MERGING TAPER LENGTHS FOR SHORT DURATION LANE CLOSURES

by

LuAnn Theiss, P.E.
Associate Research Engineer
Texas Transportation Institute

Melisa D. Finley, P.E.
Associate Research Engineer
Texas Transportation Institute

and

Gerald L. Ullman, P.E., Ph.D.
Senior Research Engineer
Texas Transportation Institute

Report 476990
FDOT Project BDK51
Project Title: Merging Taper Lengths for Short Duration Lane Closures - Research

Performed in cooperation with the
Florida Department of Transportation

FINAL REPORT

December 2009

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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1. Report No. FDOT BDK51	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MERGING TAPER LENGTHS FOR SHORT DURATION LANE CLOSURES		5. Report Date December 2009 6. Performing Organization Code
7. Author(s) LuAnn Theiss, Melisa D. Finley and Gerald L. Ullman		8. Performing Organization Report No. Report 476990
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project BDK51
12. Sponsoring Agency Name and Address Florida Department of Transportation Research Center 605 Suwannee St., MS 30 Tallahassee, Florida 32399		13. Type of Report and Period Covered Technical Report: May 2008 to October 2009 14. Sponsoring Agency Code
15. Supplementary Notes Project performed in cooperation with the Florida Department of Transportation. Project Title: Merging Taper Lengths for Short Duration Lane Closures		

16. Abstract

The Utility Industry has requested that the Florida Department of Transportation provide for the use of merging taper lengths that are significantly shorter than the lengths computed using the taper length equations published in the MUTCD Section 6C.08. This request pertains specifically to short duration lane closures of one hour or less in multilane urban areas where posted speeds are 45 mph or less. Shorter taper lengths allow for quicker installation and removal of traffic control devices, as well as reduced worker exposure time. The objectives of this study were to: (1) determine how the merging taper length affects the behavior of drivers approaching short duration work activities in the traveled way of multi-lane urban roadways with speed limits of 45 mph or less, and (2) develop recommendations regarding the use of shorter taper lengths for short duration work activities.

Field studies were conducted in two separate phases. In phase I, merging taper lengths of 100 ft, 160 ft, and 540 ft were evaluated using standard DOT pickup trucks with typical warning lights and sequential flashing LED lightbars in the work area. In phase II, a no-taper condition, similar to a mobile operation, was evaluated using utility company bucket trucks, also with typical warning lights, but no lightbar, in the work area Based on the study findings, researchers recommend that work operations that last more than 15 minutes utilize a merging taper length that meets MUTCD requirements. In addition, operations that last approximately 15 minutes or less can be accommodated as mobile operations without frequent operational or safety problems being created upstream of the work vehicle if certain conditions, which are documented in this report, are met.

17. Key Words Merging taper, short duration, lane closure, mobile operation, utility work, temporary traffic control, work zone safety, traffic operations		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 116	22. Price

ACKNOWLEDGEMENT

The research team would like to thank the Project Director, Jim Mills of the Florida Department of Transportation (FDOT). Others who provided support during this project include: FDOT Orlando South Maintenance Office, FDOT Broward Maintenance Office, FDOT Tampa Maintenance Office, Florida Power & Light Company, and Tampa Electric Company. Their participation was critical to the success of this research project.

EXECUTIVE SUMMARY

Consideration for the safe and efficient movement of the road user, as well as the safety of the workers, is an integral element of temporary traffic control. The *Manual on Uniform Traffic Control Devices* (MUTCD) defines the minimum temporary traffic control requirements on streets and highways. Similar to the MUTCD, Florida Department of Transportation (FDOT) standards for state roadways apply when work is required in the traveled way. Lane closures are used to separate road users from utility company work operations during some relamping activities. In some cases, it takes longer to setup and remove a full set of temporary traffic control devices than to perform the actual work. In addition, it is believed that the risk to workers during the temporary traffic control installation and removal may be as great, or even greater, than the risk incurred to actually perform the work. The Utility Industry requested that FDOT requirements be modified to allow for merging taper lengths to be reduced from the lengths computed using the equations in the MUTCD for short duration operations.

Field studies were conducted in two separated phases to evaluate the safety and operational impacts of shorter merging taper lengths. The data for this study were collected under the following conditions:

- the speed limit was 45 mph or less;
- the duration of the work operation was approximately 15 minutes or less;
- the work vehicle had high-intensity, rotating, flashing, oscillating, or strobe lights operating;
- there were no advance warning signs and arrow panel;
- there were no sight obstructions;
- daytime lighting conditions existed with dry pavement; and
- the volume and complexity of the roadway were considered.

The conclusions developed based on these data should not be applied to situations that are not described by all of the above conditions.

The first phase of the field studies was conducted to evaluate the safety and operational impacts of merging taper lengths of 100 ft, 160 ft, and 540 ft. Standard DOT pickup trucks with typical warning lights and sequential flashing LED lightbars were used in the work area during this phase. Researchers found that a significant percentage of traffic remained in the closed lane with all treatments. Researchers hypothesized that the combination of a lack of advance warning signing (which is not required in Florida for short duration work) and a fairly high frequency (approximately 50 percent) of vehicle occlusion of both the channelizing devices and the work vehicle contributed to these results. The data also shows that the amount of occluded vehicles in the traffic stream contributes significantly to the percentage of vehicles becoming trapped (stopping or almost stopping because they are unable to find a suitable gap in the open lane) near the taper. Data indicate that more vehicles become trapped at the beginning of the merging taper when longer (FDOT standard) merging tapers were used. However, if an occluded vehicle was unable to stop and hit the beginning of the merging taper, the longer taper provides sufficient stopping distance such that the vehicle could stop prior to reaching the work activity area where the worker or work vehicle are located. Although fewer vehicles became trapped when merging taper lengths were 100 ft in length, the percentage that became trapped at the shorter taper was certainly not negligible and adequate stopping distance was not provided.

Due the very short duration of some utility operations, such as relamping that may last fewer than 15 minutes, the researchers also evaluated a no-taper condition (similar to a mobile operation) in the second phase of the field studies. Utility company bucket trucks, also with typical warning lights, but no sequential flashing LED lightbars, were used in the work area during this phase. The researchers found that a smaller percentage of traffic remained in the closed lane when a larger, more imposing vehicle, such as a utility company bucket truck was present in the work area. In addition, the researchers concluded that the visibility of the large work vehicle itself serves as a major visual cue to exit the closed lane, such that more drivers vacate the closed lane farther upstream than when a smaller work vehicle was used in conjunction with a 100-foot taper.

Based on these findings, researchers recommend that work operations that last more than 15 minutes utilize a merging taper length that meets MUTCD requirements. Due to concerns over the number of trapped vehicles, researchers also recommend that advance warning signs be used. However, this project did not include an evaluation use of advance warning signs; therefore, further research may be desired to determine the minimum number of signs needed.

Researchers also believe that work operations that last approximately 15 minutes or less can be accommodated as mobile operations without frequent operational or safety problems being created upstream of the work vehicle if certain conditions are met. Thus, the researchers also recommended that mobile operations may be used when:

- the speed limit is 45 mph or less;
- the duration of the work operation is approximately 15 minutes or less;
- the work vehicle is large and has high-intensity, rotating, flashing, oscillating, or strobe lights operating;
- there are no sight obstructions;
- daytime lighting conditions exist with dry pavement; and
- the volume and complexity of the roadway have been considered.

There are some conditions under which mobile operations may not be suitable:

- locations where adequate sight distance is not available,
- locations where operating speeds are typically in excess of the posted speed limit of 45 mph or less, or
- locations where traffic volumes create a continuous queue in the closed and open lane(s).

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INTRODUCTION

PROBLEM STATEMENT

When the normal function of a roadway is altered for construction, maintenance, and utility operations, temporary traffic control provides for the continuity of the movement of traffic. Consideration for the safe and efficient movement of the road user, as well as the safety of the workers, is an integral element of temporary traffic control. The *Manual on Uniform Traffic Control Devices* (MUTCD) [1] defines the minimum temporary traffic control requirements on streets and highways. In Florida, the Florida Department of Transportation (FDOT) also defines temporary traffic control requirements for state roadways [2]. The MUTCD and FDOT standards also contain typical applications that depict common uses of temporary traffic control devices, since defining details that would be adequate to cover all applications is not practical. Ultimately, the temporary traffic control selected for each situation depends on many variables, including but not limited to the type of roadway, type of work, duration of operation, and location of work with respect to road users.

When work is required in the traveled way, lane closures are used to separate road users from the work activity. Lane closures typically consist of an advance warning area that contains a series of signs to inform drivers about the upcoming work zone; a transition area where drivers are redirected out of their normal path with channelizing devices and arrow panels; and the work activity area itself. At longer term stationary work zones there is ample time to install and realize the benefits from the full range of temporary traffic control devices; however, some maintenance and utility operations only take a few minutes to complete. In some cases, it takes longer to setup and remove a full set of temporary traffic control devices than to perform the actual work. In addition, it is believed that the risk to workers during the temporary traffic control installation and removal may be as great, or even greater, than the risk incurred to actually perform the work.

Consequently, the MUTCD and FDOT standards provide flexibility and allow for agency judgment concerning the use of simplified control procedures for short duration work activities. More specifically, in Florida the advance signing and arrow panel may be omitted if the work operation duration is 60 minutes or less, the speed limit is 45 mph or less, there are no sight obstructions, and work vehicles have high-intensity, rotating, flashing, oscillating, or strobe lights operating. However, a merging taper in accordance with MUTCD requirements must still be used. While the overall time to install and remove the temporary traffic control is reduced with these simplified control procedures, the time necessary to install and remove a MUTCD merging taper is still viewed as excessive by many who conduct work activities that take 15 minutes or less to complete.

The Utility Industry has requested that FDOT requirements be modified to allow for merging taper lengths to be reduced from the lengths computed using the equations in the MUTCD for short duration operations. The use of shorter tapers lengths would further reduce the time that workers are exposed to traffic during the installation and removal of traffic control devices. In addition, only a limited number of channelizing devices can currently be carried on utility vehicle bucket trucks due to their design. Thus, reduced taper lengths would negate the need for additional channelizing devices.

Previous merging taper length research is limited [3,4], so questions still exist as to whether reduced taper lengths would be acceptable for slower speed roadways (45 mph or less). Research is needed to determine the safety and operational implications of using shorter taper lengths than those currently required in the MUTCD. Worker safety, as well as the safe and efficient movement of motorists must be considered. While it is desired to analyze crash data to assess the safety impacts, actual crash data for short duration operations would be too limited. Instead, researchers must utilize surrogate measures of safety.

STUDY OBJECTIVES

The objectives of this study were as follows:

- determine how the merging taper length affects the behavior of drivers approaching short duration work activities in the traveled way of multi-lane urban roadways with speed limits of 45 mph or less and
- develop recommendations regarding the use of shorter taper lengths for short duration work activities.

BACKGROUND

Overview of National and State Standards

In Florida, the MUTCD [1] and FDOT standards [2] define the minimum temporary traffic control requirements on all state roadways. Many variables affect the traffic control selected for each work zone, but work duration is a major factor in determining the number and types of devices used in work zones [1]. The MUTCD defines the following five categories of work duration:

- Long-term stationary – work that occupies a location more than three days;
- Intermediate-term stationary – work that occupies a location more than one daylight period up to three days, or nighttime work lasting more than one hour;
- Short-term stationary – daytime work that occupies a location for more than one hour within a single daylight period;
- Short duration – work that occupies a location up to one hour; and
- Mobile – work that moves *intermittently* or *continuously*.

Past research [5,6] has shown that both disparity and overlap exist between the definitions of short duration and mobile operations among transportation agencies, as well as among the specific activities associated with each type of operation. For example, work activities that take 15 minutes or less to complete and move from location to location throughout the work period could be considered a short duration operation or a mobile operation that moves intermittently down the road. *Intermittently* is not defined in the MUTCD, but it does indicate that mobile operations often involve frequent short stops for activities such as litter cleanup, pothole patching, and utility operations, and are similar in nature to short duration operations.

The MUTCD definitions are purposely vague in order to allow individual agencies to further clarify distinctions between work durations, as deemed appropriate. In order to better classify the type of work activity described in the previous paragraph, some public agencies have decided to include the time that a mobile operation can stop to their mobile operation definition. As shown in Table 1, six public agencies have included a 15 minute period in some fashion in their mobile operations definition. This time period is based on the belief that a well-prepared, efficient crew can install and remove a full set of traffic control devices for a lane closure in approximately 15 minutes using conventional methods. In essence, the selection of a 15-minute threshold is implying that anytime the work activity is stopped for longer than the time it would take to install and remove a merging taper and other appropriate traffic control devices, those devices should be installed.

Table 1. Mobile Operations Definition Clarifications.

Public Agency	Mobile Operation Definition
Maryland State Highway Association [7]	Work activity that moves along the road either intermittently or continuously; may involve stops as long as 15 minutes.
Minnesota DOT [8]	Any temporary traffic control zone that occupies a location (area) for less than fifteen (15) minutes. Mobile operations often involve frequent short stops, each as much as 15 minutes long, for activities such as pothole patching, crack sealing or utility operations and are similar to short duration operations.
New Jersey [9]	Operation that moves intermittently (stops up to 15 minutes) or continuously in the immediate area (approximately 1000 linear feet).
Shasta County Public Works [correspondence from Paul Young, September 16, 2009]	Work that moves intermittently or continuously. If an operation is stationary for no more than fifteen minutes, it may be considered as a mobile operation.
Texas DOT [10]	Work that moves continuously or intermittently (stopping up to approximately 15 minutes).
Virginia DOT [11]	Work that moves intermittently (1-15 minutes) or continuously.

Obviously, independent of the exact definitions used for short duration and mobile operations, these types of activities are inherently different from longer term stationary operations. At longer term stationary work zones there is ample time to install and realize the benefits from the full range of temporary traffic control devices (e.g., advance warning signs, tapers, arrow panels, etc.). However, some maintenance and utility operations only take a few minutes to complete and thus the time to install and remove temporary traffic control devices can take much longer than the actual work activity itself. Even the MUTCD recognizes this issue and indicates that workers face hazards during the installation and removal of traffic control devices. In addition, there is evidence to suggest that the installation and removal of temporary traffic control is one of the more dangerous times for highway workers [12,13]. The MUTCD also notes that since the work time is short, delays affecting motorists are significantly increased when additional devices are installed and removed.

Considering these factors, the MUTCD allows for simplified control procedures for both short duration and mobile work activities. A reduction in the number of temporary traffic control devices may be offset by the use of appropriate enhanced colors or markings on the work vehicles and more dominant devices, such as high-intensity rotating, flashing, oscillating, or strobe lights on work vehicles. The appropriateness of such adjustments is ultimately based on positive guidance considerations [14]. Generally speaking, these larger and more visible devices on a vehicle allow it to be seen farther upstream thereby providing some advance information to drivers about a downstream blockage or lane closure – information that normally would have been provided through the upstream warning signs and arrow panel.

Furthermore, the MUTCD acknowledges that the work force for utility operations is usually small and that the number and types of traffic control devices placed in the work zone is usually minimal. However, the safety of short duration and mobile operations should not be compromised by using fewer devices simply because the operation will frequently change locations.

Based on the above guidance, the FDOT standards allow for the advance signing and arrow panel to be omitted if the following conditions are met:

- the work operation duration is 60 minutes or less (i.e., short duration);
- the speed limit is 45 mph or less;
- there are no sight obstructions;
- work vehicles have high-intensity, rotating, flashing, oscillating, or strobe lights operating; and
- the volume and complexity of the roadway have been considered.

However, FDOT standards still require that a merging taper in accordance with the MUTCD be used. This requirement is based on the following MUTCD standard (Section 6G.12) and an interpretation by the Federal Highway Administration (FHWA) [correspondence from Regina S. McElroy to Robert Greer, February 23, 2005].

> "When a lane is closed on a multi-lane road for other than a mobile operation, a transition area containing a merging taper shall be used [1]."

It should be noted that this statement was added to the 2000 MUTCD [15], based largely on research performed by the Texas Transportation Institute (TTI) in the late 1980s on short duration work operations on freeways [16]. In that study, a no-merging taper condition with an arrow panel in a rural/suburban freeway travel lane was briefly tried at one site, but was quickly abandoned after observing severe braking by some drivers to avoid running into the arrow panel. Certainly, driver expectancies regarding the need to brake and change lanes are much different on these types of freeway sections than they are on urban arterial streets, which raises questions about the applicability of the statement to these lower speed facilities.

While the overall installation and removal of the temporary traffic control is reduced with the FDOT simplified control procedures, the time necessary to install and remove a MUTCD merging taper is still viewed as excessive by many who conduct work activities that take 15 minutes or less to complete. The use of shorter tapers lengths would further reduce the time that workers are exposed to traffic during the installation and removal of traffic control devices. In addition, only a limited number of channelizing devices can currently be carried on utility vehicle bucket trucks due to their design. Thus, reduced taper lengths would negate the need for additional channelizing devices.

Merging Taper Length Evaluations

Until the late 1970s, the MUTCD specified minimum desirable taper lengths based on one formula: L=WS, where W is the width of the closed lane in feet and S is the 85th percentile speed in miles-per-hour. This formula applied only to relatively flat grades and straight alignments, but was considered valid for all speeds. The necessity of making adjustments to the taper length were noted, particularly for providing adequate sight distance and/or the close proximity of interchange ramps, crossroads, etc. [17]. However, some transportation professionals felt that the standard taper lengths for speeds less than 60 mph were excessively long.

In 1977, Graham and Sharp [3,18] proposed a revised taper length formula that yielded shorter tapers at speeds less than 60 mph ($L=WS^2/60$, where W is in ft and S is in mph). Proponents of the revised formula felt that the ability to stop and/or change direction was inversely proportional to the square of the velocity, and shorter taper lengths would interfere less with driveways and intersections. The difference between the two taper length formulas is shown graphically in Figure 1.

Graham and Sharp conducted field studies to directly compare traffic operations when standard and proposed taper lengths were used in the same work zones [3,18]. The data collected included speed, erratic maneuvers, traffic conflicts, and lane encroachments. The field studies only considered long-term lane closure situations (i.e., no short duration study sites were included). In addition, none of the work zone sites studied included the use of arrow panels. Graham and Sharp found that the use of the proposed taper lengths did not produce a greater number of erratic maneuvers and slow-moving vehicle conflicts than with the standard taper lengths. In addition, the proposed taper lengths did not result in a greater number of passenger vehicle or truck encroachments on adjacent lanes. Thus, Graham and Sharp concluded that the shorter proposed taper lengths were not more hazardous than those previously used. However, they also concluded that taper lengths shorter than those studied may show an increase in conflicts; thus, the new proposed taper lengths were probably the minimum that should be considered. Based on these results, the proposed taper length formula was included in the 1978 MUTCD [19] for urban, residential, and other streets where the posted speed is 40 mph or less. Since that time, two formulas have been used to determine the taper length in work zones (denoted as solid lines in Figure 1).

