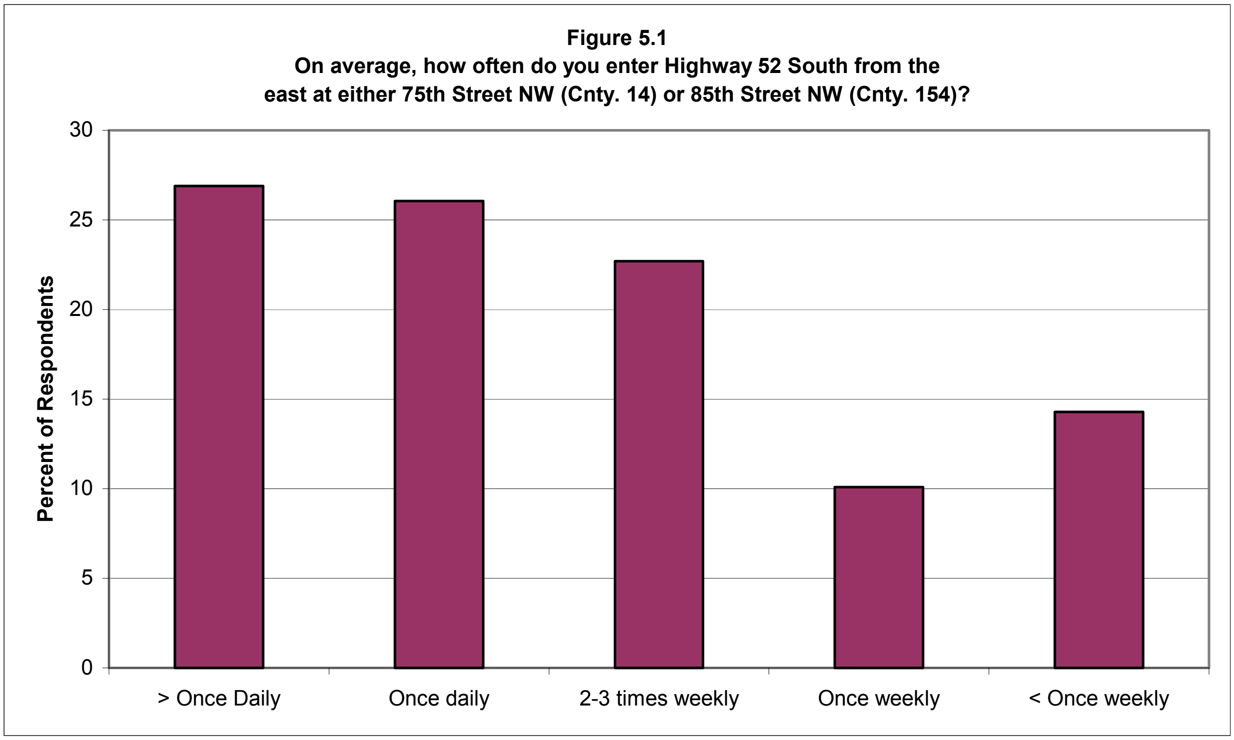


Figure 5.1
On average, how often do you enter Highway 52 South from the east at either 75th Street NW (Cnty. 14) or 85th Street NW (Cnty. 154)?
Percent of Respondents
0
5
10
15
20
25
30
> Once Daily
Once daily
2-3 times weekly
Once weekly
< Once weekly

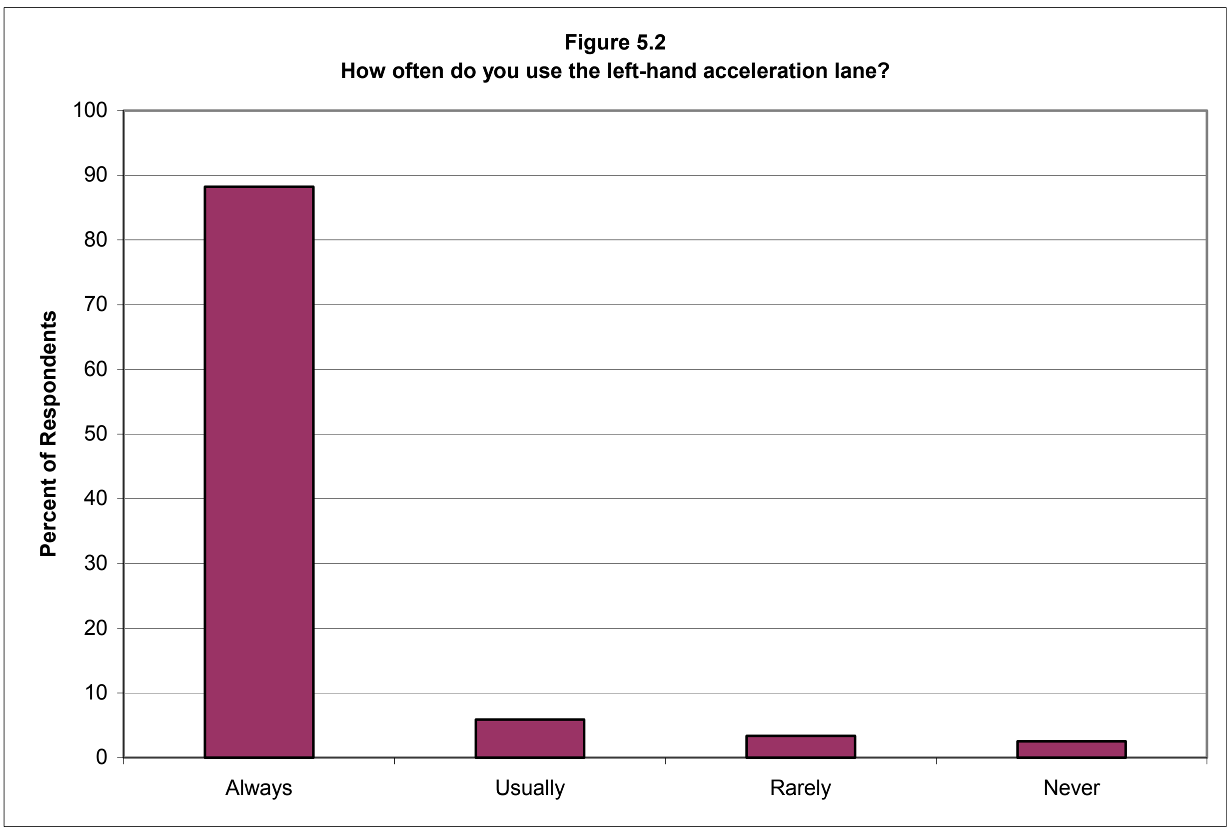


Figure 5.2
How often do you use the left-hand acceleration lane?
Percent of Respondents
0
10
20
30
40
50
60
70
80
90
100
Always
Usually
Rarely
Never

Figure 5.3
With 1 being not at all and 5 being very much, how much do you feel the left-hand acceleration lane improves the safety of these intersections?

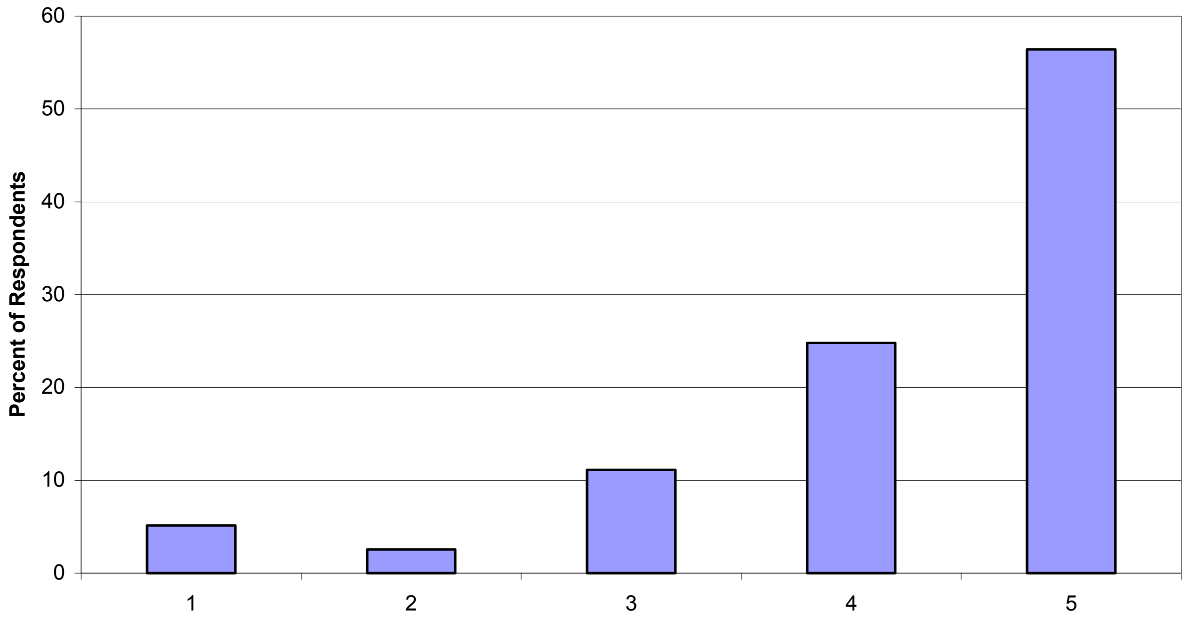
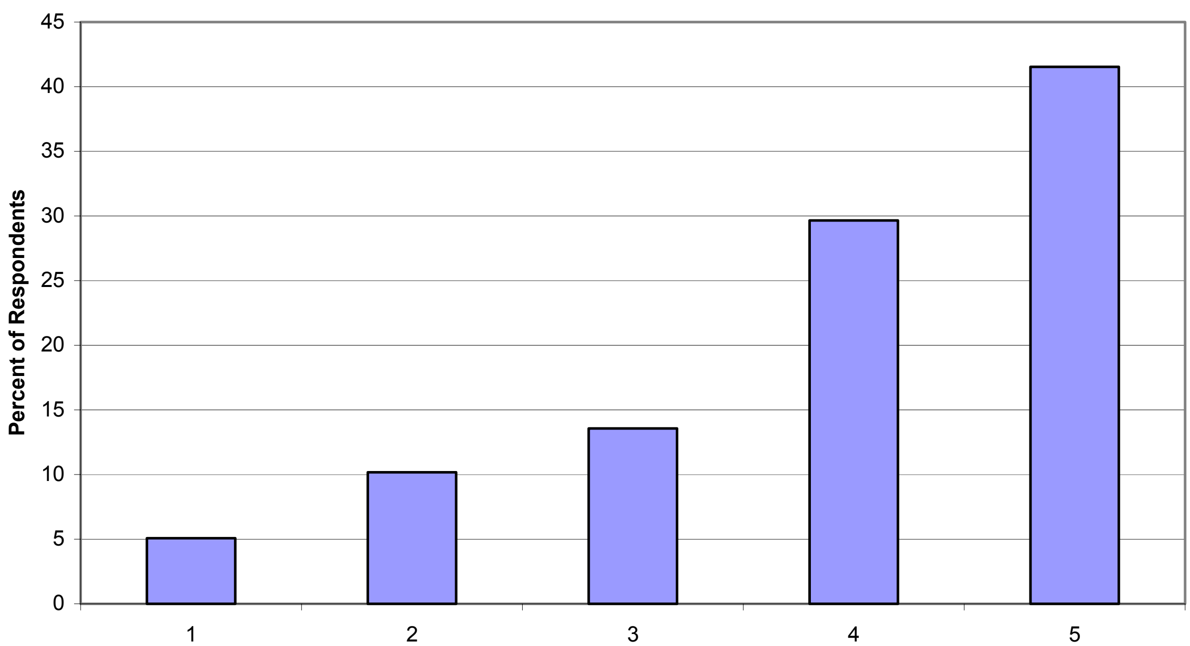


Figure 5.4
With 1 being not at all and 5 being very much, do you feel that your wait to enter Highway 52 is shortened as a result of the left-hand acceleration lane?



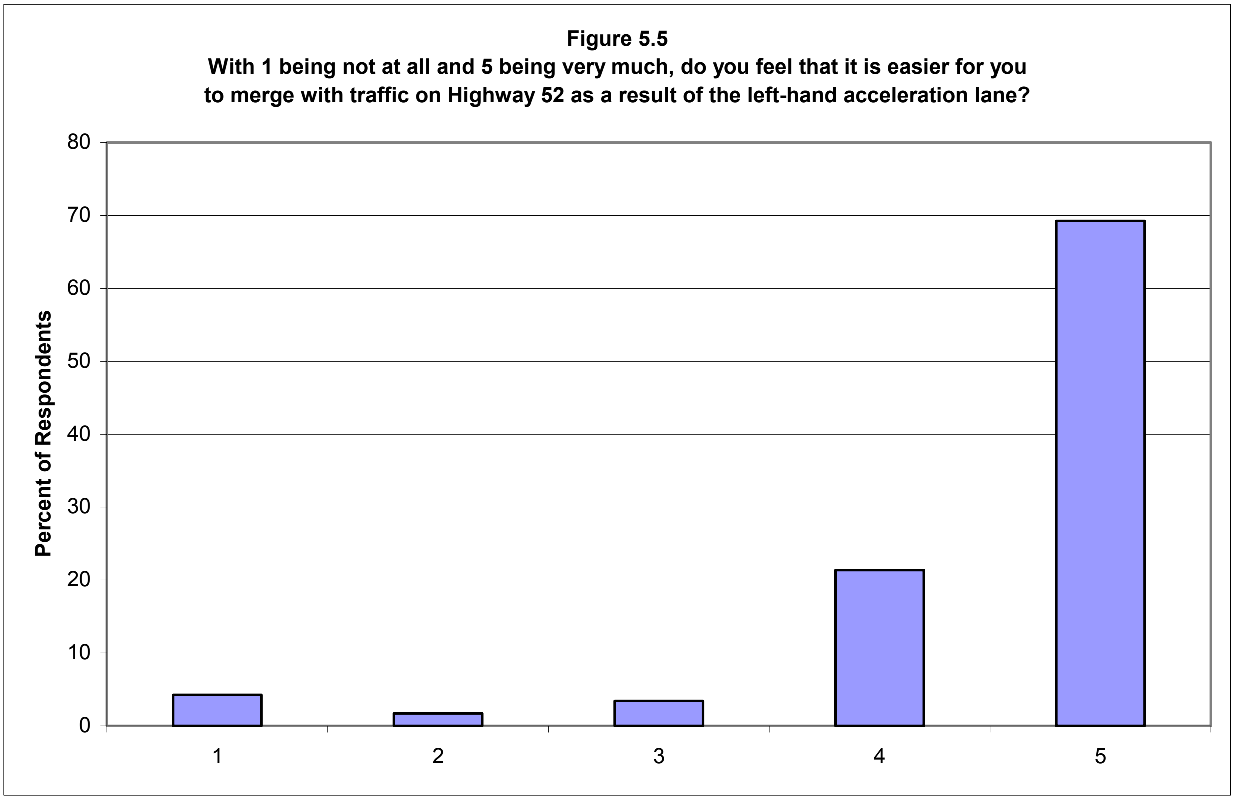


Figure 5.5
With 1 being not at all and 5 being very much, do you feel that it is easier for you to merge with traffic on Highway 52 as a result of the left-hand acceleration lane?
Percent of Respondents
80
70
60
50
40
30
20
10
0
1
2
3
4
5

VI. Conclusions/Recommendations

Operational Effects. The study of the operational effects of median acceleration lanes was quite difficult due to the variability in driver behavior. There are many variables that affect how and where drivers use MALs, if they use them at all. Differences in usage may exist depending on factors such as vehicle type, roadway grade, traffic volume, driver experience, or driver age. This study compared the operational effects of MALs based on the behavior that a sample of drivers was exhibiting. However, the results should not be used to precisely predict future driver behavior due to the variability in the data.

One of the most evident benefits of MALs is the reduction in median delay time, or the duration of time that drivers wait in the median before turning left. The study found that the percentage of vehicles that waited in the median at all was reduced from 74% to 4% when MALs were in place at the intersection. The percentage of vehicles that waited in the median for greater than 10 seconds was reduced from 17% to 1%.

The delay time experienced by drivers waiting at the minor road approach appeared to be primarily dependent on the traffic volume in the nearest two lanes instead of on the volume in the passing lane in opposite direction. This shows that drivers are not concerned with traffic in the lane they are merging into until they reach the median. A reduction in delay time not only relates to driver convenience, but it also affects safety. As the delay time increases at an intersection, drivers may become impatient and attempt to cross or merge into mainline traffic when there is not a safe gap available. Traffic waiting in the median is also more susceptible to right angle crashes if there is not ample storage room in the median, or if drivers stop with part of their vehicle still in the through traffic lane.

Length. It appears that even when sufficient gaps are available in the mainline traffic, approximately 10%-15% of drivers use almost all of the acceleration lanes. Therefore, regardless of the length of the MALs, a certain percentage of drivers will stay in them until they are forced to merge into the through lanes. Conversely, when the traffic volume is low (< 150 vph), a large percentage of drivers do not use the lanes at all.

Mn/DOT's Road Design Manual currently recommends constructing MALs based on merging vehicles achieving 60% of the posted speed limit on the mainline. Table 6.1 shows the recommended lengths from the Design Manual. These recommendations come directly from the formula displayed in the footer of the table. They assume a truck with a mass/power ratio of 192 lb/hp as the design vehicle and assume a uniform acceleration rate of 0.98 ft/s^2. They also assume that once a vehicle reaches 60% of the posted speed limit it is able to merge into traffic.

All of the in-place MALs in Minnesota are currently on high-speed four-lane divided highways, with all but one in a 65 mph speed zone. According to the Road Design Manual, at this posted speed limit the desirable length of a full width MAL is 1670 feet. This is longer than any MAL in the state of Minnesota and significantly greater than the average length of 1098 feet. The reason that the existing MALs do not meet Mn/DOT's design recommendations is because these recommendations were added to the Road Design Manual in 2000, after the MALs were constructed.