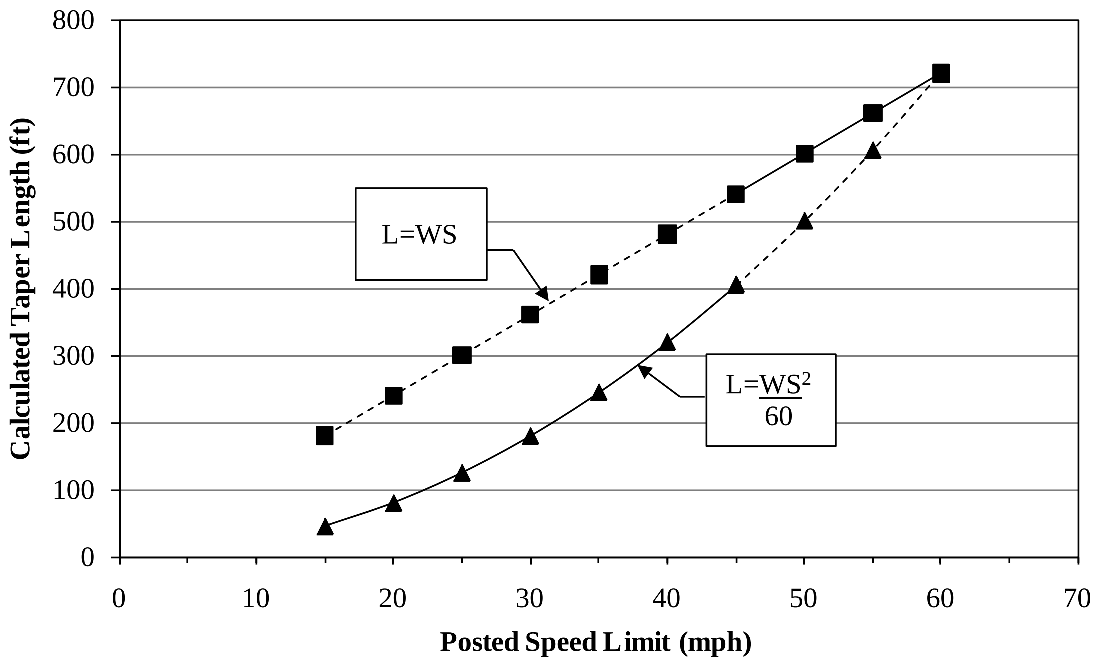

Figure 1. Comparison of the 1971 MUTCD and Proposed Taper Length Formulas.

Recently, FDOT sponsored driver simulation-based research [20] to examine the feasibility of using reduced taper lengths to decrease worker exposure while performing work within the travel way of a multilane facility with a median lane or outside lane closure. The primary purpose of this study was to investigate whether reducing the standard taper length from 540 ft to 100 ft on roadways with a lane width of 12 ft and a posted speed limit of 45 mph increases accident likelihood. Researchers also considered the affect of the presence or absence of a visually occluding lead vehicle and additional traffic that trapped the driver at the beginning of the taper. In general, those researchers interpreted their results to indicate that the reduced taper length of 100 ft increased accident likelihood, and that this likelihood was even greater when a lead vehicle occluded the work zone. However, several limitations in the study methodology, protocol used, and discussion of results makes the conclusions drawn somewhat suspect. Most important of these limitations is the lack of a work vehicle with high-intensity, rotating, flashing, oscillating, or strobe lights operating in the closed lane downstream of the merging taper (one of the key FDOT requirements that must be met to omit the advance signing and arrow panel) even though the lane closure consisted of only cones (i.e., no advance signing or arrow panel).

In summary, some maintenance and utility operations only take a few minutes to complete and thus the installation and removal of temporary traffic control devices may take much longer than the actual work activity itself. Independent of the whether these types of operations are defined as short duration or mobile work, simplified control procedures are desired as a way to minimize overall worker and motorist risk. As such, FDOT allows for the advance signing and arrow panel to be omitted if the work operation meets five criteria; however, FDOT still requires that a merging taper in accordance with the MUTCD be used. While the overall installation and removal of the temporary traffic control is reduced with these simplified control procedures, the time necessary to install and remove a MUTCD merging taper is still viewed as excessive by many who conduct work activities that take 15 minutes or less to complete. The use of shorter tapers lengths would further reduce the time that workers are exposed to traffic during the installation and removal of traffic control devices. However, previous merging taper length research is limited, so questions still exist as to whether reduced taper lengths would be acceptable for slower speed roadways. The field studies performed as part of this research were designed to better answer those questions.

METHODOLOGY

This section of the report describes the field studies that were conducted, and discusses the measures of effectiveness used to evaluate the safety and operational impacts of using shorter merging taper lengths during short duration utility operations.

Researchers conducted field studies in Broward, Orange, and Hillsborough counties in Florida. The studies were divided into two phases. The objective of the first phase was to compare the safety and operational impacts of different merging taper lengths during short duration utility operations. The second phase focused on assessing the safety and operational impacts of performing these same quick utility operations as mobile operations, since many of the work activities of interest are very short in duration (i.e., approximately 15 minutes or less).

PHASE I – MERGING TAPER LENGTH VARIATIONS

FDOT Standard Index 613 specifies taper lengths and device spacing for lane closures on multi-lane roadways based on speed and lane width. Table 2 shows the FDOT requirements for roadways with speeds of 45 mph or less.

Table 2. FDOT Taper Length Requirements

Speed (mph)	Taper Length (12 ft lane width)	
	L (ft)	Notes
25	125	$L = \frac{WS^2}{60}$
30	180	
35	245	
40	320	
45	540	$L = WS$

Because the required taper lengths were thought to be excessively long, the utility industry requested the evaluation of shorter taper lengths than those shown in the FDOT Standards. During Phase I, merging taper lengths of 100 ft, 160 ft, and the FDOT standard taper length based on MUTCD criteria were evaluated as summarized in Table 3.

Table 3. Treatments Evaluated During Phase I.

Speed Limit (mph)	Lane Width (feet)	Treatments Observed		
40	10.5	L=100, Sp=25	L=160, Sp=40	L=280, Sp=25
	12	L=100, Sp=25	L=160, Sp=40	L=320, Sp=25
45	12	L=100, Sp=25	L=160, Sp=40	L=540, Sp=25

L=Length of merging taper in feet, Sp=Cone spacing in feet

Cone spacing for the 100 ft taper treatment was based on FDOT Standards which require 25 ft spacing of cones in the taper on a facility with posted speeds of 30 to 45 mph. A 160 ft taper treatment was suggested by the research team as a short taper alternative, should safety issues arise in the field that would prevent an evaluation of the 100 ft taper. The 160 ft taper treatment uses cones placed at 40 ft spacing instead of 25 ft. Since lane stripes are generally placed at 40 foot intervals on the pavement, this merging taper would be simpler to install (i.e., field personnel could simply place cones according to the lane stripes). The FDOT standard taper length for each site was based on MUTCD criteria. Cone spacing for the FDOT standard taper treatment was also 25 feet. For all treatments, standard 36-inch reflectorized channelizing cones were used. In accordance with the duration notes on FDOT Standard Index 613, the advance warning signs, arrow panel, and buffer space were omitted for all of the treatments. The treatments evaluated are shown in Figure 2.

(a) 100 ft **(b) 160 ft** **(c) FDOT standard (540 ft)**

Figure 2. Merging Taper Lengths Evaluated in Phase I.

Because traffic volumes fluctuate throughout the day and different site characteristics would be encountered at each site, the researchers devised an experimental plan to mitigate the impacts of these differences. The plan included a randomized treatment order for each combination of speed limit and number of lanes open. The experimental plan is shown in Table 4.

Table 4. Treatment Order at Each Site for Each Variable Combination.

Posted Speed Limit (mph)	Number of Lanes Remaining Open When Right Lane Was Closed											
	2						1					
40	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
	S[a]	S	100	100	160	160	S	S	100	100	160	160
	100[b]	160	S	160	S	100	100	160	S	160	S	100
	160	100	160	S	100	S	160	100	160	S	100	S
45	Site 13	Site 14	Site 15	Site 16	Site 17	Site 18	Site 19	Site 20	Site 21	Site 22	Site 23	Site 24
	S	S	100	100	160	160	S	S	100	100	160	160
	100	160	S	160	S	100	100	160	S	160	S	100
	160	100	160	S	100	S	160	100	160	S	100	S

[a] Treatment is the standard taper described in Standard Index 613 or 616.
[b] Length of merging taper (ft)

Using the experimental plan shown in Table 4, data were collected during a two week period in November of 2008 in Orlando and Broward counties. The researchers documented site characteristics for each location where observations took place. These characteristics included: speed limit, number of lanes open, time of day, sight distance, intersection spacing, surrounding land uses, and weather conditions. All lane closures were right lane closures, and all observations were made during the day under dry pavement conditions. Site characteristics and traffic volumes are given in the Appendix.

Speed data were captured to assess the speed and deceleration rates of free-flowing vehicles in the closed lane. Speed data were recorded using laser speed measurement instruments (i.e., LIDAR) to collect speed profiles of vehicles approaching the taper. The instruments were connected to laptops to electronically download speed and distance measurements every half second for as long as the device was locked on to a vehicle. This method allowed the researchers to create a speed profile for each vehicle as it approached the work vehicle. The position of the researcher was recorded at each site so that all profiles could be adjusted to reflect the vehicles' actual distances from the first cone in the merging taper, and then to the back of the work vehicle.

Video captured lane choice and erratic maneuver data. Video data were recorded using two tripod mounted video cameras located 375 ft upstream of the first cone in each taper. One camera was pointed upstream to record lane choice data at locations 750 ft and 500 ft upstream of the first cone in each taper. The second camera was pointed downstream to record data 250 ft upstream of the first cone, as well as at the first cone in the taper. The camera time clocks were synchronized to facilitate accurate data reduction. A typical site layout for Phase I data collection is shown in Figure 3. It should be noted that no erratic maneuvers were actually observed during the field studies, and so are not included in the results section of this report.

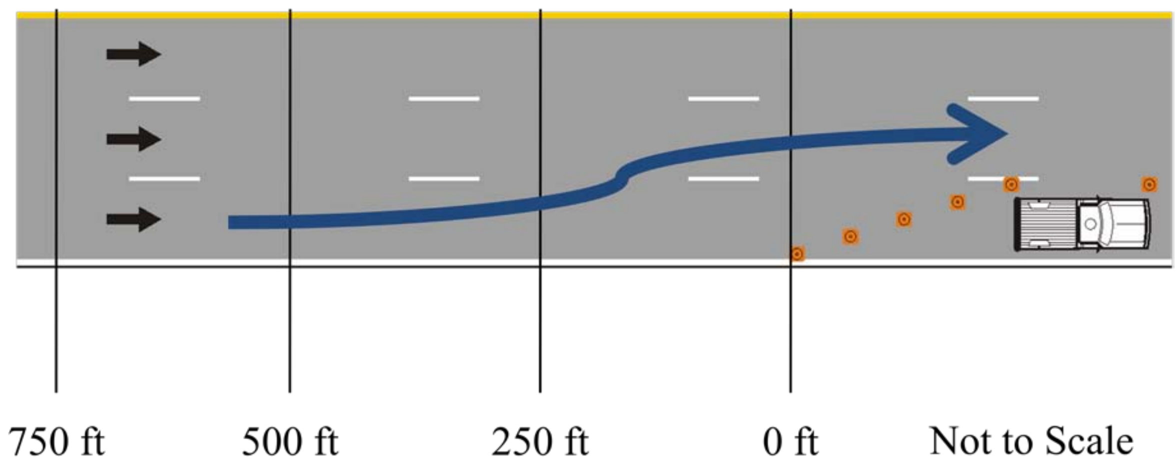

Figure 3. Typical Phase I Data Collection Site Layout.

During the first week of data collection, FDOT's Orlando South Maintenance Office provided equipment and personnel needed for all taper treatments. FDOT pickup trucks, similar to the one shown in Figure 4, were used for the short duration work zones because they represented the minimize size of vehicle that would likely be used for short duration utility operations. A total of 36 short duration utility operations were observed at twelve different locations over a four day period in the Orlando area.

Figure 4. Typical DOT Pickup Truck Used During Phase I Data Collection Effort.

During the second week, FDOT's Broward Maintenance Office provided equipment and personnel needed for all taper treatments. Again, DOT pickup trucks were used for the short duration work zones. A total of 21 short duration utility operations were observed at seven different locations over a four day period in Broward County.

Overall, 57 short duration operations were observed at 19 different locations during the entire data collection effort. Inclement weather prevented the research team from obtaining data for the remaining sites. Table 5 shows the portion of the experimental plan for which data was obtained. The sites were renumbered using a standard naming convention for easier reference throughout the remainder of this report.

Table 5. Summary of Data Collected During Phase I.

Posted Speed Limit (mph)	**Number of Lanes Remaining Open When Right Lane is Closed**											
	2						**1**					
40	Site A	Site B	N/A	N/A	N/A	N/A	N/A	Site A	Site B	Site C	Site D	Site E
	S[a]	S	100	100	160	160	S	S	100	100	160	160
	100[b]	160	S	160	S	100	100	160	S	160	S	100
	160	100	160	S	100	S	160	100	160	S	100	S
45	Site A	Site B	Site C	Site D	Site E	Site F	Site A	Site B	Site C	Site D	Site E	Site F
	S	S	100	100	160	160	S	S	100	100	160	160
	100	160	S	160	S	100	100	160	S	160	S	100
	160	100	160	S	100	S	160	100	160	S	100	S

[a] Treatment is the standard taper length described in Standard Index 613 or 616.
[b] Length of merging taper (ft)
Shading denotes planned sites that were not observed during the data collection effort.

Researchers used the LIDAR position information recorded in the field for each site to adjust the data relative to the first cone in the merging taper. For each speed profile, average deceleration rates were computed for three areas upstream of the merging taper: from 750 ft to 500 ft, from 500 ft to 250 ft, and from 250 ft to 0 ft. Average deceleration rates were used because the LIDAR reported data to the nearest 1 mph, making calculation of instantaneous deceleration rates impossible.

Video data was reduced by using pairs of video players, each connected to a separate television, to tabulate the number of cars in each lane at four locations upstream of the merging taper: 750 ft, 500 ft, 250 ft, and 0 ft. The video data were also used to track vehicles in the closed lane to determine if they were occluded upon entering the study area (at 750 ft upstream of the merging taper). Occluded vehicles were those entering the study area in the closed lane within 4 seconds of the vehicle ahead of them. The video data were also used to track vehicles in the closed lane to determine if they became trapped. Trapped vehicles were those vehicles in the closed lane within 250 ft of the beginning of the taper that decelerated to a stop, or almost stopped, waiting for a gap in the traffic stream in the open lane. The reduced data for each site is shown in the Appendix.

PHASE II – QUICK UTILITY OPERATIONS

As discussed previously, the MUTCD recognizes the relative safety and practical tradeoffs associated with traffic control requirements for stationary work activities and those that move along the roadway. The challenge is in deciding whether being at a given location longer to allow for a more thorough traffic control set up with signs and cones (and a similar duration to allow for the signs and cones to be removed prior to moving to the next location) is safer than simply stopping and doing the work quickly without the advance signs and cones. Since some work activities involve only a few minutes of work at a location, the operation may be more appropriately thought of as a mobile operation with intermittent stops. After discussions with FDOT and utility companies, a no-taper mobile work zone condition was included in the evaluation.

In this phase, the research team observed several quick utility operations lasting 15 minutes or less performed without a merging taper. MUTCD language indicates the need for appropriately colored or marked vehicles with high-intensity rotating, flashing, oscillating, or strobe lights in place of signs and channelizing devices for short-duration or mobile operations. Utility company bucket trucks are generally equipped with these lights. In addition, bucket trucks are larger than standard pickup trucks, and likely to be more visible to approaching motorists. The typical utility company bucket truck used in this phase of studies is shown in Figure 5.

Similar to previous phases, the researchers documented site characteristics for each location where observations took place. For the quick utility operations, all sites had posted speeds of 40 or 45 mph and only one lane open. Other characteristics recorded included: time of day, sight distance, presence of curb, intersection spacing, surrounding land uses, and weather conditions. All lane closures were right lane closures, and all observations were made during daylight hours under dry pavement conditions. Site characteristics and traffic volumes are given in the Appendix.

The researchers performed this phase of data collection in August of 2009 in Hillsborough County. Tampa Electric Company (TECO) provided equipment and personnel needed for the quick utility operations. Using TECO trucks similar to the one shown in Figure 5, 29 quick utility operations, lasting less than 15 minutes each, were observed at 24 different locations over a five day period. At each of the 24 locations, observations were made while the utility truck bucket was extended, as if the worker were relamping a light fixture. At five of the 24 sites, additional 15 minute observations were made with the utility truck bucket in the cradled or bucket-down position and the worker standing outside of the right-of-way.

The data collection technique employed in Phase II is illustrated in Figure 6. The researchers manually recorded lane choice by using mechanical counters and clipboards to tabulate the number of vehicles in each lane at stations 540 ft, 250 ft, and 100 ft upstream of the work vehicle. Each vehicle entering the study area in the closed lane was further categorized as occluded or not occluded at each of these stations. Occluded vehicles were those entering the study area in the closed lane within 4 seconds of the vehicle ahead of them. Researchers also documented whether vehicles in the closed lane became trapped. Trapped vehicles were those vehicles in the closed lane within 250 ft of the work vehicle that decelerated to a stop, or almost stopped, waiting for a gap in the traffic stream in the open lane. The researchers also looked for erratic maneuvers, such as hard braking, swerving, or cutting off another vehicle.

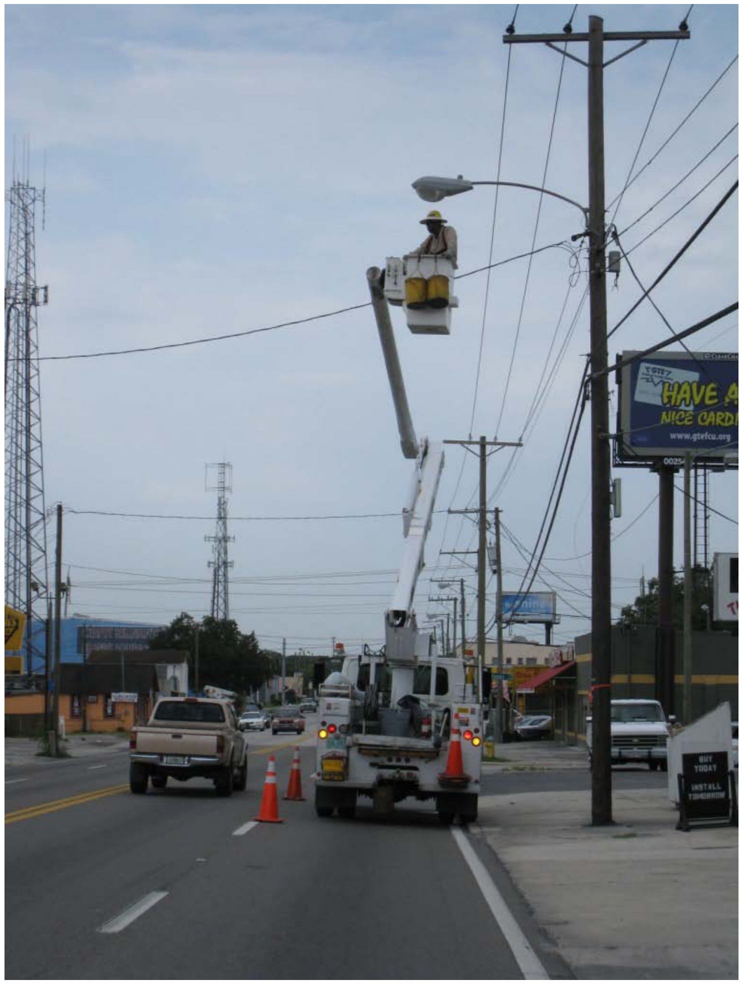

Figure 5. Temporary Traffic Control for Phase II Quick Utility Operation Observations.