Table 6.1

Recommended Lengths of MALs (Mn/DOT Road Design Manual)		
Posted Speed (mph)	**60% of Posted Speed (mph)**	**Desirable Length of Full Width MAL (ft.)**
45	27	820
50	30	990
55	33	1195
60	36	1425
65	39	1670

Note: $V_F^2 = V_I^2 + 2AS$, where

V_F = Speed achieved at the end of distance S, ft/s
V_I = Initial speed, ft/s. In Table 6.1, $V_I = 0$ was used.
A = Acceleration, ft/s^2. In Table 6.1, A = 0.98 was used.
S = Distance, ft

The data seems to show that the length of acceleration lane that is used is more a function of the volume of traffic than it is of the posted speed limit. Therefore, it would also be more relevant to base the design recommendations on the traffic volume than on the speed limit. Due to the large number of factors that affect merging vehicles and the variability in the field data, it is difficult to predict the precise length of MAL that a particular driver will use. However, general guidelines can be formed based on the field data, after making a few basic assumptions.

Table 6.2 summarizes the minimum length of MAL that 87.5% of all vehicles included in the study used at or below. This assumes that even though there are sufficient gaps for them to merge into, 10-15% of drivers stay in the MALs until the lanes taper into the driving lanes. This is the reason that the 12.5% of drivers using the greatest length of the MALs was excluded from the data. For this reason, the 87.5^{th} percentile can reasonably be used as a minimum length for the design of new MALs. The most desirable merging speed appeared to be approximately 55 mph when the mainline speed limit was 65 mph. The design vehicle taken from the TEH (passenger car) needs approximately 1000 feet to reach this speed, which is why 1000 feet is recommended for a minimum length when the mainline speed limit exceeds 55 mph.

The guidelines in Table 6.2 are based on both field data and engineering judgment. Care should be taken when applying them to the design of MALs. It may be desirable to increase the length of them at locations with an increasing grade or a relatively high volume of trucks.

Table 6.2

Recommended Minimum Lengths of MALs (Based on Field Data)	
Peak Hour Volume in Passing Lane (vph)	Length of Full Width MAL (ft.)
0 - 150	880*
150 - 300	1000
300 - 450	1225
450 +	1395

*Minimum length for mainline speed limit > 55 mph = 1000 feet

Speed. The data clearly shows that MALs allow left turning vehicles an opportunity to reduce the speed differential between themselves and the mainline traffic. As the mainline traffic volume increases, merging vehicles accelerate to higher speeds before merging.

The study did not analyze the affect of MALs on the speed of mainline traffic. From field observations it appears that mainline vehicles are frequently required to reduce their speed as a result of slower vehicles entering the traffic stream in front of them. This seemed to occur more frequently at non-MAL intersections. It also appears that mainline drivers often slow down when another vehicle is stopped in the median. This is in anticipation of a vehicle entering the mainline in front of them.

It was also observed that mainline drivers frequently slow down as they approach MAL intersections, because they are unsure if entering drivers are going to use the MAL or enter the lane they are in. The effect of MALs on mainline traffic speed should be further analyzed when the equipment is available to accurately measure their change in speed.

Vehicle type. Median acceleration lanes were primarily intended for use at intersections with the high truck volumes, but they do provide benefits for all vehicle types. The average length of acceleration lane that is used increases as the traffic volume in the passing lane increases for all vehicle types, but the length that is used is the greatest for semi tractor-trailers. Therefore, the recommended length of MAL should be greater at locations where there are relatively high volumes of trucks. This should be further studied to determine actual recommended lengths.

Safety Effects. From the data that was collected, there seems to be a relationship between the frequency of crashes and whether or not an MAL exists at an intersection. From all of the locations where crash data was analyzed, the MAL intersections had the lowest crash rate.

The greatest reduction in crash rate based on the accident type was in rear-end and sideswipe same direction crashes. There was approximately a 40% reduction in the rate of rear-end crashes at intersections after the lanes were constructed. The rate of the same type of crash was over 70% lower at MAL intersections compared to non-MAL intersections. When comparing similar intersections in Olmsted County on TH 52, the rate of rear-end crashes was over 75% lower at MAL intersections when compared to non-MAL intersections.

This is to be expected, since vehicles entering from the minor road are able to accelerate and lower the speed differential between themselves and the mainline traffic. Therefore, there should be fewer cases of the mainline traffic rear-ending the entering traffic due to the entering traffic's slower speed. Sideswipe same direction crashes were also noticeably reduced at MAL intersections. This type of crash can also be attributed to entering traffic trying to merge with mainline traffic. They may be listed as sideswipe crashes, because one of the vehicles may have swerved to avoid a rear-end crash.

The MAL intersections on TH 52 appeared to have a slightly higher rate of right angle crashes than the non-MAL intersections. These crashes could be the result of the lanes providing a false sense of security. The mainline traffic may assume that left turning vehicles are going to use the MALs, and then when the merging vehicles instead continue into the right hand through lane, a right angle crash occurs.

The preventable crash rate at MAL intersections should be further reduced if more drivers would use the lanes properly. Approximately 75% of preventable crashes that occurred at these locations were caused by drivers who did not use the MALs at all. These drivers may be unfamiliar with the lanes or intersections, or they may not feel comfortable using the lanes. Steps should be taken to increase driver awareness of MALs and to educate drivers on the use of them.

There seems to be a definite relationship between whether or not an intersection has MALs and the frequency of certain types of crashes. However, the data was somewhat variable depending on the intersection and the time period of analysis, which is to be expected with any crash data. The study of more intersections with and without MALs will improve the ability to further analyze these and other relationships between MALs and safety. This is difficult to do, because all MAL intersections in Minnesota have been included in this study.

Driver Behavior. The results of the survey clearly show that MALs are strongly supported and accepted by the public. The majority of all respondents indicated that they feel the lanes improve safety, decrease intersection delay time, and make it easier for left turning vehicles to merge. As a result, approximately 95% of the respondents said that they use the MALs usually or always. However, many of these same people commented that things need to be done to increase the effectiveness of MALs.

Several steps should be taken to increase the effectiveness of MALs. First, drivers need to be educated on how to properly use the lanes. District 6 has attempted to do this by mailing out brochures to residences in the general vicinity of newly constructed MALs. This was an initial step to educate drivers and to increase their awareness of the lanes. The brochures included information that showed diagrams of MALs, explained the benefits of them, and outlined how to use them properly. A copy of the informational brochure is on page O in the appendix.

Signage should also be provided at intersections with MALs to increase their effectiveness. The greatest concerns expressed by drivers from the survey showed both that merging traffic does not always use the lanes and the mainline through traffic is not aware of the lanes. Furthermore, many of the crashes that occurred at intersections with MALs would have likely been prevented had the drivers been more familiar with the lanes. It is likely that drivers unfamiliar with an intersection with an MAL do not become aware of the MAL until they enter the median. Signage should be provided at the minor road approach to intersections with MALs. Signs such as 'Left-Turning Traffic Use Acceleration Lane' or a diagrammatic sign could be installed to encourage drivers to use MALs.

The concern that vehicles approaching on the mainline are not aware of the lanes could also be addressed with signage. Drivers on the mainline see vehicles entering in front of them from the left and assume that they are entering their lane of travel. As a result, the mainline vehicles either decelerate unnecessarily or immediately change lanes. In this case, a sign such as 'Entering Traffic Uses Acceleration Lane' or a diagrammatic sign showing the MAL could help all in all to increase the awareness of the lanes for approaching traffic on the mainline.

The use of signs to mark MALs and increased education on their usage could provide many benefits to drivers. The number of accidents resulting from drivers not using MALs properly should be reduced. Drivers' overall intersection delay time should be reduced since the percentage of drivers that wait in the median, currently at approximately 4%, should be reduced. A final benefit resulting from driver education and signage is that the percentage of through traffic on the mainline that changes speed or lane as a result of entering traffic should be reduced, resulting in fewer potential vehicle conflicts.

Future Action. This study related the operational characteristics to the traffic volume in the passing lane, since the equipment to measure gap acceptance was not readily available at the time of this study. The traffic volume is related to the operational characteristics of MALs, however a more direct relationship exists between the operational characteristics and the gap size and frequency in mainline traffic, due to the randomness of gap distribution in traffic. This relationship should be analyzed as better measuring equipment becomes available. The effect of MALs on mainline vehicle speed is one additional area that needs further study.