MEASURES OF EFFECTIVENESS

Primary measures of effectiveness (MOEs) selected for this research were lane distribution, percent remaining in the closed lane, percent occluded, percent trapped, and vehicle acceleration/deceleration rates. The lane distribution MOE is based on the percent of traffic in each lane at various points upstream of the lane closure and at the beginning of the taper, allowing the researchers to determine how far upstream of the lane closure motorists are moving out of the closed lane. This data includes all vehicles in the study area, regardless of their point of entry to or exit from the study area. The percent remaining in the closed lane is used to more closely evaluate the behavior of vehicles in the closed lane, and was estimated as the amount of traffic in the closed lane at various points upstream of the taper and work vehicle divided by the amount of traffic in the closed lane at 750 feet upstream (or 540 feet for the Phase II studies). It includes only vehicles that entered the study area in the closed lane, perceived and reacted to the work activity, and merged into the open lane. It does not include vehicles that entered from or exited to side streets or driveways located within the study area. The percent occluded MOE is based on the percent of vehicles entering the study area in the closed lane within 4 seconds of the vehicle ahead of them. The percent trapped MOE is based on the amount of traffic in the closed lane within 250 ft of the beginning of the taper that decelerated to a stop, or almost stopped, waiting for a gap in the traffic stream in the open lane divided by the amount of traffic in the closed lane at 750 feet upstream (or 540 feet for the Phase II studies). Vehicle acceleration/deceleration rates near the taper were also selected for measurement to quantify driver reactions as they approached the utility work occurring in their lane. The average value by treatment type within each region was computed and compared.

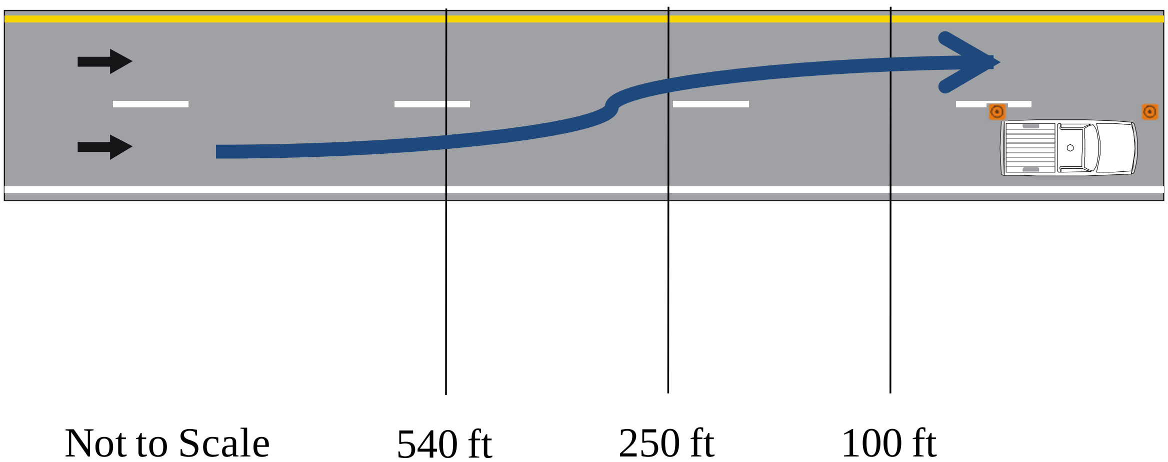

Figure 6. Typical Phase II Data Collection Site Layout.

RESULTS

This section provides the results of the data collection, reduction and analysis. It is divided into three sections. The first section discusses the effects of different merging taper lengths upon driving behavior. The second section discusses driver reaction to quick utility operations in which no merging taper was used. The final section summarizes the findings and discusses the implications of reduced traffic control for short duration utility operations.

DRIVER RESPONSE TO DIFFERENT MERGING TAPER LENGTHS

Lane Distribution

Lane distribution data collected at each site were separated into groups based on the posted speed limit and the number of lanes remaining open. Within each group, the distribution of traffic across all lanes was compared for each taper treatment. Figure 7 through Figure 10 show the distribution of traffic at each group of sites. Reviewing these figures, one sees that similar trends exist across the various speed and lane conditions. As drivers approach each type of merging taper, they exit the closed lane, creating a shift in the lane distribution. With respect to taper length effects, generally, a higher percentage of vehicles remained in the closed lane with the longer FDOT standard taper treatments at various distances from the start of the taper. At the beginning of the merging tapers themselves, the difference in the percent of traffic in the closed lane between the FDOT and 100 ft taper was between 5 and 10 percent.

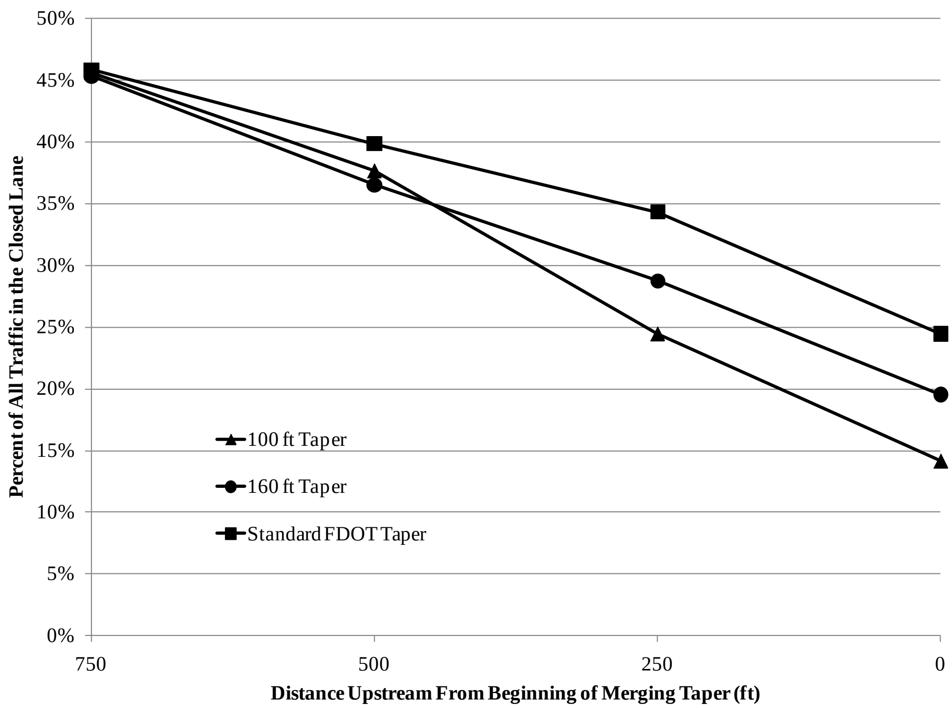

Figure 7. Lane Distribution of All 45 mph/1-Lane Open Sites.

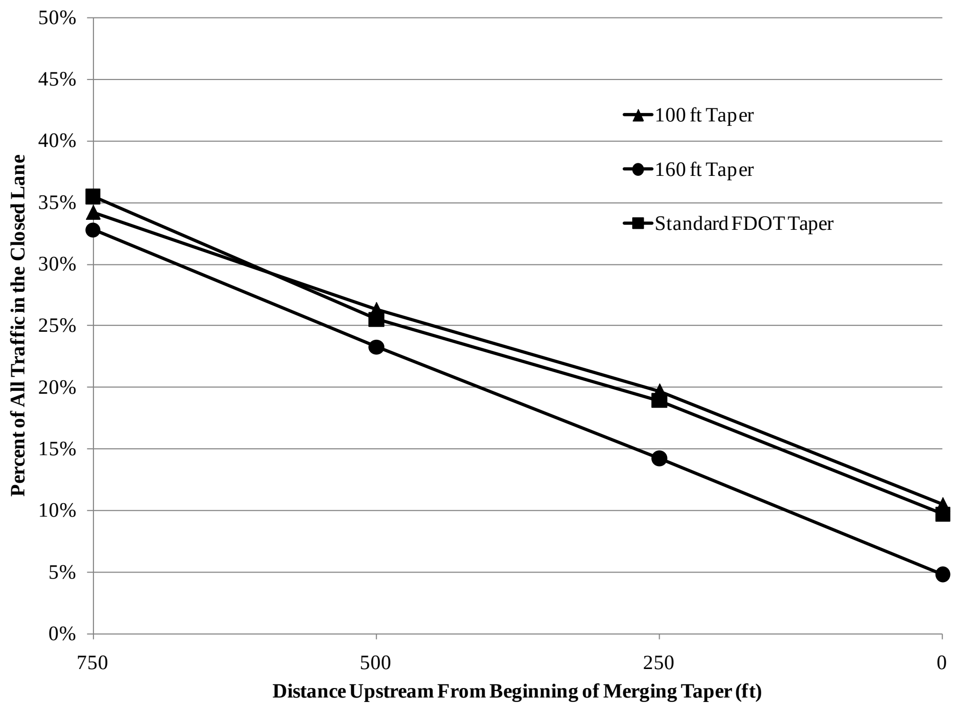

Figure 8. Lane Distribution of All 40 mph/1-Lane Open Sites.

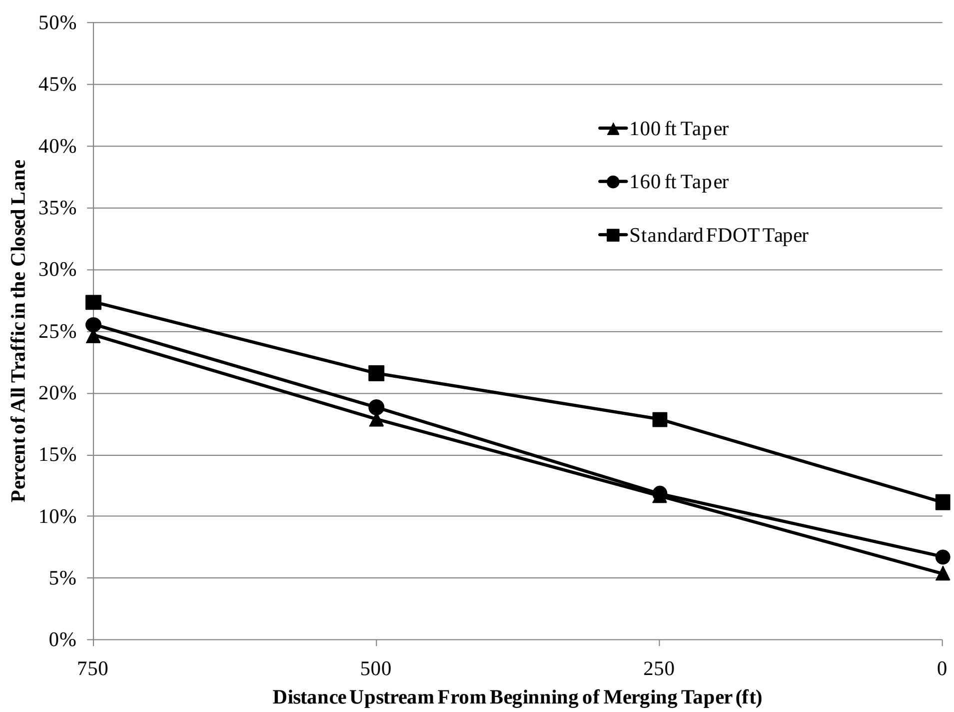

Figure 9. Lane Distribution of All 45 mph/2-Lanes Open Sites.

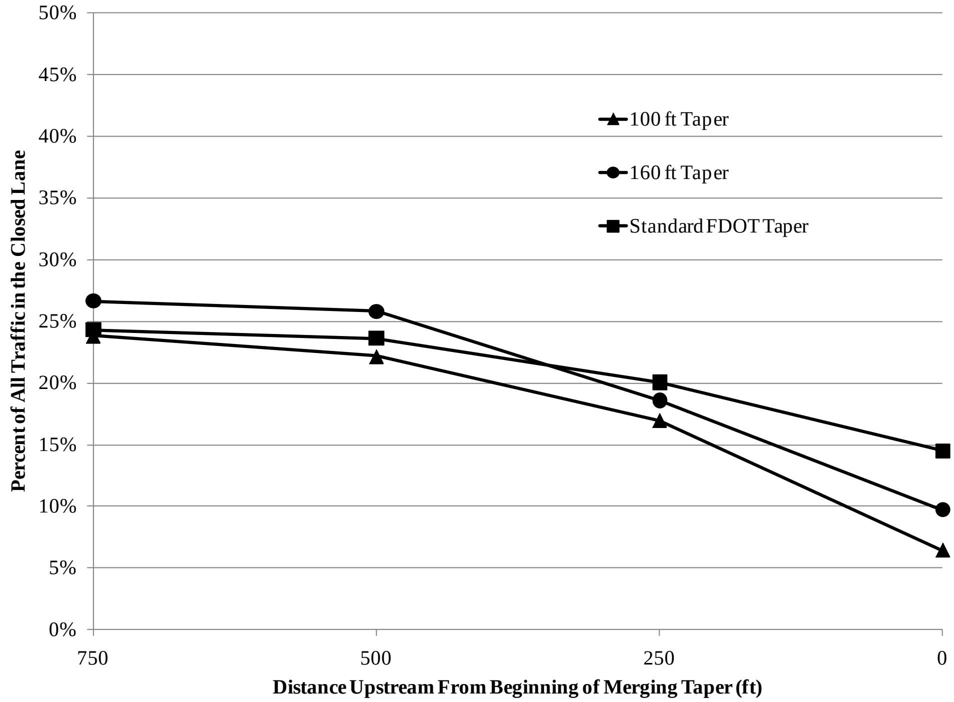

Figure 10. Lane Distribution of All 40 mph/2-Lanes Open Sites.

Although the lane distribution patterns shown in Figure 7 through

Figure 10 are fairly consistent across conditions, considerable variation in responses to a given merging taper length was found between sites within each speed and lane condition category. Certainly, traffic volumes have an impact on driver behavior by affecting a driver's ability to find a suitable gap in the open lane. At higher volumes, drivers may tend to remain in the closed lane longer than they would at a lower volume. For example, data collected during standard FDOT taper length lane closures for two 45 mph/1-lane open sites are shown in Figure 11. Traffic volumes for these sites were approximately 1345 vehicles per hour (vph) at site 45-1-D and 805 vph at site 45-1-E. Clearly, the higher-volume site has a higher percentage of traffic still in the closed lane at beginning of the merging taper.

In addition to traffic volume, a driver's ability to exit the closed lane likely depends on other site conditions such as the distance to the upstream signalized intersection, sight distance to the taper, turning movements, and the presence of bus stops (and frequency of buses in the traffic stream). Details about these conditions at the test sites are given in the Appendix.

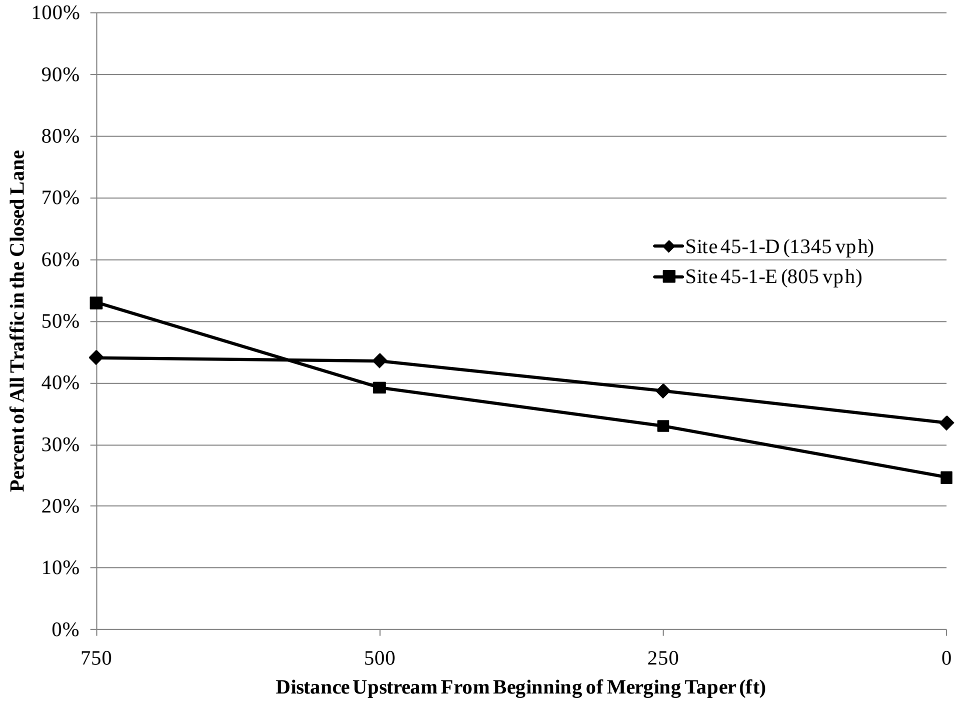

Figure 11. Comparison of Similar Sites with Different Traffic Volumes.

Upstream signals create platoons within the traffic stream that can impact a driver's ability to find a suitable gap in an open lane. However, as traffic moves further downstream from a signalized intersection, the platoon tends to disperse, creating more (and larger) gaps in which traffic can merge into the open lane when approaching a merging taper and work operation. This platoon behavior suggests that when a merging taper is located nearer an upstream signalized intersection, drivers may tend to remain in the closed lane longer than they would if the taper was further downstream of the signalized intersection. Data collected during standard FDOT merging taper length testing at two sites verifies this influence. As shown in Figure 12, two 45 mph/1-lane open sites with similar traffic volumes but different distances from an upstream signal show the percent of traffic in the closed lane remaining at higher levels for the site closer to an upstream signalized intersection.. At the beginning of the merging taper, the site located closer to an upstream intersection site has 20 percent of the traffic still in the closed lane, compared to only about 12 percent for the site located farther from an upstream intersection. This difference exists even though the percent of traffic in the closed lane was originally slightly lower for the near-intersection site than for the site farther downstream (33 percent versus 40 percent, respectively).