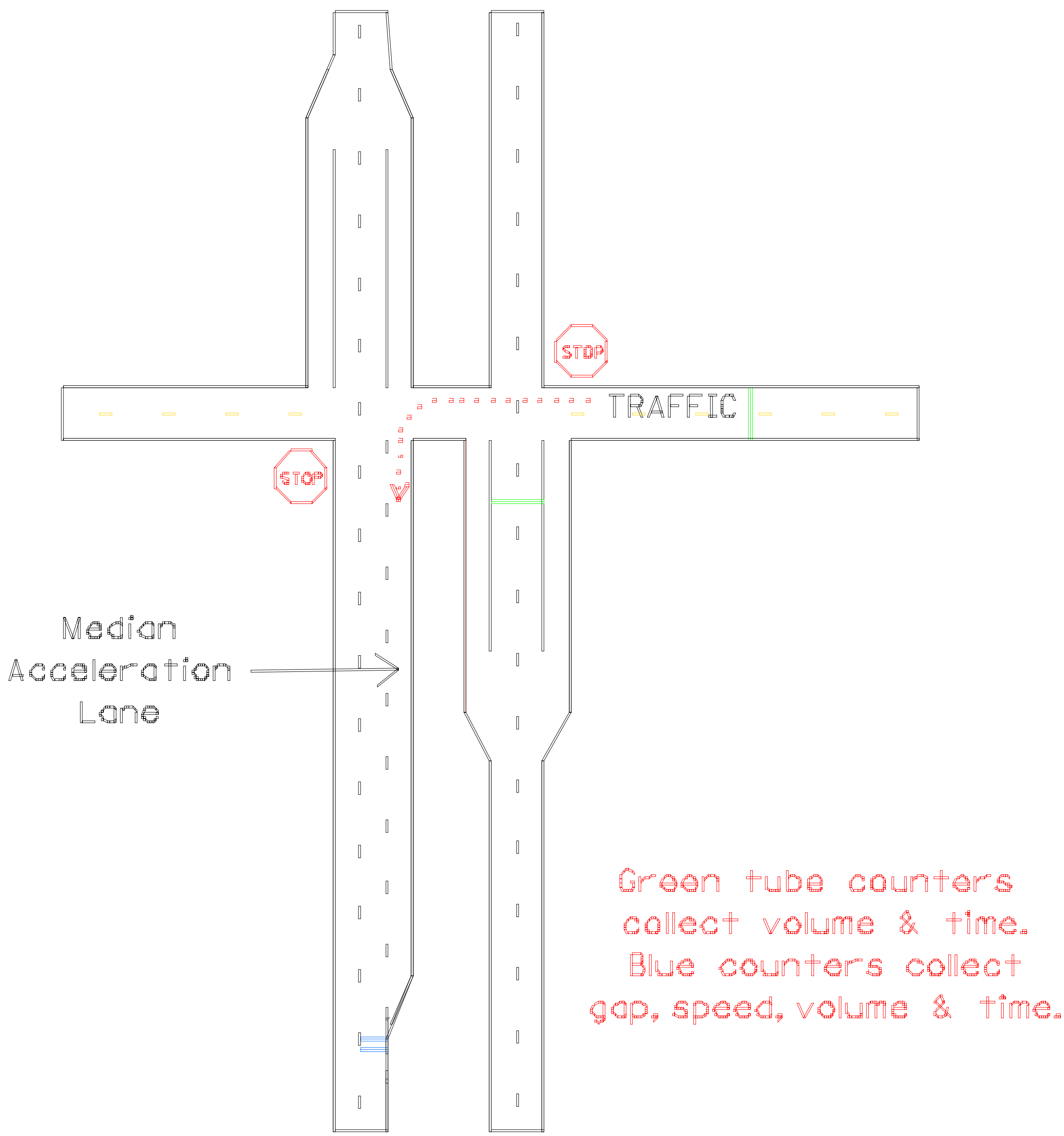
One key advantage of MALs is that they provide a few of the same benefits as interchanges, but they are relatively low cost and can be designed and constructed more quickly. One reason for this is because they do not typically require the purchase of any additional right-of-way and can be constructed on existing right-of-way, given the median is of ample width. Based on past costs of MALs, the cost for a 12-foot wide, 1500 feet in length lane was estimated at $115,000. For these reasons, MALs can be used at intersections on four-lane divided highways as an interim measure before interchanges are constructed, when future traffic volumes are uncertain, or when they are expected to continue to increase.

Summary. Overall, the study supports the assumption that median acceleration lanes provide multiple benefits at a relatively low cost. They decrease the delay time for left-turning vehicles entering a four-lane divided highway from a minor road. They increase the safety at intersections by decreasing the speed differential between merging vehicles and mainline vehicles. Finally, MALs increase drivers' comfort and safety level when merging onto a four-lane divided highway from a minor road.

Appendix

Figure A.1

Tube Counter Locations



Vehicle Type			Q'd Up	SideSt. Wait Time (s)	Median Wait Time (s)	Merging Speed	Merging Distance	Time	Lane @ Tbs.		Notes
PC	SU	TT							Pass	Drive	

For more information

Regarding left side acceleration

Lanes or other traffic devices,

Contact:

Minnesota Department

Of Transportation

District 6

2900 48th Street NW

Rochester, MN 55901-5848

July, 2002

Minnesota Department of
Transportation
District 6
2900 498th Street NW
Rochester, MN 55901-5848

Left Side Acceleration Lanes

What They Are

And How To Use Them

This Traffic Safety Information Is Provided To You By

The Minnesota Department of Transportation

How You Should Use a Left Side Acceleration Lane

What is a left side acceleration lane?

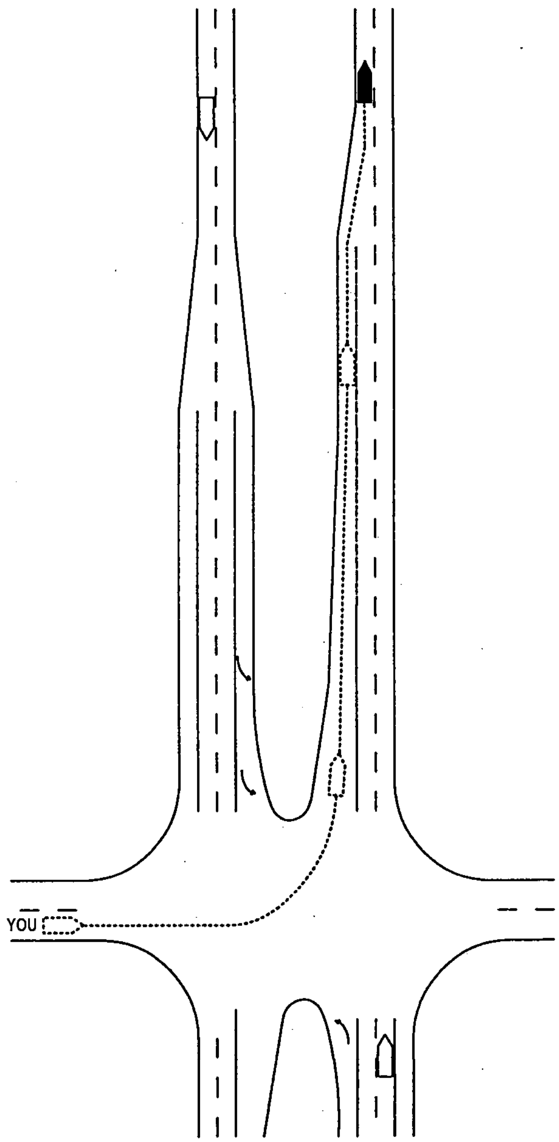
A left side acceleration lane is an additional lane located alongside regular traffic lanes. The lane allows motorists making a left turn onto a four-lane roadway a safer option for merging into high speed traffic.

Why are left side acceleration lanes used?

Left side acceleration lanes on four-lane roadways have been used for more than 30 years in many southeastern Minnesota counties. The acceleration lanes allow you to concentrate on crossing only two lanes of traffic at low speeds when making a left turn onto a major highway.

After crossing one pair of lanes and reaching the median, you can immediately enter the left side acceleration lane and begin to accelerate to the speeds of the major highway before merging.

The left side acceleration lanes offer a special advantage to longer (semi) trucks. After crossing two lanes of traffic, truck drivers can immediately enter the acceleration lane, allowing the trailer to clear the lanes just crossed.



What is the proper way to use a left side acceleration lane?

When approaching an intersection with an acceleration lane, you should cross the first two lanes as you normally would. After moving into the median area, you should immediately move into the acceleration lane and increase speed. After reaching a speed that will allow you to move safely into the mainstream of traffic, you should then merge when an opening is available.

Where are these special lanes located in southeastern Minnesota?

Left side acceleration lanes are located in areas where a large number of vehicles make left turns onto high volume, four-lane divided roadways.

In southeastern Minnesota, left side acceleration lanes have been installed on Highway 52 in Cannon Falls and Pine Island, on Highway 63 in south Rochester, on Highway 61 near Red Wing, and on Highway 14 in Byron.

Do I have to use a left lane acceleration lane if it is there??

No. If traffic is light, you may turn directly into the mainline traffic. However, use of acceleration lanes is encouraged any time they are present in order to develop good, safe driving habits.