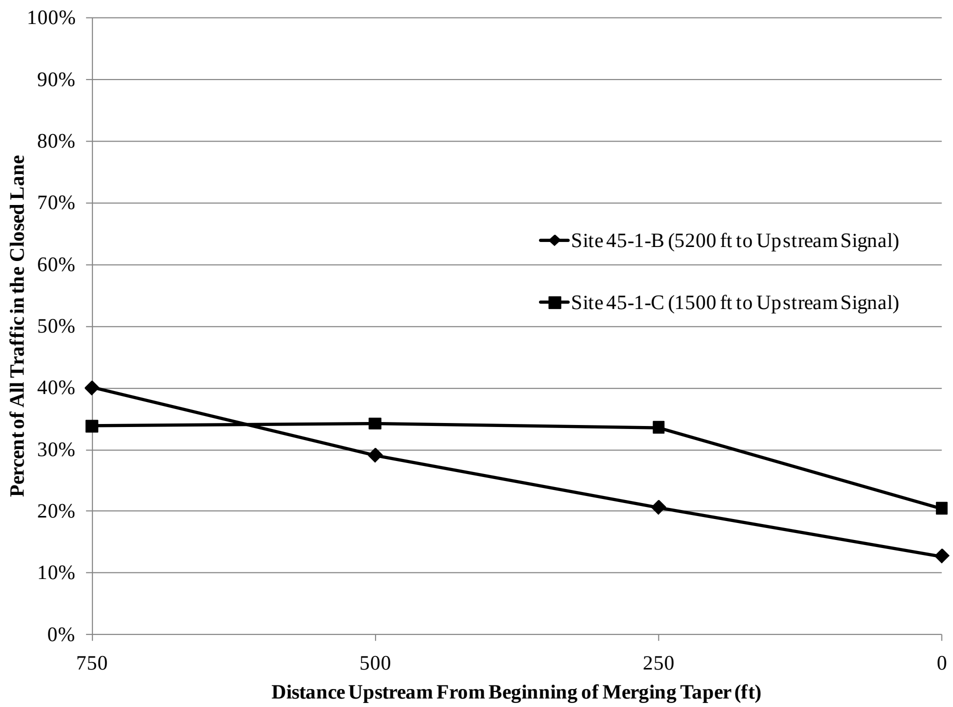

Figure 12. Comparison of Similar Sites at Different Distances from Upstream Signals.

To this point, the discussion presented has focused on how drivers behave relative to the location of the beginning of the merging taper. Examined in this frame of reference, one might be tempted to conclude that a shorter merging taper length has a more significant effect upon driver lane change behavior than longer taper lengths, as the percent of traffic that is in the closed lane at various upstream distances is consistently lower for the shorter tapers. However, these results must be interpreted considering the fact that the beginning of the tapers is located at different distances upstream of the actual work vehicle located in the closed lane. The researchers hypothesize that both the merging taper and the work vehicle serve as cues to approaching drivers about the need to exit the closed lane. For the longer FDOT taper, the work vehicle is located much farther downstream and so expected to have a much smaller effect on drivers. In other words, with the longer FDOT taper, researchers believe that drivers are reacting primarily to the merging taper. For the shorter 100 ft and 160 ft tapers, the proximity to the work vehicle decreases, and so researchers believe that more drivers move out of the closed lane prior to reaching the beginning of the merging taper because many are reacting to the realization that there is a work vehicle blocking the closed lane. Considered relative to where the work vehicle is located, a longer taper length actually tends to result in smaller amount of traffic in the closed lane at various distances upstream of the work vehicle, as shown in Figure 13.

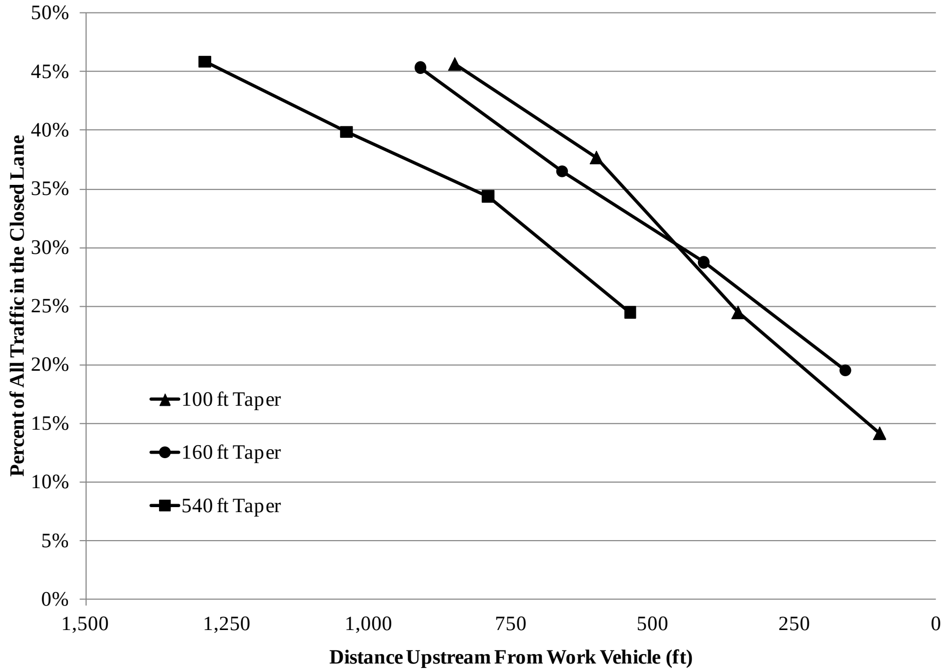

Figure 13. Lane Distribution of All 45 mph/1-Lane Open Sites Normalized to the Location of the Work Vehicle.

Percent of Traffic Remaining in the Closed Lane

The beginning of the merging taper defines the point at which drivers must either begin to merge or stop to wait for an acceptable gap in the traffic stream in the open lane. From the results described above, even when the merging taper is as short as 100 ft, there was still a percentage of drivers remaining in the closed lane at the beginning of the taper. Presumably, some drivers make a deliberate decision to move as far forward in the closed lane as possible prior to beginning to merge. Meanwhile, other drivers are forced to stay in the closed lane because a suitable gap in the open lane may not be available. In order to further understand how those drivers who have to make a lane change react to the merging tapers, researchers further examined the closed lane traffic in isolation. This was accomplished by studying a subset of the lane distribution data, which included only vehicles that entered the study area in the closed lane, perceived and reacted to the work activity ahead, and merged out of the closed lane into the adjacent open lane. The closed lane data does not include vehicles that entered from or exited to side streets or driveways.

For all data collected with merging tapers in place, the study area began at a location 750 ft upstream of the beginning of the merging taper. Thus, all percentages of traffic remaining in the closed lane are expressed as a percentage of the traffic in the closed lane at 750 ft from the beginning of the merging taper. Figure 14 shows the percent of traffic remaining in the closed lane for all sites combined. Detailed data are given in the Appendix.

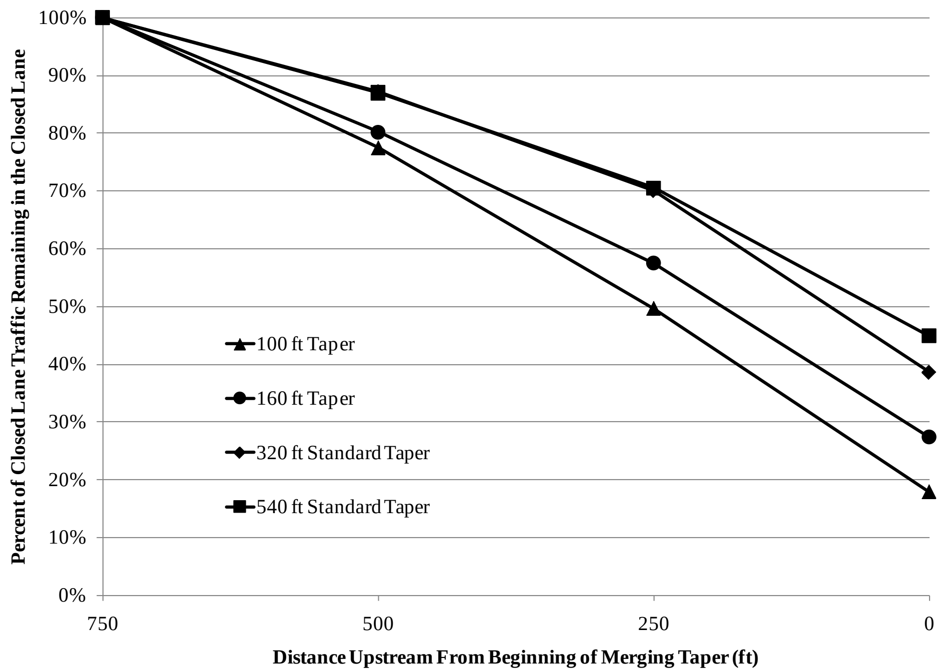

Figure 14. Percent of Traffic Remaining in the Closed Lane for All Sites Combined.

The general trend is that the percent of closed lane traffic remaining in the closed lane tends to be higher with longer taper lengths. The difference between the FDOT and 100 ft merging tapers is as much as 20 percent at the beginning of each merging taper. As discussed previously, these differences may be due in large part to closer proximity of the work vehicle for the shorter merging taper length. As further illustration of this effect, Figure 15 shows the relationship between the percent of traffic remaining in the closed lane at the beginning of the merging taper at various taper lengths tested.

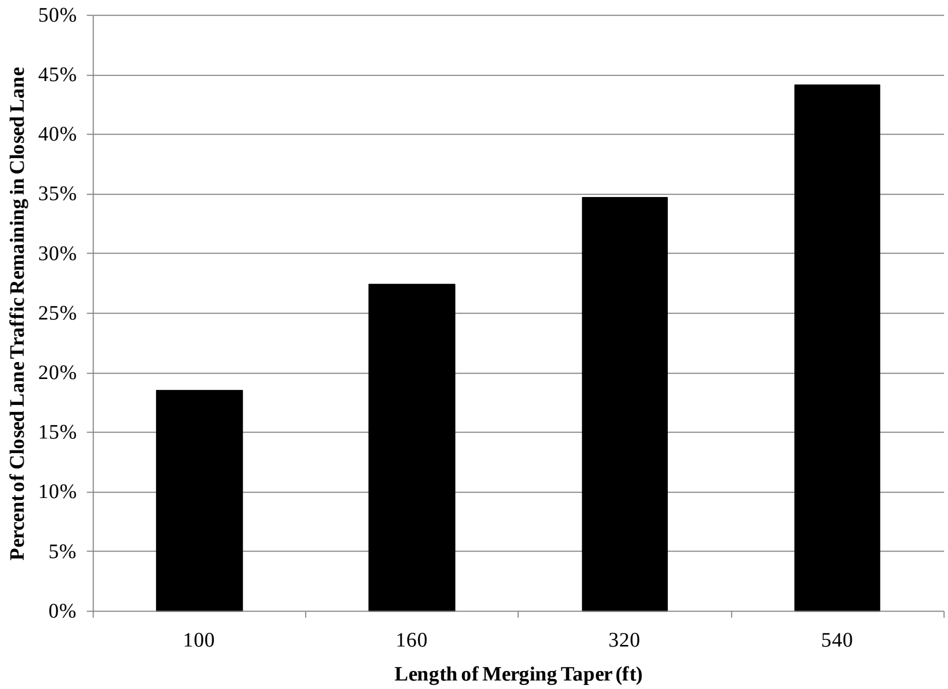

Figure 15. Percent of Traffic Remaining in the Closed Lane at the Beginning of the Merging Taper for All Sites

Although many more drivers have vacated the closed lane by the time the reach the 100 ft taper (as compared to the longer FDOT taper lengths), the fairly sizeable proportion of traffic still in the closed lane is somewhat disconcerting. In essence, none of the merging taper lengths does a good job of getting all of the closed lane traffic to vacate the lane prior reaching the beginning of the merging taper. Researchers hypothesized that the combination of a lack of advance warning signing (a key positive guidance component of work zone traffic control systems) and a fairly high frequency of vehicle occlusion of the channelizing devices and work vehicle together contribute to these result. In the absence of advance warning signs that would typically inform motorists of the lane closure ahead, drivers must depend on other visual clues to detect the presence of the lane closure. Certainly, some drivers will intentionally remain in the closed lane to move as far forward as possible before merging. However, it is very possible that a considerable number of drivers in the closed lane were unaware of the lane closure as they encountered the beginning of the merging taper because they were right behind another vehicle and so had the taper and work vehicle occluded from view. The researchers evaluated this possibility by identifying those vehicles entering the study area occluded, and assessing how many of those occluded vehicles became trapped in the closed lane at the beginning of the taper. Occluded vehicles were those entering the study area in the closed lane within 4 seconds of the vehicle ahead of them. Figure 16 shows the percent of occluded vehicles that entered the study area for each merging taper length evaluated. Regardless of taper length, a substantial percentage of vehicles entering the study areas did so in an occluded fashion. Of 8,332 closed lane vehicles observed, 4,197 (approximately 50 percent) were occluded.

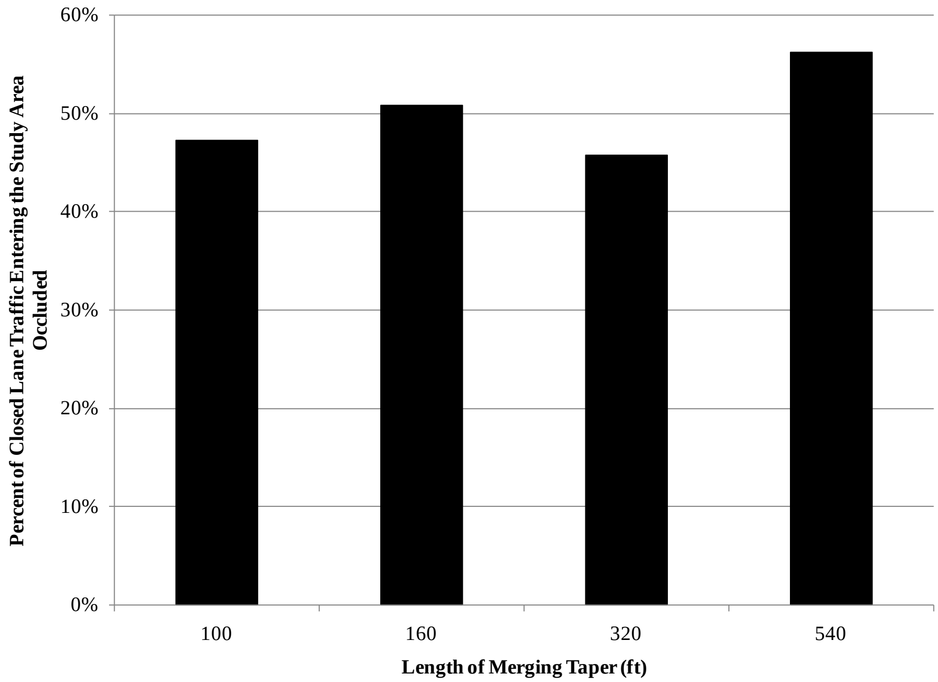

Figure 16. Percent of Closed Lane Traffic Entering the Study Area Occluded.

For this analysis, trapped vehicles were those vehicles in the closed lane within 250 ft of the beginning of the taper that decelerated to a stop, or almost stopped, waiting for a gap in the traffic stream in the open lane. Trapped vehicles present some concern because they create speed differentials within the traffic stream that can contribute to traffic flow turbulence. In addition, one could envision that trapped vehicles could become more impatient as they wait for a gap to move into the open lane, and could tend to select shorter gaps in which to merge, creating other potential safety concerns.

Figure 17 shows the percent of closed lane traffic remaining in the closed lane at the beginning of the merging taper plotted against the percent of vehicles becoming trapped at the merging taper. These data are for six 45 mph/1-lane open sites. The correlation of these percentages is fairly high for all merging taper lengths examined.

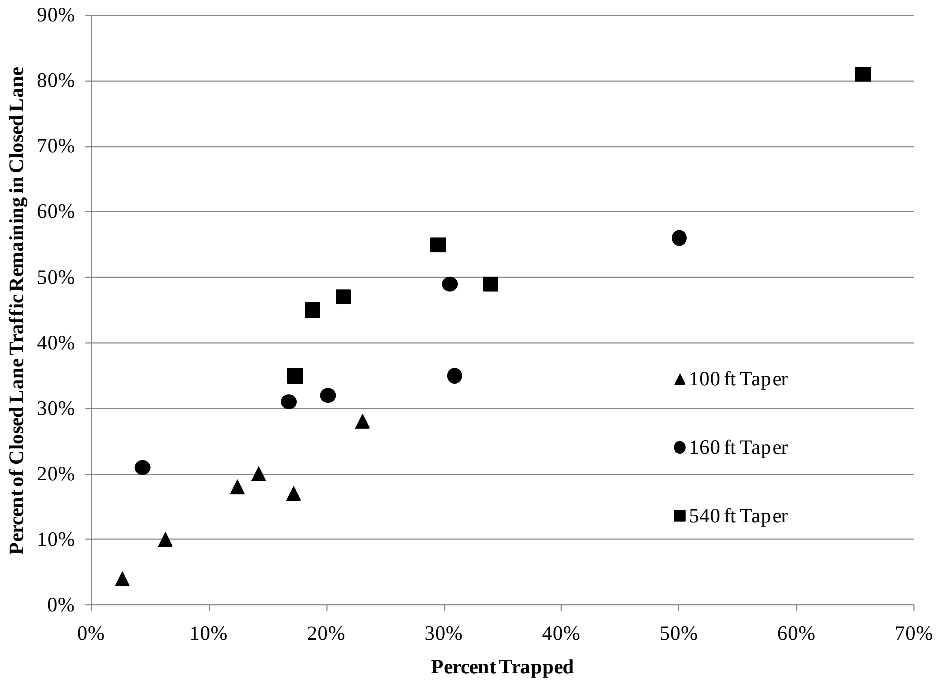

Figure 17. Percent of Traffic Remaining in the Closed Lane at the Beginning of the Merging Taper vs. Percent of Trapped Vehicles.

Next, it does appear that it is the amount of occluded vehicles in the traffic stream that contributes significantly to the percentage of vehicles becoming trapped. These data, shown in Figure 18, show the relationship between the percentage of vehicles that enter the study area occluded and the percentage that become trapped.

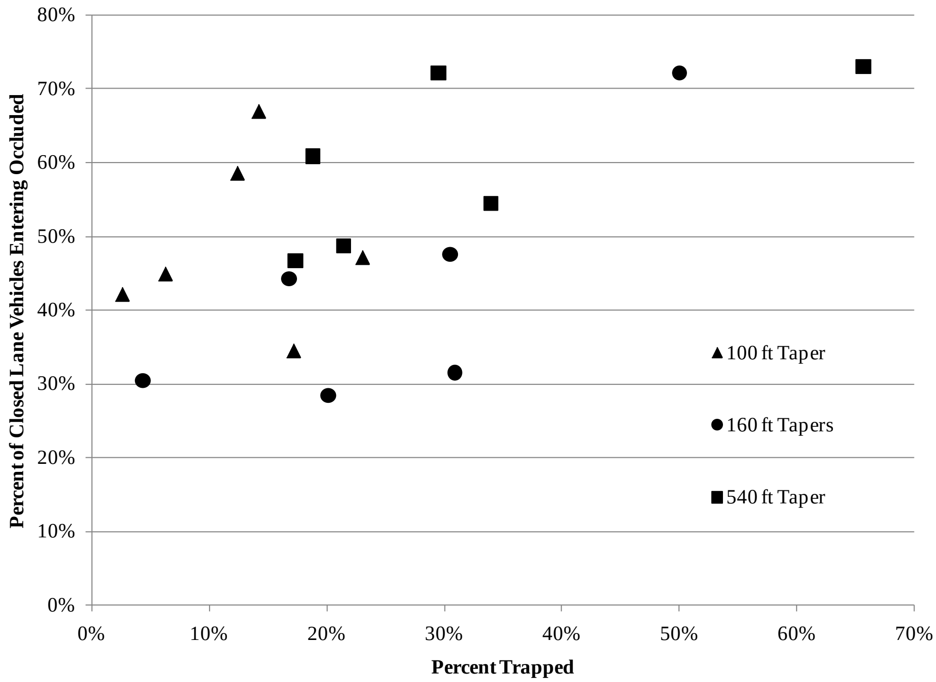

Figure 18. Percent of Vehicles Entering Occluded vs. Percent Trapped at the Beginning of the Merging Taper

Deceleration Data

Figure 19 provides average deceleration rate data for the six 45 mph/1-lane open sites. Although there appears to be small differences in deceleration rates, they are too small to consider practically significant. *A Policy on Geometric Design of Highways and Streets* [21] identifies a comfortable deceleration rate for drivers as 11.2 ft/sec^2 for drivers making a normal stop. It also identifies a maximum deceleration rate as 14.8 ft/sec^2 for drivers making a panic stop. In contrast, the average deceleration rates computed from the field data were generally 2.0 ft/sec^2 or less. Detailed deceleration data are given in the Appendix.