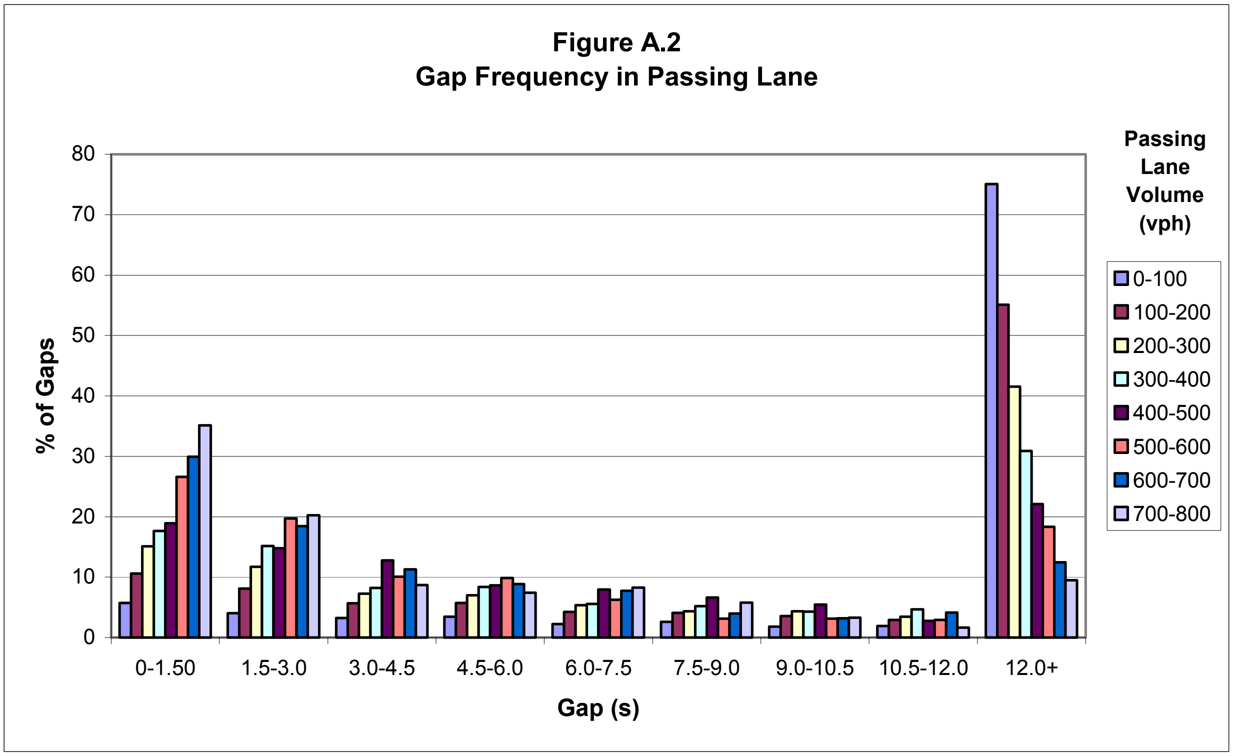


Figure A.2
Gap Frequency in Passing Lane
% of Gaps
0
10
20
30
40
50
60
70
80
0-1.50
1.5-3.0
3.0-4.5
4.5-6.0
6.0-7.5
7.5-9.0
9.0-10.5
10.5-12.0
12.0+
Gap (s)
Passing Lane Volume (vph)
0-100
100-200
200-300
300-400
400-500
500-600
600-700
700-800

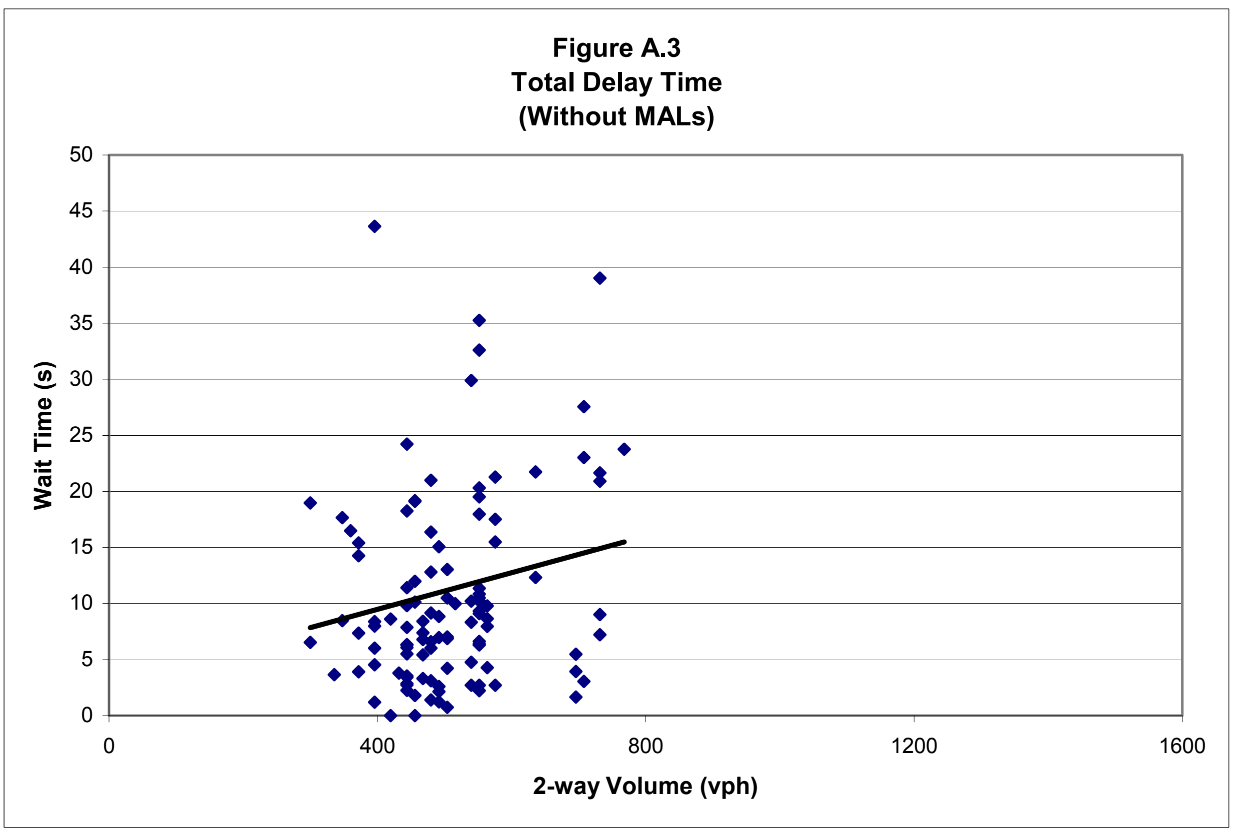


Figure A.3
Total Delay Time
(Without MALs)
Wait Time (s)
0
5
10
15
20
25
30
35
40
45
50
0
400
800
1200
1600
2-way Volume (vph)

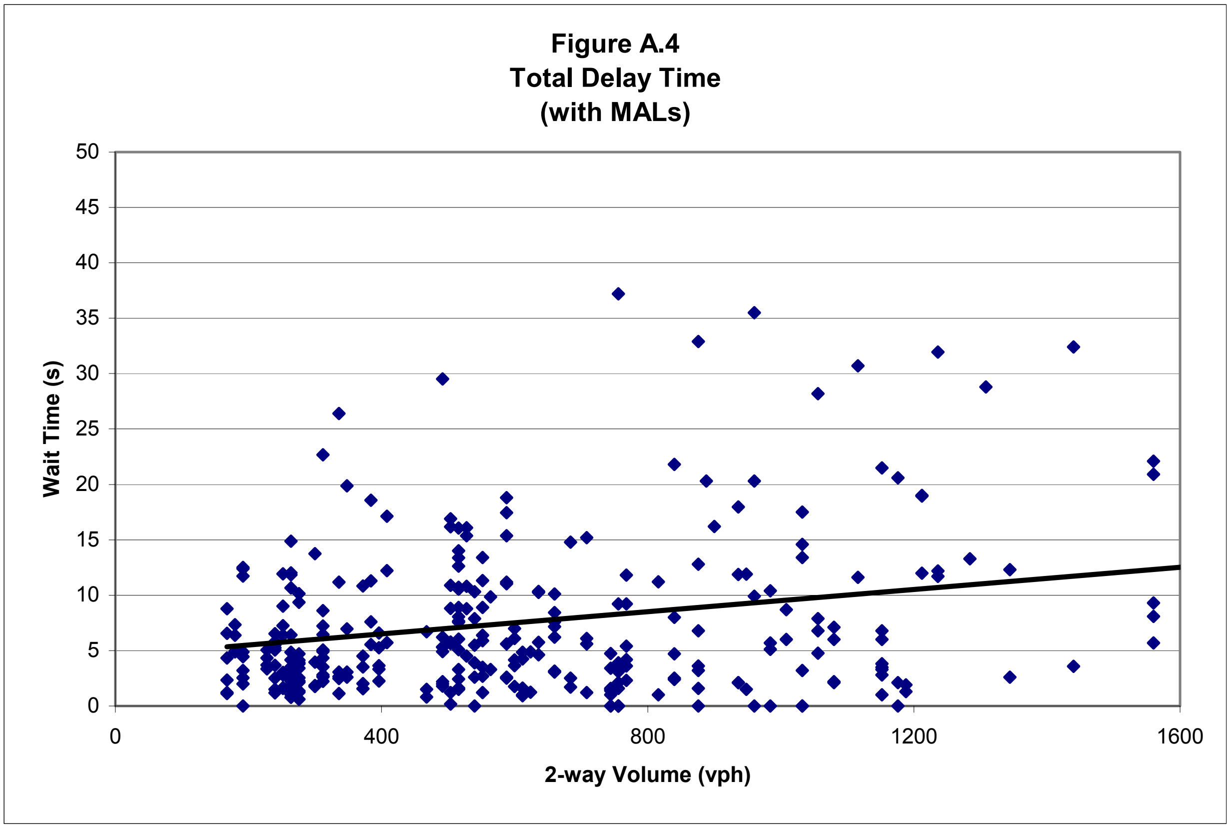


Figure A.4
Total Delay Time
(with MALs)
Wait Time (s)
50
45
40
35
30
25
20
15
10
5
0
0
400
800
1200
1600
2-way Volume (vph)