It should be remembered that researchers obtained speed profile data (from which decelerations were computed) from free-flowing vehicles only. At higher volumes, the free-flow vehicles were typically the first vehicle in a platoon of vehicles from an upstream intersection. These drivers have a clear view of the merging taper. Drivers of subsequent vehicles in the platoon did not necessarily have a clear view of the merging taper and their reaction was dependent upon the reaction of the driver they were following. Although the deceleration rates of the subsequent vehicles in the closed lane platoons may have been higher than the lead vehicle, these deceleration rates could not be captured in the speed data.

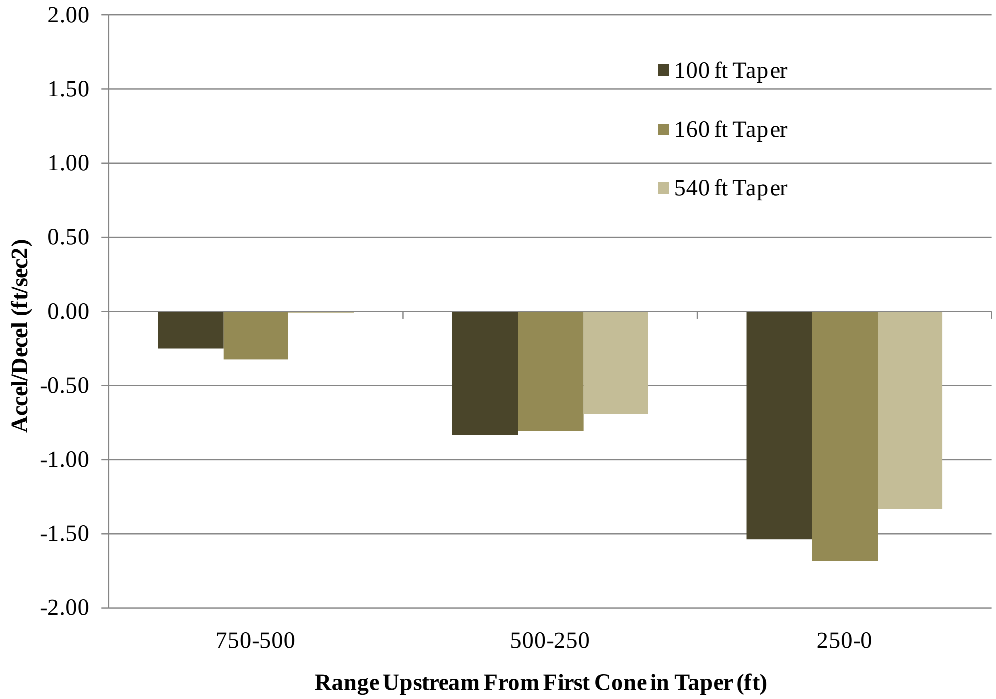

Figure 19. Deceleration Data for 45 mph/1-Lane Open Sites.

Phase I Summary

The results of the Phase I field studies indicate that there are differences in how drivers react to merging tapers of different lengths upstream of a work vehicle. Measured relative to the start of the tapers, shorter taper lengths result in more drivers being out of the closed lane at given distances upstream of the taper. However, measured relative to the location of the work vehicle, one finds that more drivers have exited the closed lane farther upstream of the work vehicle when longer tapers are used. These differences reflect the fact that both the merging taper and the work vehicle in the closed lane can serve as visual cues to drivers that they need to vacate the closed lane. For longer taper lengths, though, the channelizing devices begin farther upstream of the work vehicle, and are the primary motivator of driver lane changing (in fact, they physically require drivers to vacate the closed lane once they reach the channelizing devices). For shorter taper lengths, drivers are reacting to both the merging taper presence and the work vehicle itself. As a result, more drivers have vacated the lane by the time they reach a shorter taper length than a longer one. Of course, the beginning of the merging taper is much closer to the work vehicle.

Recognition that the work vehicle itself serves as a visual cue to exit the closed lane does raise an important question; namely, does a short taper itself serve any value from a driver lane choice and merging perspective? In the Phase I studies, it would appear that the answer is yes, since there were a significant number of vehicles still in the closed lane at the beginning of the taper. However, would the same type of response exist if the work vehicle were much larger than the one used in the Phase I studies? Intuitively, one would expect that larger work vehicles would be seen and detected as being stopped in the lane at a greater distance upstream, and would also encourage lane changes farther upstream. If so, it may be that a short merging taper would have little use as a visual cue for motorists when the work vehicle is large. To investigate this hypothesis, researchers conducted a second series of field studies to assess how drivers react to a large utility vehicle making very short intermittent stops along a roadway (consistent with the definition of a mobile operation in the MUTCD).

DRIVER RESPONSE TO QUICK UTILITY OPERATIONS

Researchers evaluated no-taper quick utility operations on both 45 mph/1-lane open and 40 mph/1-lane open roadways during phase II. Data were collected at 540 ft, 250 ft, and 100 ft upstream of the work vehicle. Lane distribution data for the 100 ft taper in Phase I were compared to the lane distribution for the quick utility operations with no merging taper. For comparison purposes, the data for the 100 ft merging tapers evaluated during phase I were normalized to the location of the work vehicle. These comparisons are shown in Figure 20 and Figure 21. It is again important to emphasize that data for the 100 ft taper were collected with standard DOT pickup trucks equipped with typical warning lights plus a sequential flashing LED lightbar, while data for the no-taper condition were collected with larger utility bucket trucks also outfitted with typical warning lights (but no lightbar in use).

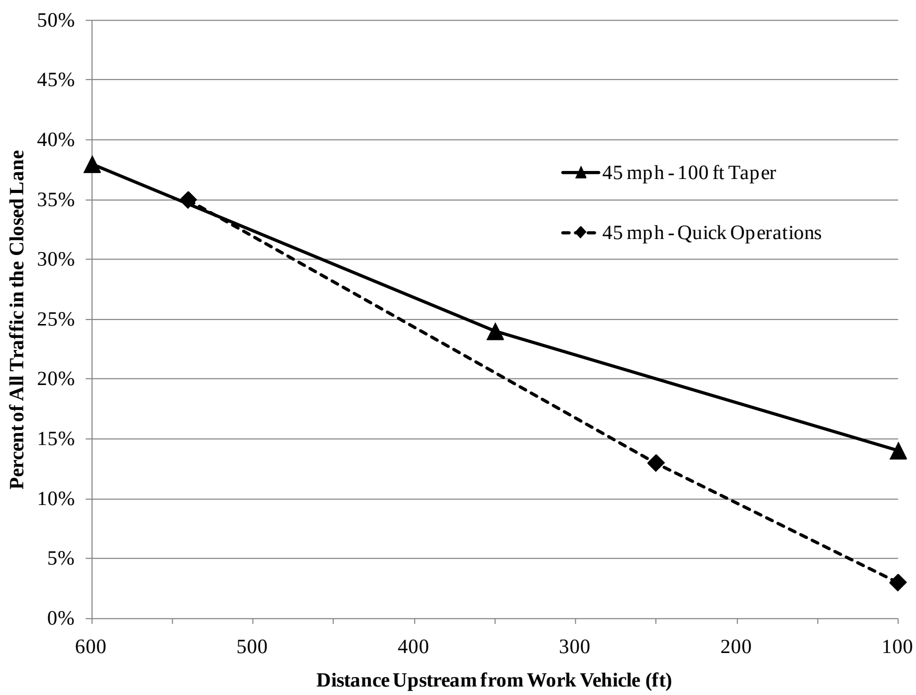

Figure 20. Lane Distribution Comparison, 100 ft Taper vs. No Taper (Quick Operations), 45 mph Sites.

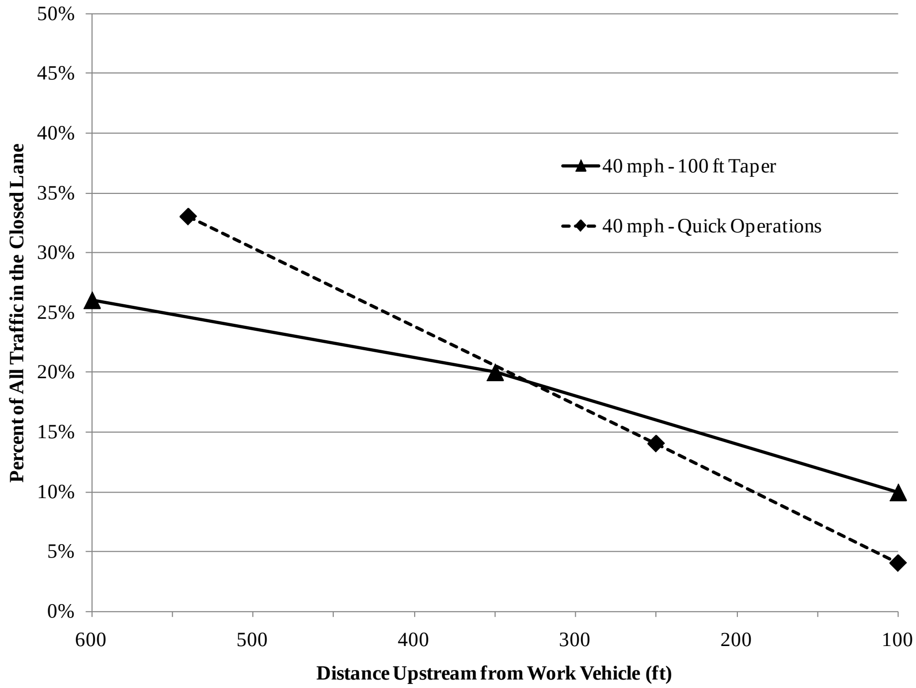

Figure 21. Lane Distribution Comparison, 100 ft Taper vs. No Taper (Quick Operations), 40 mph Sites.

When the larger utility work vehicle was used, fewer drivers are in the closed lane at a distance 100 ft upstream of the work vehicle. This is true for both 45 mph and 40 mph roadways. Similar trends are evident when the data are analyzed in terms of the percent of traffic remaining in the closed lane at various distances upstream of the work vehicle. For comparison purposes, data for the 100 ft merging tapers from the Phase I studies are again included in the graph. For both speed limits evaluated, the percent of traffic remaining in the right lane is shown in Figure 22.

The utility trucks used for the quick utility operations were larger than the pickup trucks used for the merging taper data collection and therefore, likely to be more visible and more imposing to approaching motorists than the smaller pickup trucks. In addition, the quick utility operations typically involved a worker in the aerial bucket simulating a relamping operation. With the bucket extended in the up position, it is likely that the vehicle could be seen from even farther upstream than when the bucket was in a down position. To further investigate the concept of bucket truck conspicuity, the researchers also collected additional data at five of the quick utility operation sites with the aerial bucket in the down position. A summary of the results is shown in Figure 23. It is important to realize that the data shown in this figure represents a very limited sample, consequently these values should only be compared to one another, not to the entire data set.

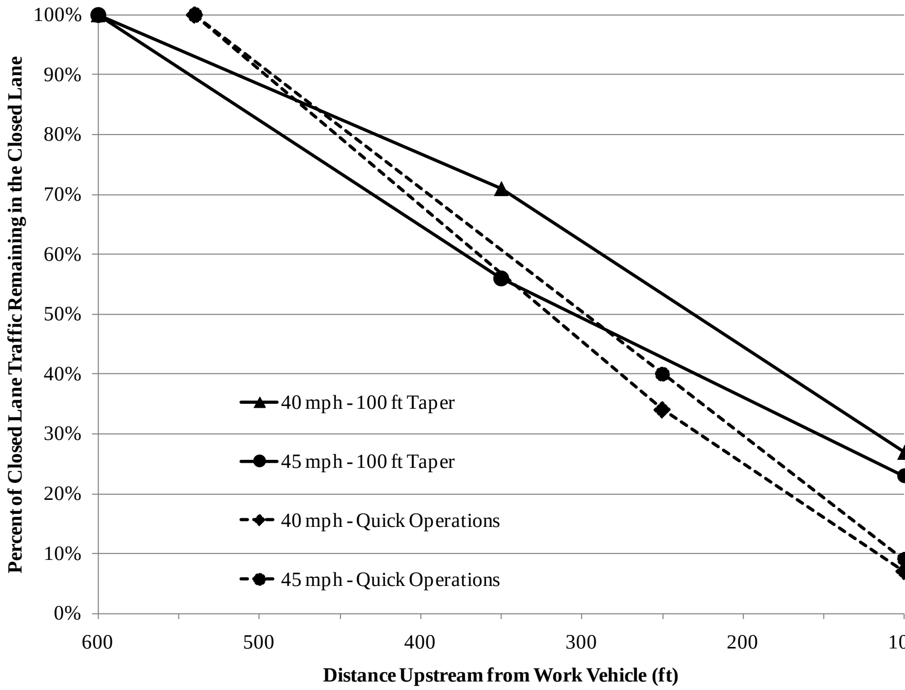

Figure 22. Comparison of Percent of Traffic Remaining in the Closed Lane, 100 ft Taper vs. No Taper (Quick Operations).

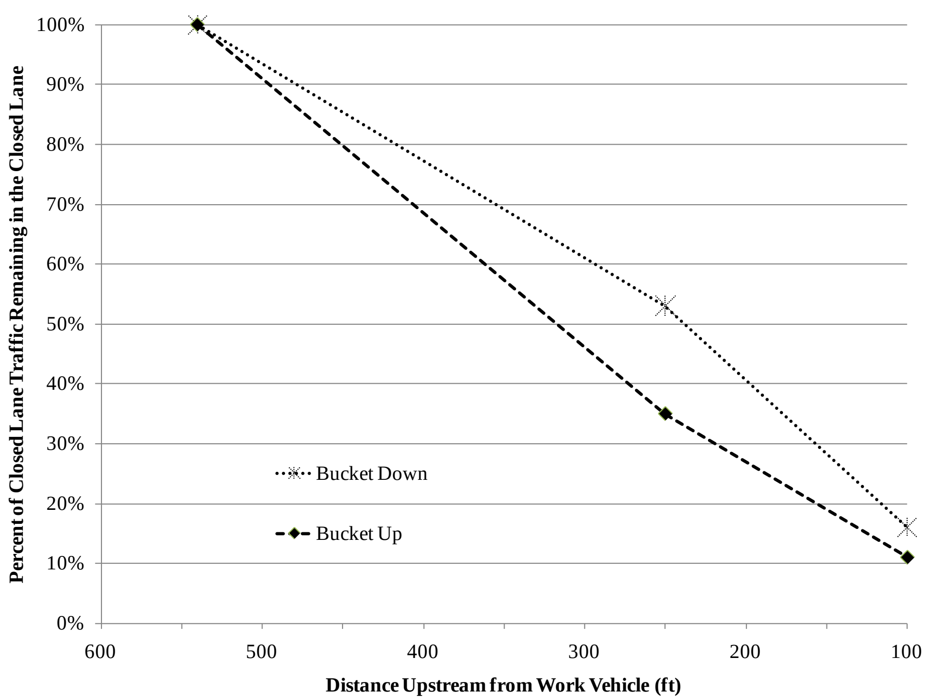

Figure 23. Comparison of Bucket Up and Bucket Down Data During Quick Operations.

At a distance of 250 ft from the rear of the bucket truck, a higher percentage of traffic remained in the closed lane when the bucket was down. These results do seem to verify the hypothesis that visibility of the utility truck was increased with the bucket extended, which in turn leads more drivers approaching the utility operation to vacate the closed lane at a greater distance upstream of the operation.

Finally, during observation of the quick utility operations, only one erratic maneuver was recorded. In this instance, a driver left the open lane and used the closed lane to pass a slower moving vehicle in the open lane, and then re-entered the open lane just upstream of the utility vehicle. Although it is possible that having a merging taper upstream of the work vehicle may have discouraged this maneuver, researchers believe that is also possible that the driver may have attempted the pass even when the cones were present.

DISCUSSION AND INTERPRETATION OF RESULTS

These results must be interpreted with consideration given for both worker and motorist safety. With regards to motorist safety considerations, the data indicate that more vehicles become trapped at the beginning of the merging taper when a longer (FDOT standard) merging taper is used. The stopping, or almost stopped condition, of these vehicles can increase turbulence at the merge point. This is a concern because increased speed differentials are often associated with increased crash risk. Without advance warning signs to inform drivers of the upcoming lane closure, the merging taper is the first information source that drivers encounter indicating that a merge out of the closed lane is necessary. Researchers believe that the existence of vehicle platoons (released from upstream signals) on many 40- and 45-mph urban/suburban facilities often creates a situation where many of the platoon vehicles traveling in the closed lane are occluded from view of the merging taper. Unless the vehicle in front of them chooses to exit the closed lane upstream of the taper, the occluded vehicle does not receive the visual cue to exit the lane until they become trapped at the beginning of the merging taper and must look for an open gap in traffic (along with all of the other trapped vehicles around them).

Although the percentage of trapped vehicles is higher for the longer FDOT tapers relative to the short 100-foot taper, the percentage that became trapped at the shorter taper was certainly not negligible (from Figure 17, as much as 25 percent of the closed lane traffic was trapped at the 100-foot taper at some sites). One advantage that a longer FDOT taper does provide is sufficient distance to stop should an occluded vehicle not realize that the lane is closed and initiate an emergency braking condition once he or she has reached the start of the merging taper. In essence, the cones can potentially serve as a tactile intrusion warning device for distracted, inattentive, or otherwise impaired drivers. Although the MUTCD taper lengths were not developed based on this consideration, the taper lengths are generally equal to or greater than computed stopping sight distances from AASHTO, as shown in Figure 24. If a driver is unaware of the closure until striking the first cone in the merging taper, the taper length provides adequate stopping distance between the decelerating vehicle and the work vehicle.