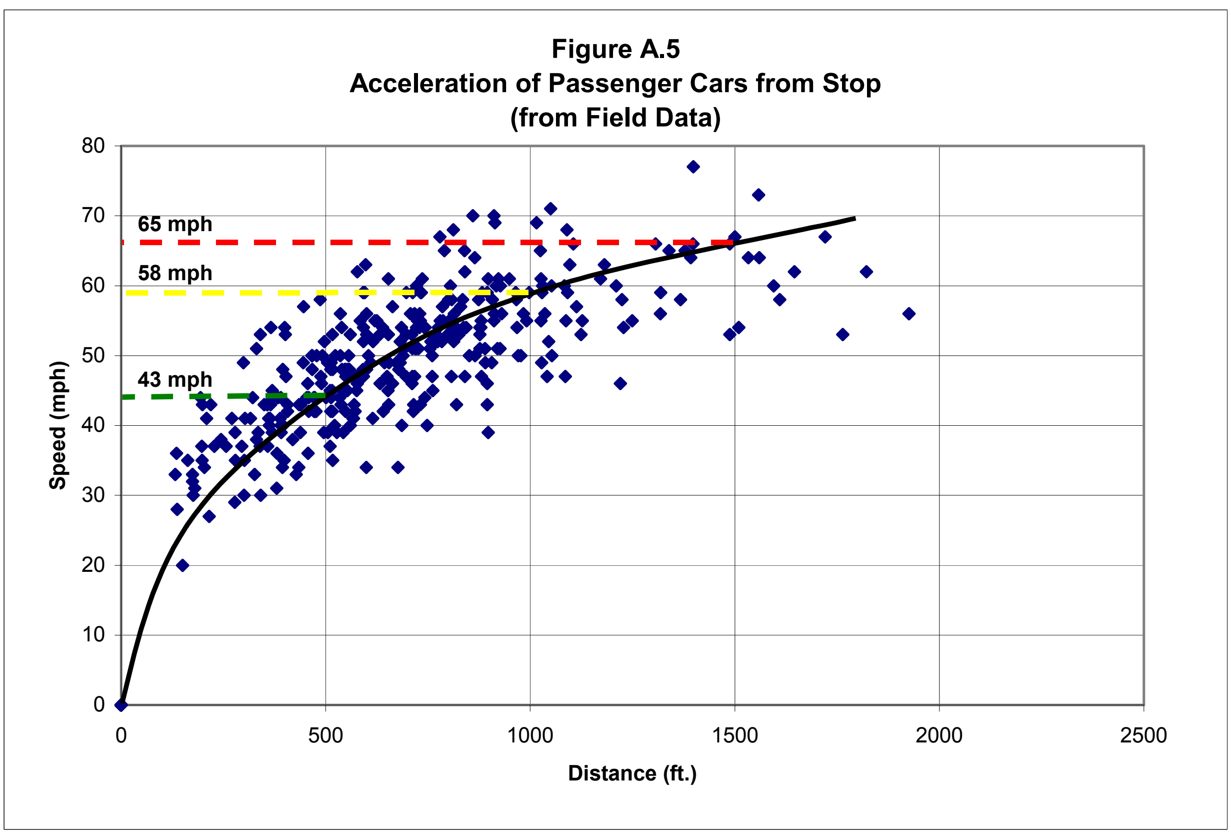


Figure A.5
Acceleration of Passenger Cars from Stop
(from Field Data)
Speed (mph)
80
70
60
50
40
30
20
10
0
65 mph
58 mph
43 mph
0
500
1000
1500
2000
2500
Distance (ft.)

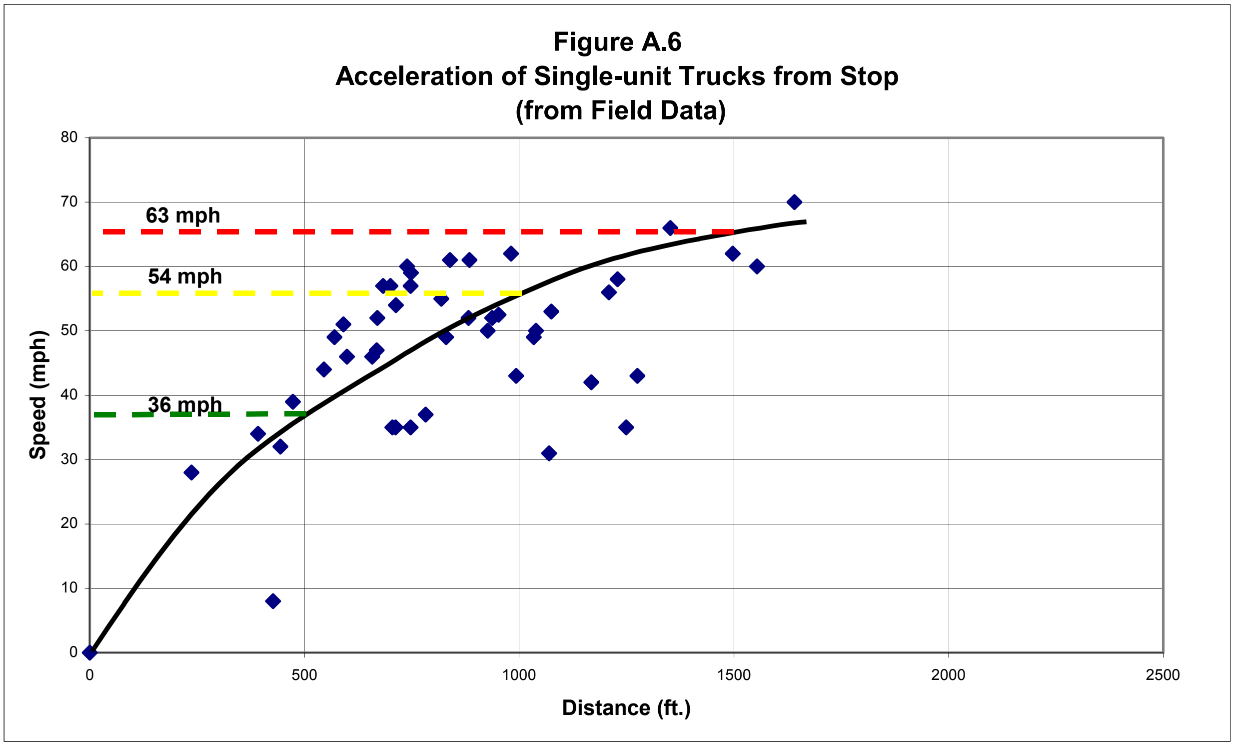


Figure A.6
Acceleration of Single-unit Trucks from Stop
(from Field Data)
63 mph
54 mph
36 mph
Speed (mph)
Distance (ft.)
0
10
20
30
40
50
60
70
80
0
500
1000
1500
2000
2500