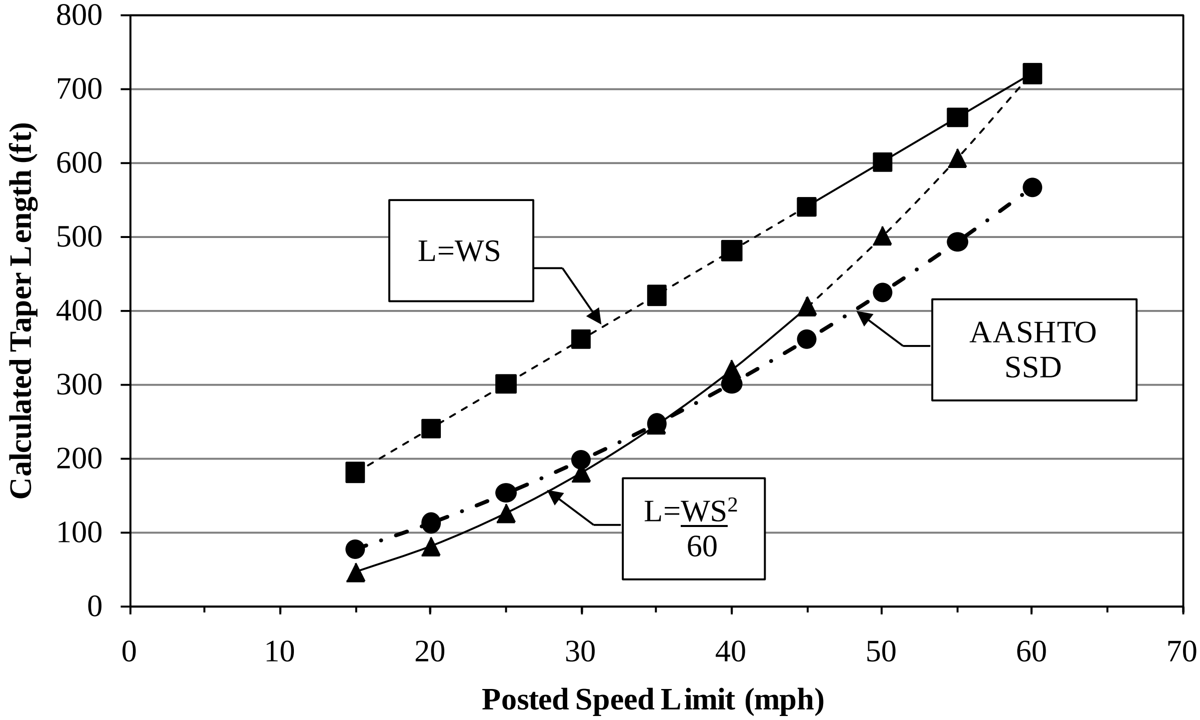

Figure 24. Comparison of MUTCD Taper Length and AASHTO Stopping Sight Distance.

If intrusion by distracted, inattentive or impaired drivers is a concern, then there is a need to have a merging taper long enough to allow these drivers to stop before striking the worker or work vehicle. Many agencies and contractors use buffer spaces between their merging tapers and work operations exactly for this reason.

From the worker safety perspective, though, researchers realize that continuing to require a full FDOT merging taper to be deployed does mean that worker exposure is significantly higher than it would be for deploying and removing a shorter taper length. For true short-duration operations that last most of an hour, the trade-offs between worker and motorist risks appear to favor the deployment of a full FDOT merging taper (as well as the use of advance warning signs). However, for short stops, those more on the order of about 15 minutes or less, the evidence is less clear. The time required for installation and removal of the traffic control devices for a short-duration operation more than double the exposure risk to both motorists and workers. Field study results of quick utility operations without a merging taper strongly indicate that the visibility of the large work vehicle itself serves as a major visual cue to exit the closed lane, such that more drivers vacate the closed lane farther upstream than when a smaller work vehicle was used in conjunction with a 100-foot taper. For work operations that last only a few minutes at a location and thus are more appropriately considered as a mobile operation rather than a short-duration activity, it does appear that relying on vehicle conspicuity and size as the visual cue to exit the closed lane may be sufficient.

It must be remembered that the inattentive driver crashing into the cones is not likely to be a frequent occurrence. During the monitoring of 8,979 vehicles during the merging tapers study, for example, none actually struck a cone. One could argue that drivers on urban arterials may tend to be more alert, since they must continually watch for turning vehicles, driveways, pedestrians, signals, etc.

The data suggests that very short (i.e., about 15 minutes or less) operations can be accommodated as mobile operations without frequent operational or safety problems being created upstream of the work vehicle. However, the vehicle should be a larger, more imposing vehicle, such as a bucket truck, and the required truck lighting should be provided. Additional lights and supplemental devices likely would not reduce safety, but may not provide substantial benefits either, since no operational issues were observed with the use of typical warning lights. There are some conditions under which mobile operations may not be suitable. This would include locations where adequate sight distance is not available, where operating speeds are typically in excess of the posted speed limit of 45 mph or less, or where traffic volumes create a continuous queue in the closed and open lane(s). As delays increase, driver patience decreases, resulting in greater risk being taken by drivers. This might include accepting shorter gaps, driver rage, etc. If this type of congestion and associated driver behavior occurs, it is desirable to have the conflict point located farther upstream of the work vehicle, which can be accomplished by using a longer merging taper. If the merging taper is used, advance warning signs should be provided.

SUMMARY AND CONCLUSIONS

This report documents studies conducted to determine the safety and operational effectiveness of merging taper lengths shorter than those shown in the MUTCD. The data for this study were collected under the following conditions:

- the speed limit was 45 mph or less;
- the duration of the work operation was approximately 15 minutes or less;
- the work vehicle had high-intensity, rotating, flashing, oscillating, or strobe lights operating;
- there were no advance warning signs and arrow panel;
- there were no sight obstructions;
- daytime lighting conditions existed with dry pavement; and
- the volume and complexity of the roadway were considered.

The conclusions developed based on these data should not be applied to situations that are not described by all of the above conditions.

Measured relative to the start of the tapers, shorter taper lengths resulted in more drivers being out of the closed lane at given distances upstream of the taper. However, measured relative to the location of the work vehicle, one finds that more drivers have exited the closed lane farther upstream of the work vehicle when longer tapers are used. These differences reflect the fact that both the merging taper and the work vehicle in the closed lane can serve as visual cues to drivers that they need to vacate the closed lane.

Data indicate that more vehicles become trapped at the beginning of the merging taper when longer (FDOT standard) merging tapers were used. However, if an occluded vehicle was unable to stop and hit the beginning of the merging taper, the longer taper provides sufficient stopping distance such that the vehicle could stop prior to reaching the work activity area where the worker or work vehicle are located. Although fewer vehicles became trapped when merging taper lengths were 100 ft in length, the percentage that became trapped at the shorter taper was certainly not negligible and adequate stopping distance was not provided.

Based on these findings, researchers recommend that work operations that last more than 15 minutes utilize a merging taper length that meets MUTCD requirements. Due to concerns over the number of trapped vehicles, researchers also recommend that advance warning signs be used. However, this project did not include an evaluation use of advance warning signs; therefore, further research may be desired to determine the minimum number of signs needed.

Additional data suggests that work operations that last approximately 15 minutes or less can be accommodated as mobile operations without frequent operational or safety problems being created upstream of the work vehicle if certain conditions are met. Thus, the researchers concluded that mobile operations may be used when:

- the speed limit is 45 mph or less;
- the duration of the work operation is approximately 15 minutes or less;

- the work vehicle is large and has high-intensity, rotating, flashing, oscillating, or strobe lights operating;
- there are no sight obstructions;
- daytime lighting conditions exist with dry pavement; and
- the volume and complexity of the roadway have been considered.

There are some conditions under which mobile operations may not be suitable:

- locations where adequate sight distance is not available,
- locations where operating speeds are typically in excess of the posted speed limit of 45 mph or less, or
- locations where traffic volumes create a continuous queue in the closed and open lane(s).

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APPENDIX

Table A-1. Site Characteristics for 45 mph/1-Lane Open Sites.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Lane Width (ft)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
45-1-A	SR 551	NB	1700 Goldenrod	Orlando	12	4200	1400	1	2	S	Y
45-1-B	SR 551	SB	1900 Goldenrod	Orlando	12	5200	--	1[3]	2	S	Y
45-1-C	SR 552	EB	5900 Curry Ford	Orlando	12	1500	--	1	2	M	Y
45-1-D	SR 552	EB	6400 Curry Ford	Orlando	12	900	--	0	0	U	Y[4]
45-1-E	SR 869	WB	2400 SW 10th	Deerfield Beach	12	2300	850	1	0	U	N
45-1-F	SR 869	EB	2900 SW 10th	Deerfield Beach	12	2700	1000	1	1	M	N

Dir=Direction; M=Multi-Family Residential, S=Single Family Residential, U=Undeveloped; distances measured from beginning of merging taper

[1]Sight distance is not listed if it was greater than the distance to the upstream signal

[2]Shows the number of driveways, side streets or turn bays within the study area

[3]Study area included a designated U-turn area with no left turn bay

[4]Although the site was located on the bus route, bus stops did not occur within the study area

Table A-2. Site Characteristics for 40 mph/1-Lane Open Sites.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Lane Width (ft)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
40-1-A	SR 15	NB	2900 Conway	Orlando	10.5	1000	--	1	1	M	Y
40-1-B	SR 15	SB	2800 Conway	Orlando	10.5	1100	--	2	1	U	Y
40-1-C	SR 811	NB	5800 Dixie Hwy	Oakland Park	12	1400	1100	2	0	U	Y
40-1-D	SR 811	SB	5800 Dixie Hwy	Oakland Park	12	1500	--	0	3	M	Y
40-1-E	SR 811	NB	2700 Dixie Hwy	Pompano Beach	12	1800	--	1	0	U	Y

Dir=Direction; M=Multi-Family Residential, U=Undeveloped; distances measured from beginning of merging taper
[1]Sight distance is not listed if it was greater than the distance to the upstream signal
[2]Shows the number of driveways, side streets or turn bays within the study area

Table A-3. Site Characteristics for 45 mph/2-Lanes Open Sites.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Lane Width (ft)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
45-2-A	SR 530	WB	7800 Irlo Bronson	Kissimmee	12	1600	--	1	3	R	Y[3]
45-2-B	SR 530	EB	7800 Irlo Bronson	Kissimmee	12	1900	900	0	1	R	Y[3]
45-2-C	SR 530	WB	4500 Irlo Bronson	Kissimmee	12	4400	--	1	3	R	Y[4]
45-2-D	SR 530	EB	4500 Irlo Bronson	Kissimmee	12	4000	2000	1	4	R	Y[4]
45-2-E	SR 530	WB	4200 Vine	Kissimmee	12	2600	--	1[5]	2	R	Y[4]
45-2-F	SR 530	EB	4200 Vine	Kissimmee	12	1700	--	1	0	U	Y[4]

Dir=Direction; C=Commercial, M=Multi-Family Residential, R=Retail, S=Single Family Residential, U=Undeveloped; distances measured from beginning of merging taper

[1]Sight distance exceeded distance to upstream signalized intersection

[2]Shows the number of driveways, side streets or turn bays within the study area

[3]Although the site was located on the bus route, bus stops did not occur within the study area

[4]Bus stops designed so that stopped buses did not block travel lane, but instead used auxiliary lanes

[5]Study area included a designated U-turn area with no left turn bay

Table A-4. Site Characteristics for 40 mph/2-Lanes Open Sites.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Lane Width (ft)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
40-2-A		EB	3700 Sheridan	Hollywood	10.5	1600	--	0	7	C	Y
40-2-B		WB	3700 Sheridan	Hollywood	10.5	1000	--	1	3	M	Y

Dir=Direction; C=Commercial, M=Multi-Family Residential; distances measured from beginning of merging taper

[1]Sight distance exceeded distance to upstream signalized intersection

[2]Shows the number of driveways, side streets or turn bays within the study area

Table A-5. Estimated Traffic Volumes for 45 mph/1-Lane Open Sites.

Site Number	Estimated Hourly Traffic Volume (vph) by Taper Treatment			
	100 ft	160 ft	Standard	Average
45-1-A	1100	992	1233	1108
45-1-B	983	898	892	924
45-1-C	666	1043	845	851
45-1-D	795	1041	1345	1060
45-1-E	876	900	805	860
45-1-F	1036	1088	1210	1111
Average	909	994	1055	986

vph=vehicles per hour across all lanes

Table A-6. Estimated Traffic Volumes for 40 mph/1-Lane Open Sites.

Site Number	Estimated Hourly Traffic Volume (vph) by Taper Treatment			
	100 ft	160 ft	Standard	Average
40-1-A	872	745	1000	872
40-1-B	754	695	771	740
40-1-C	550	596	576	574
40-1-D	766	637	620	674
40-1-E	529	535	546	537
Average	694	642	703	680

vph=vehicles per hour across all lanes

Table A-7. Estimated Traffic Volumes for 45 mph/2-Lanes Open Sites.

Site Number	Estimated Hourly Traffic Volume (vph) by Taper Treatment			
	100 ft	160 ft	Standard	Average
45-2-A	870	684	681	745
45-2-B	1396	1088	1298	1261
45-2-C	1124	1281	1557	1321
45-2-D	1482	1486	1424	1464
45-2-E	1132	1221	1301	1218
45-2-F	1005	1069	807	960
Average	1168	1138	1178	1162

vph=vehicles per hour across all lanes

Table A-8. Estimated Traffic Volumes for 40 mph/2-Lanes Open Sites.

Site Number	Estimated Hourly Traffic Volume (vph) by Taper Treatment			
	100 ft	160 ft	Standard	Average
40-2-A	1390	1498	1577	1488
40-2-B	1471	1416	1347	1411
Average	1431	1457	1452	1450

vph=vehicles per hour across all lanes

Table A-9. Traffic Volumes and Site Characteristics for 45 mph/1-Lane Open Quick Operations.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Estimated Traffic Volume (vph)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
45-Q-A	SR 45	SB	11200 Nebraska	Tampa	564	1500	-	1	2	I	Y
45-Q-B	SR 45	SB	10500 Nebraska	Tampa	453	780	-	3	5	C	Y
45-Q-C	SR 45	SB	10100 Nebraska	Tampa	606	880	-	2	3	S	Y
45-Q-D	SR 45	SB	9700 Nebraska	Tampa	678	1050	-	3	4	R	Y[3]
45-Q-E	SR 600	SB	5300 Dale Mabry	Tampa	816	1250	-	2	6	C	Y
45-Q-F	SR 573	NB	5300 Dale Mabry	Tampa	618	1100	-	2	2	C	Y
45-Q-G	SR 600	SB	4200 Dale Mabry	Tampa	945	825	-	2	3	C	Y[3]
45-Q-H	SR 600	EB	1400 Baker	Plant City	217	4200	650	2	5	R	N
45-Q-I	SR 600	WB	1400 Baker	Plant City	384	730	-	2	7	R	N
45-Q-J	SR 39	SB	1400 Collins	Plant City	671	2800	570	2	3	R	N
45-Q-K	SR 39	NB	1500 James Redman	Plant City	731	950	-	3	2	S	N

Dir=Direction; I=Industrial, C=Commercial, S=Single Family Residential, R=Retail; distances measured from beginning of merging taper

[1]Sight distance is not listed if it was greater than the distance to the upstream signal

[2]Shows the number of driveways, side streets or turn bays within the study area

[3]Although the site was located on the bus route, bus stops did not occur within the study area

Table A-10. Traffic Volumes and Site Characteristics for 40 mph/1-Lane Open Quick Operations.

Site Number	Florida Roadway	Dir	Block Number & Street Name	City	Estimated Traffic Volume (vph)	Distance to Upstream Signalized Intersection (ft)	Sight Distance (ft)[1]	Number of Turning Movements[2]		Study Area Land Use	Bus Route
								Left Turns	Right Turns		
40-Q-A	SR 685	NB	10000 Florida	Tampa	645	1050	-	1	1	C	Y
40-Q-B	SR 685	NB	10400 Florida	Tampa	870	820	-	1	3	C	Y
40-Q-C	SR 685	NB	10900 Florida	Tampa	585	2200	-	2	4	C	Y
40-Q-D	SR 583	NB	9300 56th	Temple Terrace	690	900	-	1	2	R	Y
40-Q-E	SR 583	NB	10300 56th	Temple Terrace	960	840	540	0	3	S	Y[3]
40-Q-F	SR 45	SB	8500 Nebraska	Tampa	589	600	-	4	3	R	Y
40-Q-G	SR 45	SB	6700 Nebraska	Tampa	535	630	-	4	5	R	Y
40-Q-H	SR 685	NB	7800 Florida	Tampa	660	1000	-	3	1	P	Y
40-Q-I	SR 600	NB	3300 Dale Mabry	Tampa	944	850	-	5	3	C	Y
40-Q-J	SR 600	NB	3200 Dale Mabry	Tampa	960	1800	-	6	4	R	Y
40-Q-K	SR 600	NB	2700 Dale Mabry	Tampa	1365	740	530	4	3	C	Y
40-Q-L	SR 685	EB	3600 Henderson	Tampa	624	1100	575	4	4	R	Y[3]
40-Q-M	SR 39A	NB	1400 Alexander	Plant City	921	750	-	1	3	C	N

C=Commercial, R=Retail, S=Single Family Residential, P=Public Park; distances measured from beginning of merging taper

[1]Sight distance is not listed if it was greater than the distance to the upstream signal

[2]Shows the number of driveways, side streets or turn bays within the study area

[3]Although the site was located on the bus route, bus stops did not occur within the study area

Table A-11. Lane Distribution for 45 mph/1-Lane Open Sites.

Site Number	Taper Length (ft)	Location											
		750 ft			500 ft			250 ft			0 ft		
		Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
		n	%	n	n	%	n	n	%	n	n	%	n
45-1-A	100	104	31	331	71	73	97	53	16	337	31	9	333
	160	117	32	364	55	15	364	36	10	364	13	4	355
	540	235	42	562	191	34	561	150	27	560	95	17	565
45-1-B	100	132	40	333	111	34	331	67	20	333	12	4	331
	160	130	37	356	107	30	355	72	20	367	41	12	351
	540	153	40	382	110	29	378	80	21	388	49	13	386
45-1-C	100	157	39	405	119	33	357	52	13	392	10	3	378
	160	192	42	452	151	34	442	133	30	448	72	18	406
	540	89	34	263	91	34	266	91	34	271	52	20	254
45-1-D	100	172	44	395	141	36	395	94	24	395	44	11	395
	160	278	43	642	253	39	642	215	33	642	171	27	642
	540	326	44	740	323	44	742	288	39	745	249	34	743
45-1-E	100	271	53	516	171	33	514	116	23	505	65	13	505
	160	340	52	660	253	38	660	200	30	660	148	23	640
	540	231	53	436	171	39	436	140	33	424	105	25	426
45-1-F	100	334	57	583	245	42	583	241	41	583	196	34	583
	160	347	56	623	307	49	621	236	38	622	140	23	602
	540	334	56	600	303	51	600	284	46	620	173	30	583
Totals	100	1170	46	2563	858	38	2277	623	24	2545	358	14	2525
	160	1404	45	3097	1126	37	3084	892	29	3103	585	20	2996
	540	1368	46	2983	1189	40	2983	1033	34	3008	723	24	2957

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of all traffic in right lane.

Table A-12. Lane Distribution for 40 mph/1-Lane Open Sites.