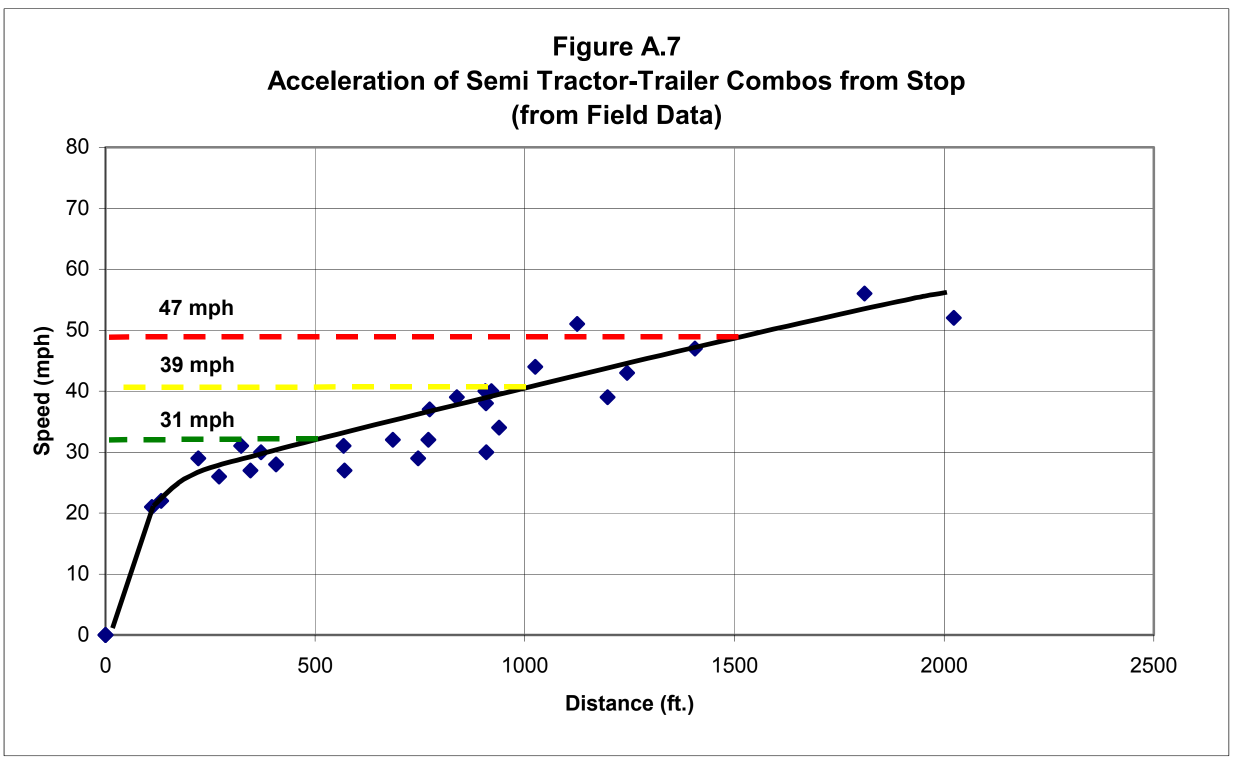


Figure A.7
Acceleration of Semi Tractor-Trailer Combos from Stop
(from Field Data)
47 mph
39 mph
31 mph
Speed (mph)
Distance (ft.)
0
10
20
30
40
50
60
70
80
0
500
1000
1500
2000
2500

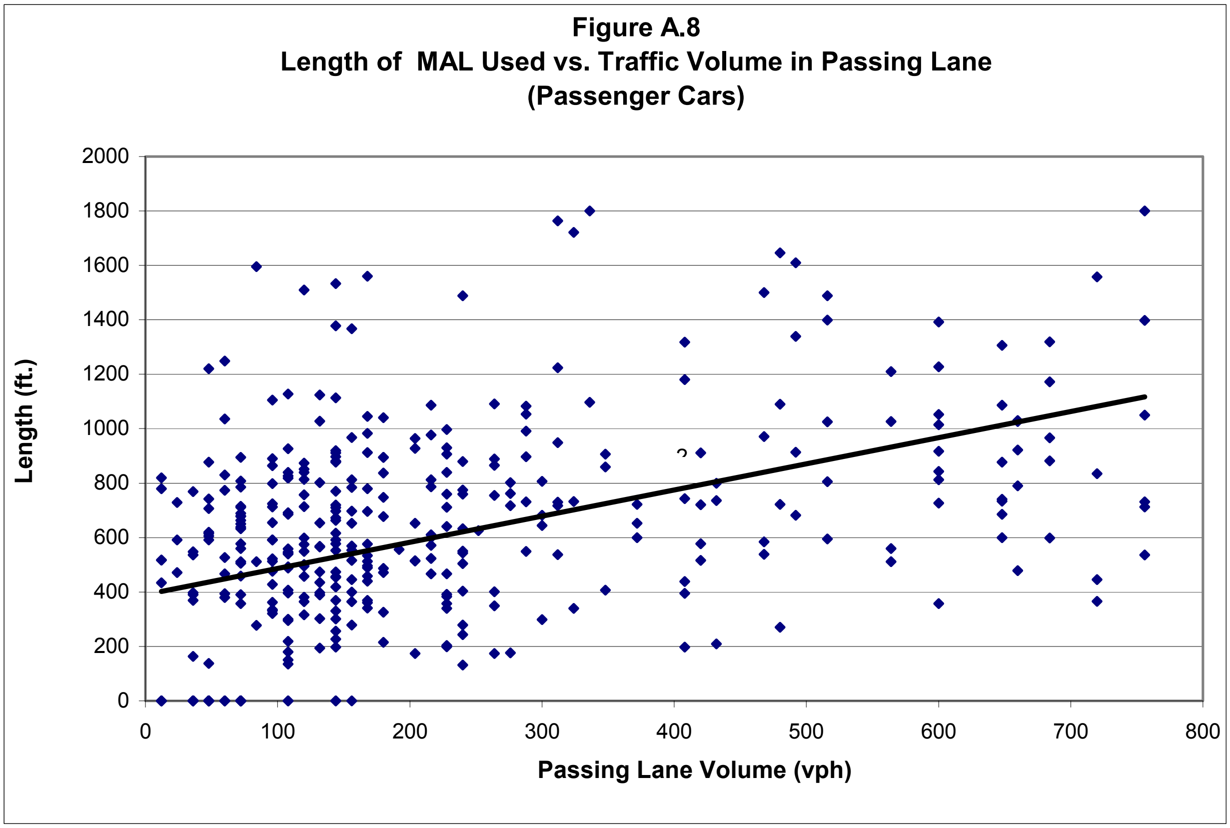


Figure A.8
Length of MAL Used vs. Traffic Volume in Passing Lane
(Passenger Cars)
Length (ft.)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
Passing Lane Volume (vph)

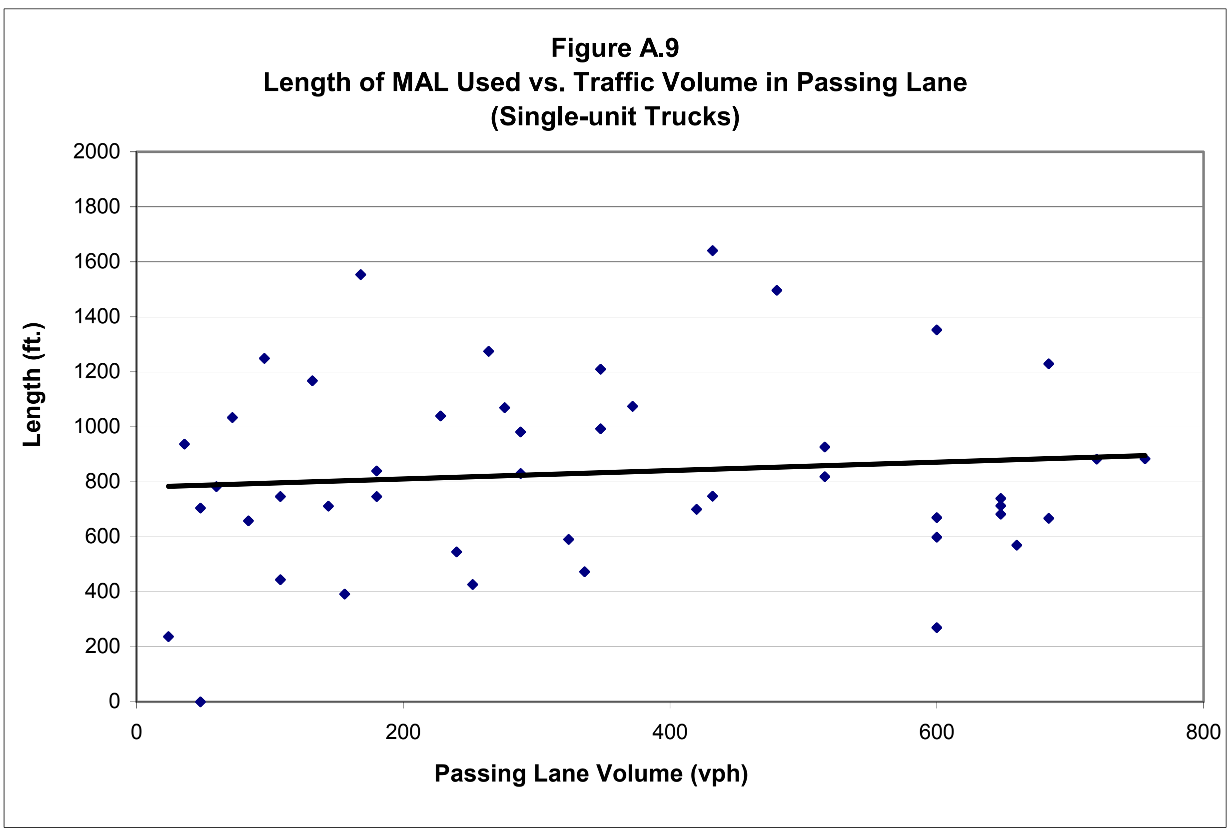


Figure A.9
Length of MAL Used vs. Traffic Volume in Passing Lane
(Single-unit Trucks)
Length (ft.)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
Passing Lane Volume (vph)