Site Number	Taper Length (ft)	Location											
		750 ft			500 ft			250 ft			0 ft		
		Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
		n	%	n	N	%	n	n	%	n	n	%	n
40-1-A	100	114	42	269	84	30	282	62	22	282	46	16	282
	160	67	29	232	59	25	232	26	11	231	8	4	228
	540	119	39	302	85	28	299	65	21	308	38	13	301
40-1-B	100	68	20	333	38	11	335	29	9	327	24	7	321
	160	98	27	365	33	9	365	22	6	351	11	3	350
	540	104	28	371	36	10	371	34	9	373	9	2	367
40-1-C	100	94	30	309	82	27	309	61	20	302	11	4	302
	160	80	30	271	54	20	265	38	14	265	17	6	265
	540	94	33	283	70	25	279	35	12	283	49	17	283
40-1-D	100	139	44	318	116	36	319	80	25	318	39	13	311
	160	108	45	239	94	39	239	48	20	239	0	0	239
	540	118	40	292	114	39	291	93	32	290	39	13	291
40-1-E	100	125	36	350	99	29	347	80	23	353	44	13	346
	160	96	37	263	76	30	256	57	22	256	28	11	247
	540	149	37	398	112	28	394	85	22	393	24	6	391
Totals	100	540	34	1579	419	26	1592	312	20	1582	164	10	1562
	160	449	33	1370	316	23	1357	191	14	1342	64	5	1329
	540	584	35	1646	417	26	1634	312	19	1647	159	10	1633

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of all traffic in right lane.

Table A-13. Lane Distribution for 45 mph/2-Lanes Open Sites.

Site Number	Taper Length (ft)	Location											
		750 ft			500 ft			250 ft			0 ft		
		Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
		n	%	n	n	%	n	n	%	n	n	%	n
45-2-A	100	81	17	482	55	12	462	23	5	461	4	1	456
	160	62	16	385	42	12	361	14	4	356	4	1	355
	540	57	20	281	41	15	273	26	9	279	14	5	276
45-2-B	100	134	22	621	81	13	621	68	11	619	31	5	618
	160	163	25	644	100	16	644	67	10	644	23	4	630
	540	202	28	725	155	21	725	119	16	725	79	11	725
45-2-C	100	216	28	768	172	22	768	108	15	743	63	8	743
	160	157	29	538	133	25	538	84	17	509	48	9	509
	540	203	29	701	172	25	701	133	20	665	87	13	665
45-2-D	100	173	27	630	136	22	630	99	16	623	55	9	623
	160	182	26	706	131	19	706	79	11	703	58	8	703
	540	176	32	546	144	26	546	134	25	535	88	17	519
45-2-E	100	126	24	533	92	17	533	53	10	533	12	2	533
	160	136	244	574	117	20	574	80	14	574	51	9	570
	540	123	25	488	87	18	488	66	14	488	19	4	486
45-2-F	100	54	15	356	32	9	358	16	4	356	5	1	352
	160	81	19	418	48	11	419	37	9	421	17	4	418
	540	63	14	437	58	13	442	43	10	434	24	6	430
Totals	100	784	23	3390	568	17	3372	367	11	3335	170	5	3325
	160	781	24	3265	571	18	3242	361	11	3207	201	6	3185
	540	824	26	3178	657	21	3175	521	17	3126	311	10	3101

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of all traffic in right lane.

Table A-14. Lane Distribution Data for 40 mph/2-Lanes Open Sites.

Site Number	Taper Length (ft)	Location											
		750 ft			500 ft			250 ft			0 ft		
		Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
		n	%	n	n	%	n	n	%	n	n	%	n
40-2-A	100	190	24	787	167	21	790	136	17	788	42	5	765
	160	177	28	641	153	23	652	114	17	652	54	8	638
	540	246	26	962	235	24	986	184	19	968	127	13	968
40-2-B	100	169	22	755	156	21	755	99	13	740	49	7	740
	160	162	25	656	161	25	656	108	17	650	60	9	650
	540	131	22	606	124	21	596	112	18	606	72	12	603
Totals	100	359	23	1542	323	21	1545	235	15	1528	91	6	1505
	160	339	26	1297	314	24	1308	222	17	1302	114	9	1288
	540	377	24	1568	359	23	1582	296	19	1574	199	13	1571

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of all traffic in right lane.

Table A-15. Closed Lane Data for 45 mph/1-Lane Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Location							Occluded Vehicles at 750 ft		Trapped Vehicles at Taper		Occluded & Trapped	
		750 ft	500 ft		250 ft		0 ft							
		n	n	%	n	%	n	%	n	%	n	%	n	%
45-1-A	100	104	79	76	41	39	29	28	49	47	24	23	16	15
	160	92	59	69	30	33	19	21	28	30	4	4	3	3
	540	215	186	87	141	66	106	49	117	54	73	34	48	22
45-1-B	100	127	104	82	56	44	13	10	57	45	8	6	6	5
	160	131	103	79	69	53	41	31	58	44	22	17	15	11
	540	150	120	80	81	54	52	35	70	47	26	17	19	13
45-1-C	100	114	80	70	32	28	5	4	48	42	3	3	2	2
	160	164	150	92	124	76	80	49	78	48	50	30	34	21
	540	154	126	82	105	68	72	47	75	49	33	21	27	18
45-1-D	100	169	126	75	75	44	30	18	99	59	21	12	17	10
	160	276	240	87	217	79	155	56	199	72	138	50	120	44
	540	326	307	94	297	91	264	81	238	73	214	66	178	55
45-1-E	100	244	179	73	101	41	43	18	84	34	42	17	33	14
	160	298	230	77	179	60	104	35	94	32	92	31	79	27
	540	207	176	85	141	68	94	45	126	61	39	19	31	15
45-1-F	100	309	222	72	138	45	61	20	207	67	44	14	43	19
	160	348	294	85	213	61	110	32	99	28	70	20	68	20
	540	305	276	91	233	76	167	55	220	72	90	30	79	26
Totals	100	1067	790	74	443	42	181	17	544	51	142	13	117	11
	160	1309	1076	82	832	64	509	39	556	42	376	29	319	24
	540	1357	1191	88	998	74	755	56	846	62	475	35	382	28

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

Table A-16. Closed Lane Data for 40 mph/1-Lane Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Location							Occluded Vehicles at 750 ft		Trapped Vehicles at Taper		Occluded & Trapped	
		750 ft	500 ft		250 ft		0 ft							
		n	n	%	n	%	n	%	n	%	n	%	n	%
40-1-A	100	97	73	75	55	57	28	29	33	34	0	0	0	0
	160	69	44	64	21	30	5	7	27	39	2	3	2	3
	280	115	87	76	53	46	15	13	52	45	13	11	10	9
40-1-B	100	67	43	64	26	39	15	22	28	42	14	21	6	9
	160	81	37	46	20	25	6	7	22	27	5	6	4	5
	280	89	42	47	22	24	8	9	32	36	6	7	6	7
40-1-C	100	97	86	89	57	59	13	13	29	30	0	0	0	0
	160	73	53	73	38	52	17	23	22	30	5	7	5	7
	320	74	68	92	44	57	17	0	24	32	3	4	1	1
40-1-D	100	129	102	79	82	64	34	26	68	53	0	0	0	0
	160	97	87	90	48	50	12	12	36	37	6	6	3	3
	320	115	106	92	90	78	44	38	53	46	18	16	11	10
40-1-E	100	140	108	77	74	53	20	14	78	56	2	1	0	0
	160	100	80	80	50	50	18	18	28	28	0	0	0	0
	320	143	117	82	76	53	24	17	31	22	0	0	0	0
Totals	100	530	412	78	294	56	110	21	236	45	16	3	6	1
	160	420	301	72	177	42	58	14	135	32	18	4	14	3
	280/320	536	420	78	285	53	108	20	192	36	40	7	28	5

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

Table A-17. Closed Lane Data for 45 mph/2-Lanes Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Location							Occluded Vehicles at 750 ft		Trapped Vehicles at Taper		Occluded & Trapped	
		750 ft	500 ft		250 ft		0 ft							
		n	n	%	n	%	n	%	n	%	n	%	n	%
45-2-A	100	83	46	55	23	28	5	6	19	23	0	0	0	0
	160	59	35	59	15	25	2	3	19	32	0	0	0	0
	540	66	43	65	32	49	12	18	26	39	0	0	0	0
45-2-B	100	108	99	92	70	65	1	1	45	42	0	0	0	0
	160	95	81	85	52	55	1	1	28	29	0	0	0	0
	540	158	141	89	98	62	0	0	78	49	0	0	0	0
45-2-C	100	192	145	76	108	56	32	17	87	45	20	10	16	8
	160	128	107	84	80	63	23	18	60	47	11	9	9	7
	540	162	149	92	131	81	63	39	71	44	31	19	18	11
45-2-D	100	170	138	81	82	48	33	19	98	58	20	12	19	11
	160	137	100	73	64	47	21	15	69	50	0	0	0	0
	540	166	142	86	117	71	70	42	91	55	31	19	24	14
45-2-E	100	101	74	73	48	48	14	14	49	49	8	8	5	5
	160	119	112	94	76	64	0	0	63	53	0	0	0	0
	540	96	92	96	48	50	11	12	47	49	5	5	4	4
45-2-F	100	45	38	84	19	42	0	0	17	38	0	0	0	0
	160	70	62	89	38	54	0	0	26	37	0	0	0	0
	540	74	51	69	42	57	23	31	28	38	8	11	4	5
Totals	100	699	540	77	350	50	85	12	315	45	48	7	40	6
	160	608	497	82	325	54	47	8	265	44	21	3	16	3
	540	722	618	86	468	65	179	25	341	47	75	10	50	7

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

Table A-18. Closed Lane Data for 40 mph/2-Lanes Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Location							Occluded Vehicles at 750 ft		Trapped Vehicles at Taper		Occluded & Trapped	
		750 ft	500 ft		250 ft		0 ft							
		n	n	%	n	%	n	%	n	%	n	%	n	%
40-2-A	100	147	133	90	98	67	43	29	68	45	22	15	15	10
	160	167	122	73	102	61	50	30	72	43	31	19	23	14
	320	210	173	82	151	72	104	50	110	52	60	29	38	18
40-2-B	100	161	142	88	108	67	47	29	69	43	25	16	19	12
	160	148	131	89	90	61	63	43	63	43	31	21	13	9
	320	129	121	94	109	84	70	54	55	43	35	27	21	16
Totals	100	308	275	89	206	67	90	29	137	44	47	15	34	11
	160	315	253	80	192	61	113	36	135	43	62	20	36	11
	320	339	294	87	260	77	174	51	165	49	95	28	59	17

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

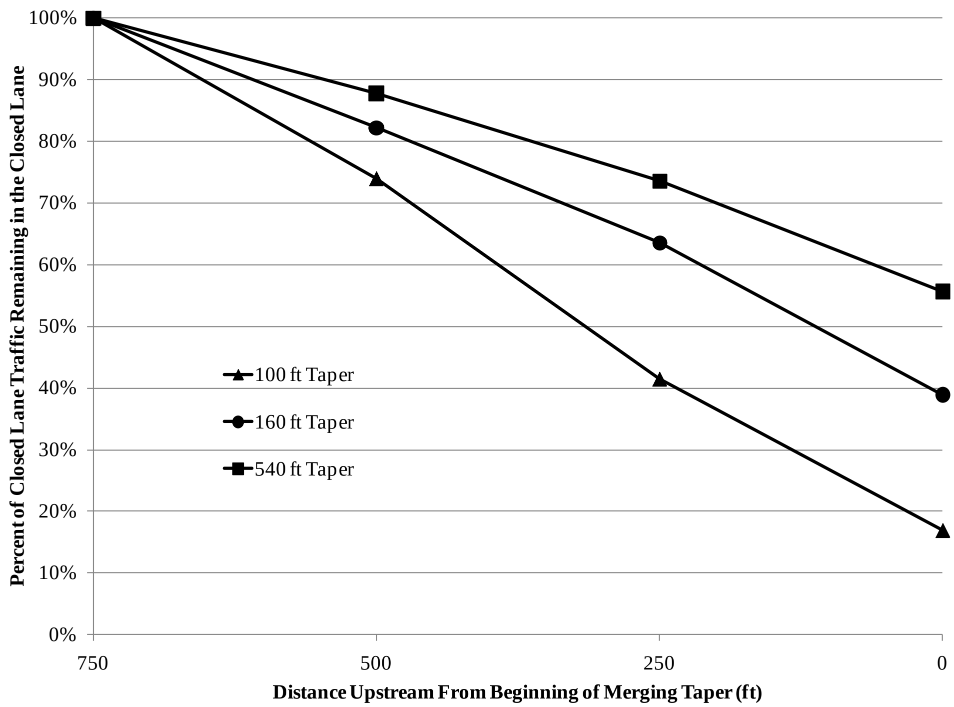

Figure A-1. Percent of Traffic Remaining in the Closed Lane for 45 mph/1-Lane Open Sites.

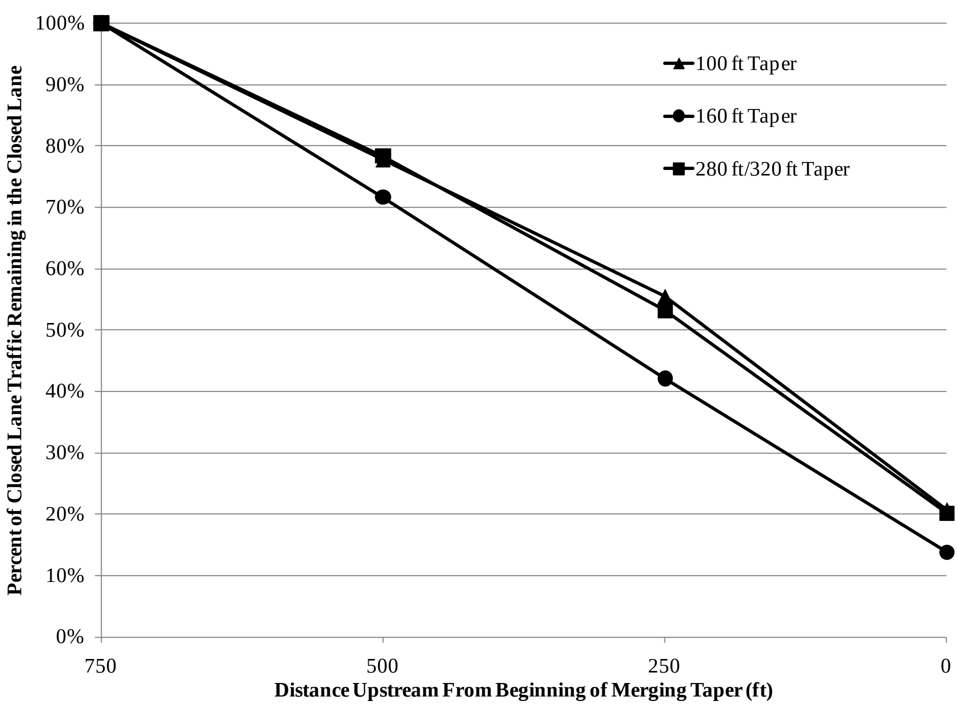

Figure A-2. Percent of Traffic Remaining in the Closed Lane for 40 mph/1-Lane Open Sites.

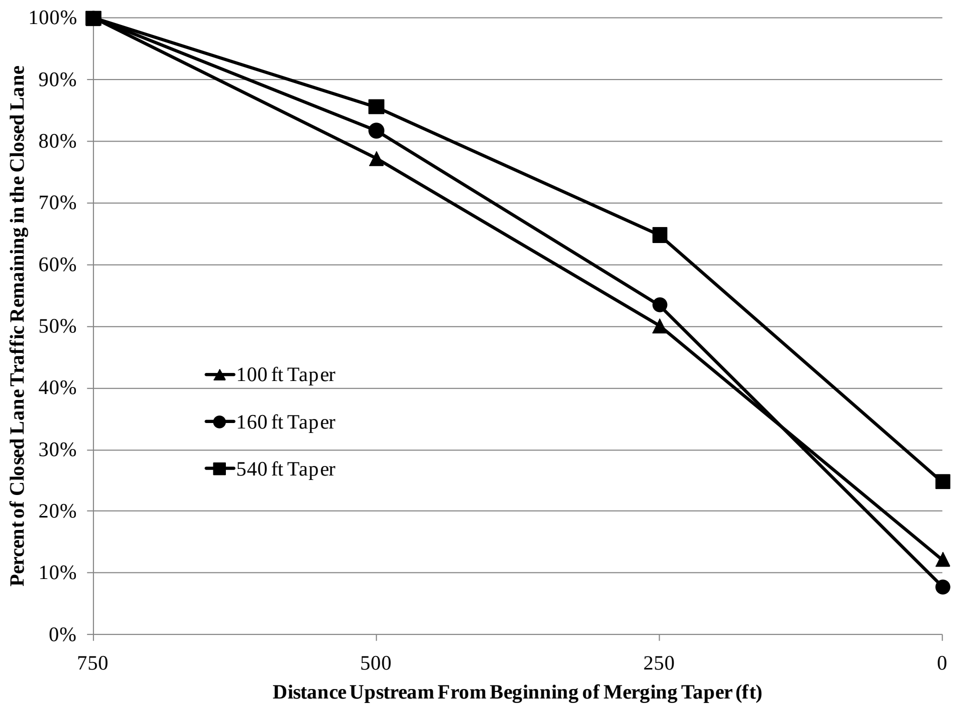

Figure A-3. Percent of Traffic Remaining in the Closed Lane for 45 mph/2-Lanes Open Sites.

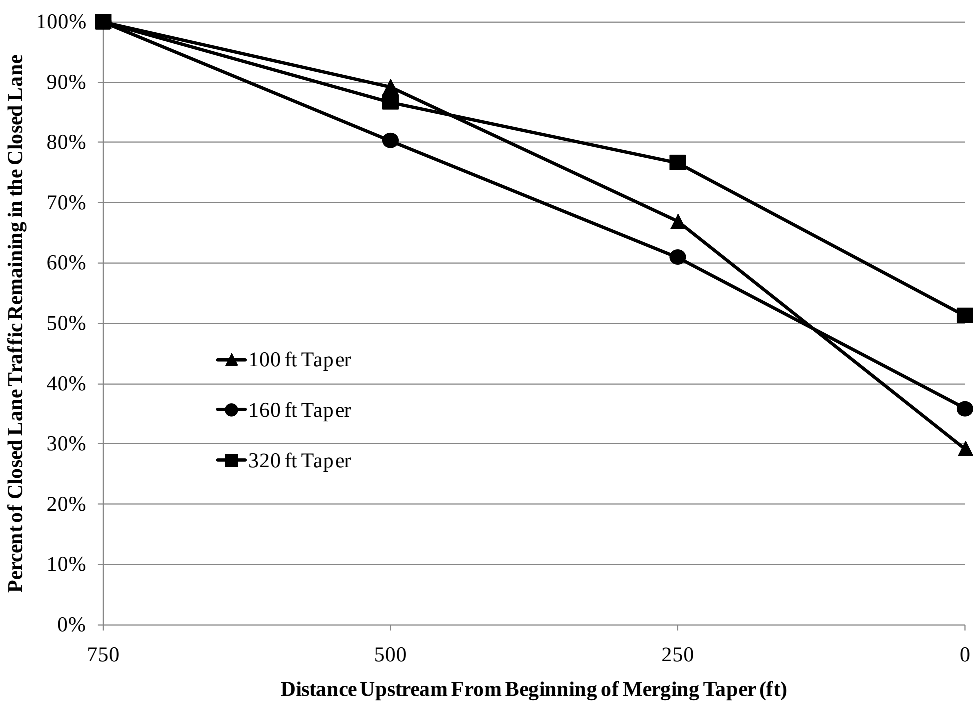

Figure A-4. Percent of Traffic Remaining in the Closed Lane for 40 mph/2-Lanes Open Sites.

Table A-19. Deceleration Data for 45 mph/1-Lane Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Average Deceleration (ft/sec^2)			Maximum Deceleration (ft/sec^2)			Average Speed (mph)			
		750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft	500 ft	250 ft	0 ft
45-1-A	100 ft	-0.59 n=16	-1.49 n=13	-1.98 n=4	-1.47	-5.38	-3.98	41.0 n=21	38.8 n=25	32.2 n=20	18.8 n=4
	160 ft	-0.66 n=30	-0.69 n=19	-1.97 n=3	-5.67	-1.83	-3.81	41.8 n=37	39.4 n=37	35.6 n=19	29.9 n=3
	540 ft	-0.67 n=18	-2.08 n=22	-1.90 n=15	-2.93	-5.13	-4.99	42.1 n=22	40.7 n=33	34.2 n=38	27.9 n=15
45-1-B	100 ft	-0.05 n=16	-0.53 n=22	-2.10 n=9	-1.47	-2.93	-5.90	38.9 n=18	40.5 n=34	39.1 n=36	37.6 n=11
	160 ft	-0.14 n=25	-1.21 n=14	-1.26 n=6	-1.47	-3.81	-3.18	39.6 n=32	39.9 n=37	34.8 n=19	29.4 n=8
	540 ft	+0.29 n=19	-0.34 n=23	-1.33 n=22	-0.59	-1.96	-5.38	40.8 n=22	40.8 n=41	40.6 n=35	36.1 n=22
45-1-C	100 ft	+0.06 n=19	-0.52 n=15	-0.49 n=3	-2.64	-2.93	-1.76	36.8 n=30	35.2 n=30	31.9 n=27	28.7 n=3
	160 ft	+0.51 n=13	-0.80 n=24	-0.61 n=17	-0.73	-3.67	-3.16	37.6 n=17	37.4 n=33	34.3 n=37	29.4 n=22
	540 ft	+0.69 n=10	+0.03 n=18	-0.64 n=21	-0.37	-1.83	-2.44	37.1 n=14	38.1 n=23	35.8 n=34	33.0 n=31
45-1-D	100 ft	-0.05 n=14	-6.04 n=15	-0.89 n=10	-7.33	-5.57	-3.18	35.1 n=15	35.5 n=37	30.4 n=33	23.7 n=12
	160 ft	+0.34 n=4	-0.56 n=19	-1.74 n=18	-0.98	-4.89	-4.16	33.8 n=5	35.0 n=29	33.0 n=44	24.0 n=20
	540 ft	+2.05 n=6	+0.04 n=15	-1.71 n=18	-0.37	-2.57	-5.13	31.7 n=6	37.0 n=25	35.8 n=34	27.9 n=27
45-1-E	100 ft	-0.24 n=16	-0.95 n=20	-1.88 n=9	-2.44	-3.30	-5.13	47.5 n=19	46.1 n=40	43.5 n=26	39.6 n=10
	160 ft	-0.41 n=14	-0.92 n=22	-1.95 n=10	-1.83	-4.40	-3.91	44.4 n=15	44.9 n=36	41.3 n=34	33.6 n=10
	540 ft	-0.15 n=20	-0.54 n=23	-1.09 n=18	-2.44	-3.91	-6.23	46.5 n=23	45.6 n=36	45.4 n=32	43.4 n=18
45-1-F	100 ft	-0.49 n=27	-1.04 n=20	-1.47 n=2	-5.87	-3.42	-2.05	47.0 n=3	45.4 n=45	39.6 n=33	26.5 n=2
	160 ft	-0.68 n=20	-0.76 n=27	-2.70 n=16	-4.03	-3.91	-5.38	47.8 n=22	45.3 n=39	42.4 n=45	34.6 n=16
	540 ft	-0.75 n=14	-1.02 n=17	-1.60 n=12	-3.42	-4.40	-5.40	47.6 n=14	46.4 n=23	44.3 n=23	39.8 n=13
Totals	100 ft	-0.25 n=108	-0.84 n=105	-1.54 n=37	-7.33	-5.57	-5.87	41.5 n=136	40.8 n=211	36.3 n=175	31.1 n=42
	160 ft	-0.33 n=106	-0.81 n=125	-1.68 n=70	-5.67	-4.89	-5.38	41.7 n=128	40.8 n=211	37.2 n=198	29.6 n=79
	540 ft	-0.01 n=87	-0.69 n=118	-1.33 n=106	-3.42	-5.13	-6.23	42.5 n=100	41.6 n=181	38.9 n=196	34.0 n=123

Table A-20. Deceleration Data for 40 mph/1-Lane Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Average Deceleration (ft/sec^2)			Maximum Deceleration (ft/sec^2)			Average Speed (mph)			
		750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft	500 ft	250 ft	0 ft
40-1-A	100	-0.20 n=8	-0.99 n=12	n=0	-2.80	-3.23		34.1 n=17	36.1 n=25	33.3 n=24	27.0 n=3
	160	+0.75 n=3	-0.79 n=9	-1.27 n=2	+0.37	-2.57	-2.30	36.0 n=12	37.4 n=26	32.8 n=12	27.0 n=2
	280	-0.06 n=11	-0.14 n=17	-1.17 n=7	-1.83	-1.26	-3.18	37.1 n=14	35.1 n=41	32.6 n=26	29.6 n=7
40-1-B	100	-0.46 n=8	-1.12 n=8	-1.97 n=4	-2.64	-2.51	-2.64	35.8 n=13	36.2 n=17	29.8 n=17	16.0 n=4
	160	+0.37 n=14	-0.24 n=9	-1.59 n=2	-3.67	-2.93	-1.71	36.7 n=31	38.3 n=23	35.0 n=16	28.0 n=5
	280	+0.05 n=26	-0.80 n=13	-1.03 n=6	-2.57	-4.03	-1.93	37.0 n=39	37.4 n=33	37.1 n=17	27.6 n=7
40-1-C	100	-0.13 n=27	-0.26 n=34	-0.56 n=16	-2.01	-2.69	-2.30	39.9 n=32	39.0 n=42	36.9 n=41	31.5 n=17
	160	+0.15 n=22	-0.14 n=17	-1.73 n=12	-1.40	-1.89	-4.69	39.7 n=27	39.3 n=32	38.8 n=29	33.1 n=12
	320	+0.40 n=21	-0.02 n=22	-0.73 n=20	-1.47	-1.47	-4.99	41.1 n=28	41.2 n=35	39.7 n=34	35.8 n=21
40-1-D	100	+0.42 n=28	-0.64 n=38	-1.36 n=8	-1.17	-3.30	-3.48	39.8 n=35	39.0 n=51	38.0 n=46	31.0 n=9
	160	+1.27 n=21	-0.12 n=28	-0.96 n=15	-2.93	-3.23	-3.3	42.6 n=22	41.2 n=41	39.3 n=39	36.9 n=16
	320	+0.35 n=27	-0.29 n=30	-0.15 n=25	-0.98	-2.93	-3.91	41.7 n=28	42.4 n=37	40.4 n=41	38.8 n=30
40-1-E	100	+0.58 n=19	-0.49 n=24	-1.97 n=4	-0.73	-5.50	-3.10	40.8 n=23	41.9 n=43	37.0 n=38	22.8 n=5
	160	+0.02 n=25	-0.24 n=32	-1.76 n=14	-1.83	-3.52	-5.50	39.0 n=29	38.6 n=54	37.1 n=41	29.4 n=14
	320	+0.30 n=28	-0.06 n=26	-1.19 n=12	-2.20	-1.96	-3.77	40.4 n=38	40.4 n=44	39.0 n=40	32.2 n=13
Totals	100	+0.15 n=90	-0.57 n=116	-1.11 n=32	-2.80	-5.50	-3.48	38.8 n=120	39.0 n=178	36.0 n=166	28.1 n=40
	160	+0.17 n=84	-0.24 n=95	-1.46 n=45	-3.67	-3.52	-5.50	38.9 n=121	39.1 n=176	37.5 n=137	32.5 n=49
	280/ 320	+0.24 n=113	-0.22 n=108	-0.67 n=70	-2.57	-4.03	-4.99	39.6 n=147	39.3 n=190	38.3 n=158	35.0 n=78

Table A-21. Deceleration Data for 45 mph/2-Lanes Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Average Deceleration (ft/sec^2)			Maximum Deceleration (ft/sec^2)			Average Speed (mph)			
		750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft	500 ft	250 ft	0 ft
45-2-A	100	+0.23 n=12	-0.55 n=14	+1.25 n=2	-1.47	-4.40	+0.29	41.0 n=16	40.2 n=30	37.0 n=21	33.8 n=4
	160	+0.13 n=15	+0.15 n=9	+0.34 n=3	-0.59	-1.96	-0.73	40.5 n=26	41.2 n=26	40.2 n=15	38.3 n=3
	540	+0.34 n=14	-0.53 n=18	-0.10 n=9	-2.17	-3.30	-2.20	43.9 n=20	44.4 n=31	41.4 n=22	40.7 n=13
45-2-B	100	-0.04 n=19	-0.44 n=25	-1.23 n=8	-1.60	-4.11	-2.93	46.2 n=24	44.3 n=47	41.4 n=30	36.5 n=11
	160	-0.55 n=20	-0.76 n=20	+0.39 n=4	-2.20	-2.35	-0.49	43.9 n=22	42.7 n=39	39.5 n=36	38.1 n=7
	540	-0.66 n=10	-0.67 n=18	-0.64 n=14	-2.93	-2.44	-2.20	47.2 n=11	46.6 n=31	41.0 n=34	36.1 n=19
45-2-C	100	-0.24 n=7	-0.22 n=17	-2.31 n=4	-1.17	-2.93	-6.23	42.4 n=12	40.9 n=25	38.0 n=30	25.1 n=7
	160	-0.11 n=8	-0.70 n=23	-1.08 n=7	-1.47	-2.57	-3.98	39.8 n=12	40.3 n=31	37.4 n=35	29.7 n=7
	540	-0.20 n=6	-0.02 n=27	-1.00 n=18	-1.10	-2.20	-4.16	44.9 n=7	42.5 n=33	40.0 n=50	32.8 n=19
45-2-D	100	-0.52 n=9	-0.81 n=21	-1.73 n=4	-1.71	-4.77	-2.51	40.6 n=16	39.5 n=35	36.3 n=27	28.3 n=4
	160	-1.09 n=12	-0.75 n=20	-0.78 n=3	-5.50	-2.93	-0.88	41.8 n=22	39.5 n=33	35.4 n=27	37.0 n=4
	540	-0.44 n=18	-0.23 n=26	-0.81 n=8	-1.47	-1.47	-4.25	41.9 n=23	39.7 n=35	39.2 n=35	37.7 n=9
45-2-E	100	+0.03 n=22	-0.77 n=21	-0.41 n=6	-1.10	-5.50	-2.05	41.7 n=30	38.1 n=37	33.0 n=28	29.5 n=6
	160	+0.33 n=15	-0.77 n=17	-0.97 n=9	-0.73	-3.23	-4.77	41.9 n=24	41.6 n=31	38.6 n=26	30.9 n=10
	540	+0.47 n=20	-0.74 n=20	-0.61 n=14	-1.10	-4.40	-4.40	44.3 n=23	42.2 n=34	39.1 n=36	35.5 n=14
45-2-F	100	-0.47 n=22	-0.75 n=14	-0.29 n=1	-2.20	-3.67	-0.29	45.0 n=29	41.9 n=32	39.6 n=18	29.0 n=1
	160	-0.31 n=25	-0.45 n=20	-1.38 n=5	-5.38	-6.75	-2.51	44.4 n=31	43.0 n=35	41.5 n=26	37.2 n=6
	540	-0.39 n=18	-0.44 n=16	-0.98 n=7	-2.44	-3.42	-3.30	45.4 n=27	43.7 n=29	42.4 n=25	35.9 n=7
Totals	100	-0.06 n=89	-0.58 n=111	-0.98 n=33	-2.20	-4.77	-6.23	43.7 n=120	41.7 n=203	38.6 n=162	33.0 n=41
	160	-0.27 n=95	-0.62 n=109	-0.74 n=31	-5.50	-6.75	-4.77	42.3 n=137	41.4 n=195	38.6 n=165	34.3 n=37
	540	-0.10 n=86	-0.40 n=125	-0.71 n=70	-2.93	-4.40	-4.40	44.3 n=111	43.1 n=193	40.3 n=202	36.1 n=81

Table A-22. Deceleration Data for 40 mph/2-Lanes Open Sites with Merging Tapers.

Site Number	Taper Length (ft)	Average Deceleration (ft/sec^2)			Maximum Deceleration (ft/sec^2)			Average Speed (mph)			
		750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft to 500 ft	500 ft to 250 ft	250 ft to 0 ft	750 ft	500 ft	250 ft	0 ft
40-2-A	100	+0.39 n=20	-0.23 n=35	-1.64 n=7	-0.98	-5.83	-4.99	39.4 n=27	39.2 n=44	38.2 n=46	32.1 n=8
	160	+0.52 n=9	-0.04 n=25	-1.11 n=22	-0.49	-2.57	-6.60	34.4 n=10	37.0 n=34	37.4 n=50	35.8 n=26
	320	+0.40 n=16	-0.06 n=34	-0.49 n=31	-2.27	-2.57	-2.75	34.3 n=17	35.5 n=38	35.7 n=49	34.4 n=34
40-2-B	100	+0.56 n=20	-0.35 n=31	-0.98 n=1	-1.47	-2.93	-0.98	40.9 n=22	41.6 n=39	39.2 n=46	30.0 n=1
	160	+0.60 n=13	-0.33 n=32	-0.86 n=26	-0.73	-3.23	-5.57	38.3 n=13	39.3 n=37	37.5 n=56	34.2 n=33
	320	+0.99 n=18	-0.48 n=26	-1.05 n=29	-0.49	-4.03	-5.87	39.9 n=18	42.1 n=30	40.2 n=44	34.7 n=37
Totals	100	+0.48 n=40	-0.28 n=66	-1.55 n=8	-1.47	-5.83	-4.99	40.1 n=49	40.3 n=83	38.7 n=92	31.9 n=9
	160	+0.57 n=22	-0.22 n=57	-0.97 n=48	-0.73	-3.23	-6.60	36.6 n=23	38.2 n=71	37.5 n=106	35.0 n=59
	320	+0.71 n=34	-0.24 n=60	-0.77 n=60	-2.27	-4.03	-5.87	37.2 n=35	38.5 n=68	37.9 n=93	34.6 n=71

Table A-23. Lane Distribution for 45 mph/1-Lane Open Sites During Quick Operations.

Site Number	Location								
	540 ft			250 ft			100 ft		
	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
	N	%	n	n	%	n	n	%	n
45-Q-A	24	26	94	-	-	-	0	0	92
45-Q-B	17	20	83	6	8	77	0	0	77
45-Q-C	36	36	101	11	11	100	4	4	100
45-Q-D	54	37	147	25	16	153	5	3	151
45-Q-E	51	38	136	19	15	129	4	3	126
45-Q-F	37	28	134	13	10	136	4	3	136
45-Q-G	61	32	189	20	12	167	2	1	167
45-Q-H	17	36	47	3	6	47	0	0	47
45-Q-I	17	27	64	5	8	63	0	0	62
45-Q-J	80	65	123	21	18	119	7	6	120
45-Q-K	40	33	122	17	15	115	4	3	115
Totals	434	35	1240	140	13	1106	30	3	1193

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of all traffic in right lane.

Table A-24. Lane Distribution for 40 mph/1-Lane Open Sites During Quick Operations.

Site Number	Location								
	540 ft			250 ft			100 ft		
	Right Lane		All Lanes	Right Lane		All Lanes	Right Lane		All Lanes
	n	%	n	n	%	n	n	%	n
40-Q-A	32	60	53	-	-	-	1	2	53
40-Q-B	18	31	58	5	9	58	1	2	58
40-Q-C	22	28	78	8	10	77	1	1	77
40-Q-D	52	38	138	22	17	132	12	9	132
40-Q-E	37	23	160	10	6	158	5	3	157
40-Q-F	57	34	167	28	18	157	2	1	158
40-Q-G	37	35	107	20	19	103	11	11	101
40-Q-H	37	34	110	20	18	112	1	1	112
40-Q-I	63	36	173	22	13	168	4	2	169
40-Q-J	47	27	176	12	7	175	3	2	175
40-Q-K	35	38	91	20	24	85	5	6	88
40-Q-L	58	56	104	29	28	102	11	11	101
40-Q-M	51	24	215	21	9	236	7	3	235
Totals	546	33	1630	217	14	1563	64	4	1616

Table A-25. Closed Lane Data for 45 mph/1-Lane Open Sites During Quick Operations.

Site Number	Location					Occluded Vehicles at 540 ft		Trapped Vehicles	
	540 ft	250 ft		100 ft					
	n	n	%	n	%	n	%	n	%
45-Q-A	24	-	-	0	0	3	13	5	21
45-Q-B	17	6	35	0	0	4	24	5	30
45-Q-C	36	11	31	4	11	7	19	5	14
45-Q-D	50	25	50	6	11	10	20	2	4
45-Q-E	44	16	36	3	7	16	36	2	5
45-Q-F	31	10	32	1	3	4	13	0	0
45-Q-G	58	20	34	2	3	22	38	1	2
45-Q-H	17	3	18	0	0	0	0	0	0
45-Q-I	16	5	31	0	0	1	6	0	0
45-Q-J	78	19	24	5	6	21	27	0	0
45-Q-K	40	17	43	4	10	11	28	1	56
Totals	411	132	32	26	7	99	24	21	5

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

Table A-26. Closed Lane Data for 40 mph/1-Lane Open Sites During Quick Operations.

Site Number	Location					Occluded Vehicles at 540 ft		Trapped Vehicles	
	540 ft	250 ft		100 ft					
	n	n	%	n	%	n	%	n	%
40-Q-A	22	-	-	1	5	3	14	0	0
40-Q-B	17	4	24	0	0	3	18	0	0
40-Q-C	22	8	36	1	5	4	18	0	0
40-Q-D	44	15	34	5	11	11	25	2	4
40-Q-E	36	9	25	4	11	10	28	2	5
40-Q-F	55	28	51	2	4	18	33	3	5
40-Q-G	37	20	54	6	16	8	22	5	14
40-Q-H	32	15	47	1	3	6	19	1	3
40-Q-I	62	22	35	4	6	30	48	0	0
40-Q-J	47	12	26	3	6	15	32	1	2
40-Q-K	34	19	56	4	12	15	44	7	20
40-Q-L	58	24	41	7	12	24	41	2	3
40-Q-M	51	21	41	7	14	19	37	3	6
Totals	517	197	38	45	9	166	32	26	5

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.

Table A-27. Closed Lane Data for Quick Operations with "Bucket Down."

Site Number	Location					Occluded Vehicles at 540 ft		Trapped Vehicles	
	540 ft	250 ft		100 ft					
	n	n	%	n	%	n	%	n	%
45-Q-F	58	25	43	4	7	15	26	3	5
40-Q-C	27	13	48	3	11	7	26	0	0
40-Q-D	72	39	54	9	13	26	36	8	11
40-Q-E	72	42	58	14	19	32	44	11	15
40-Q-M	30	15	50	7	23	8	27	7	23
Totals	259	134	52	14	5	88	34	29	11

Location is measured in ft upstream of the beginning of the merging taper, n=number of vehicles, %=percent of right lane traffic remaining in the right lane.