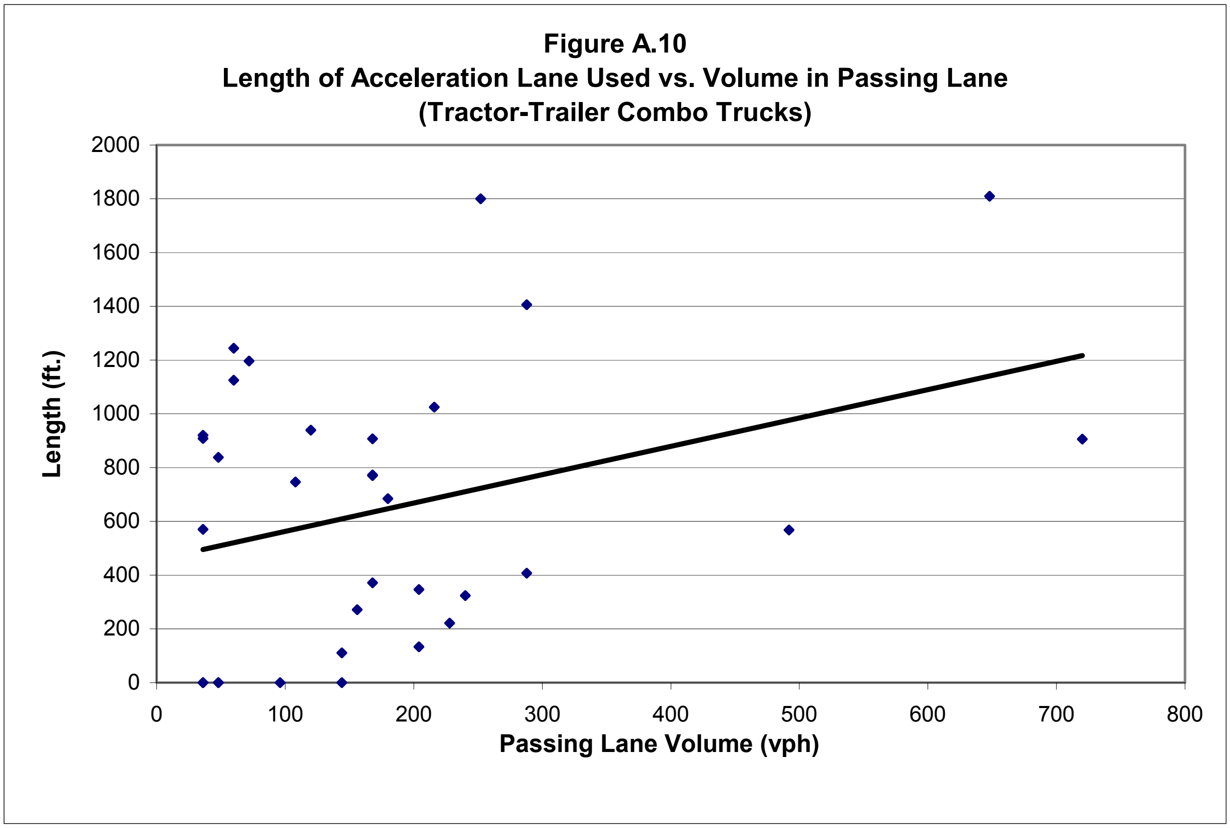


Figure A.10
Length of Acceleration Lane Used vs. Volume in Passing Lane
(Tractor-Trailer Combo Trucks)
Length (ft.)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
Passing Lane Volume (vph)

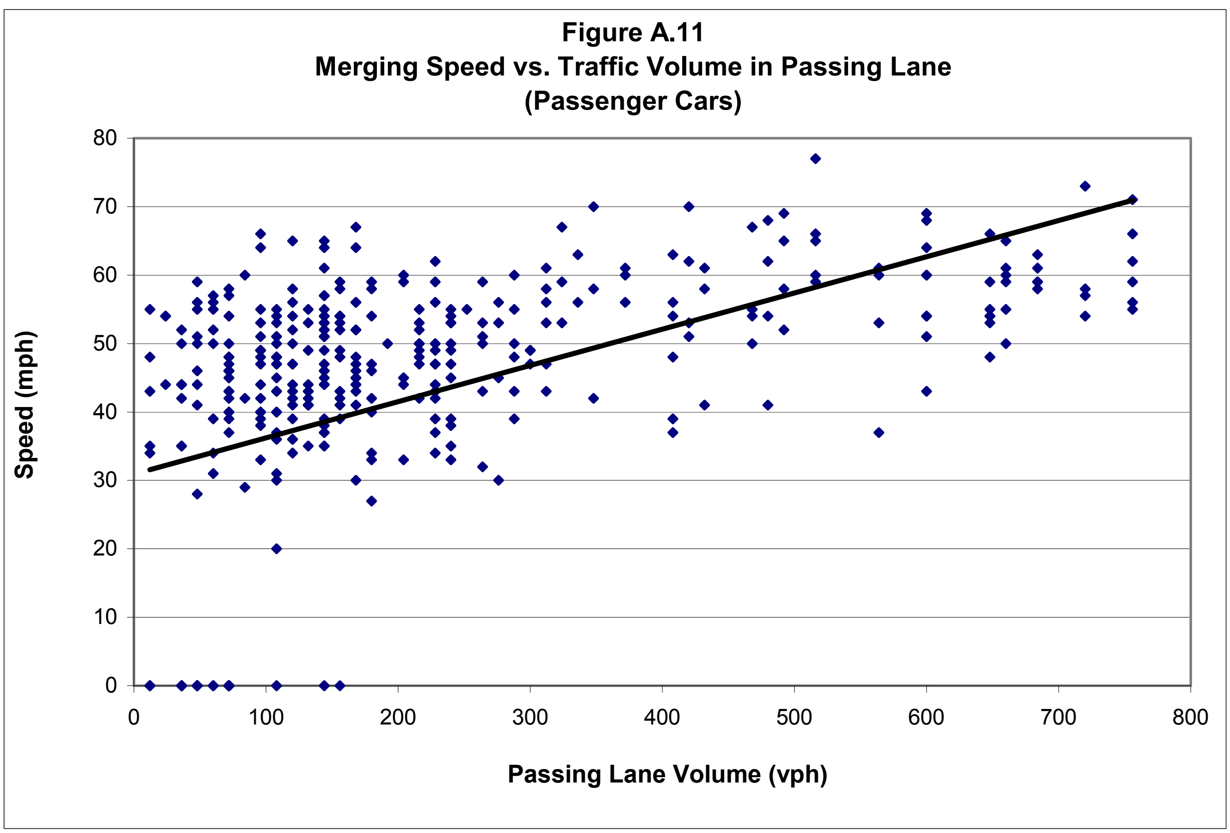


Figure A.11
Merging Speed vs. Traffic Volume in Passing Lane
(Passenger Cars)
Speed (mph)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
Passing Lane Volume (vph)

Figure A.12
Merging Speed vs. Traffic Volume in Passing Lane
(Single-unit Trucks)

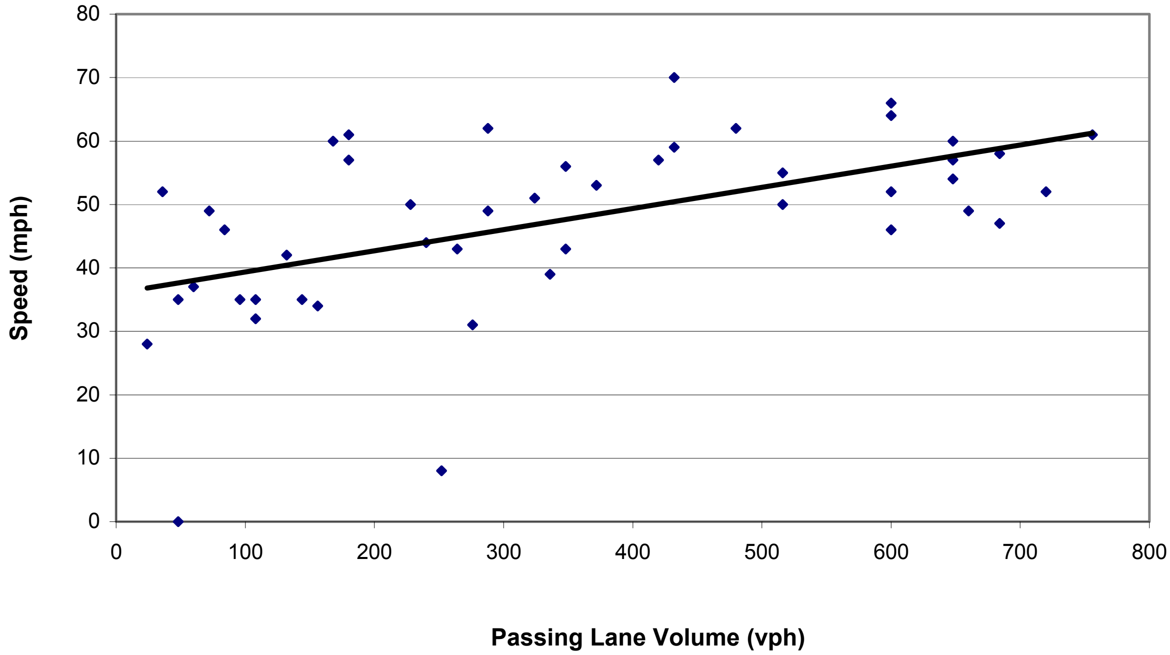


Figure A.13
Merging Speed vs. Traffic Volume in Passing Lane
(Tractor-Trailer Combo Trucks)