

# Improving the Effectiveness of Zipper Merge Lane Control in Freeway Work Zones

tech transfer summary

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## RESEARCH PROJECT TITLE

Improving the Effectiveness of Zipper Merge Lane Control in Freeway Work Zones

## SPONSORS

Smart Work Zone Deployment Initiative  
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## SWZDI

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The Smart Work Zone Deployment Initiative (SWZDI) is a transportation pooled fund that supports research investigations into better ways to improve the safety and efficiency of traffic operations and highway work in work zones. The primary objective is to promote and support research and outreach activities that focus on innovative policies, processes, tools, and products that enhance the implementation, safety, and mobility impacts of work zones. The fund is administered by Iowa State University's Institute for Transportation, and the lead agency is the Iowa Department of Transportation.

The sponsors of this research are not responsible for the accuracy of the information presented herein. The conclusions expressed in this publication are not necessarily those of the sponsors.

This study involved a state agency survey, road user survey, and series of field evaluations that culminated in guidance as to the use of late, or zipper, merge lane control in freeway work zones.

## Objectives

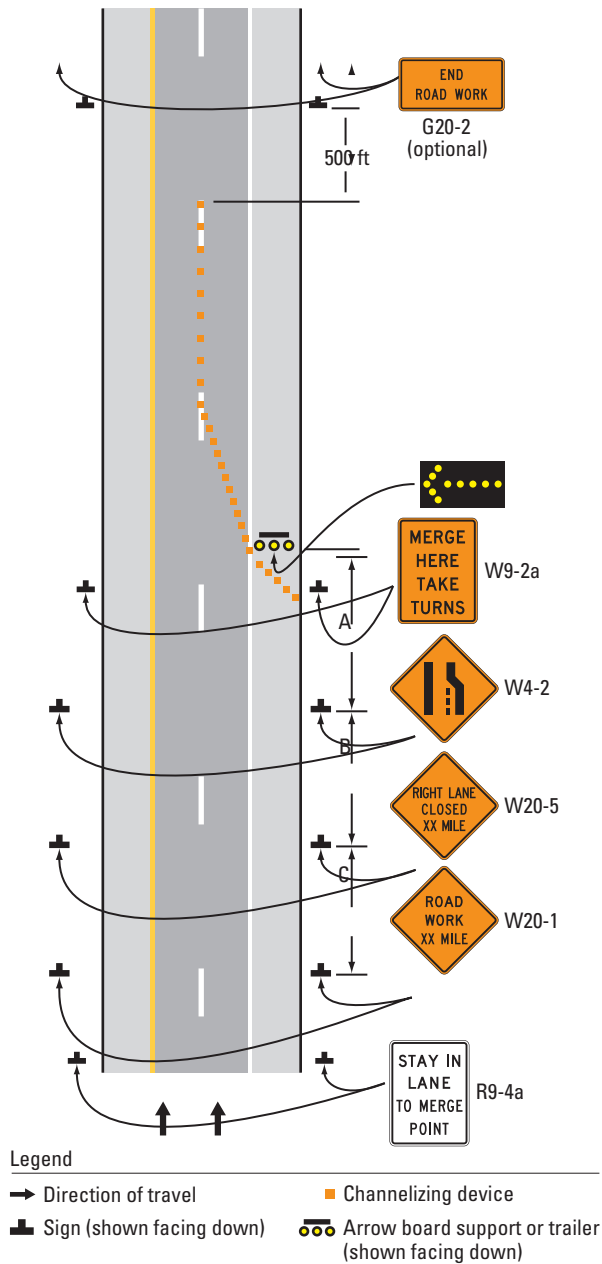
- Conduct a synthesis of different work zone lane merge control strategies in the United States through an extensive literature review and an analysis of different work zone lane merge control schemes across Smart Work Zone Deployment Initiative (SWZDI) states.
- Assess factors associated with work zone lane merge control and their impacts on efficiency and safety as measured by flow rate, speed, and driver compliance.
- Provide guidance on the type and location of work zone lane merge control based on these factors, including thresholds for when different lane merge controls are appropriate and strategies for how to best communicate pertinent information to drivers in order to yield the anticipated results.

## Background

Single-lane closures are quite common in freeway work zones and require drivers to determine when and where to merge from a lane that is about to close to an adjacent open lane. Under conventional temporary traffic control plans, vehicles start merging maneuvers based on available gaps, flow characteristics, the presence of heavy vehicles, and guidance from traffic control devices.

These merging maneuvers can result in significant variability in travel speeds between vehicles in the open and soon-to-close lanes and in driver decision-making as to when and where to merge. This variability potentially elevates the risks for some of the most common types of work zone crashes, such as rear-end and sideswipe crashes. In addition, lane closures can lead to reduced capacity, increased delays, extremely long queues in the open lane, confusion, and queue-jumping behavior.

To overcome these issues, a late merge strategy (known as the zipper merge) was developed by the Pennsylvania Department of Transportation (PennDOT). Under late merge lane control, a series of signs encourages drivers to stay in the closed lane up to the start of the taper, thereby utilizing the full capacity of the closed lane. Drivers then cooperatively merge at the start of the taper.



From *Manual on Uniform Traffic Control Devices*, 11th Edition

### Sample layout for a single-lane closure with late merge

## Problem Statement

Despite the widespread use of the zipper merge strategy, mixed results related to its safety and operational efficiency have been found. The zipper merge relies on both the cooperation and compliance of drivers, and there is significant potential to improve merging behavior.

The latest edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) offers general guidance on sign placement for work zone lane closures on limited-access freeways for conventional and zipper merge lane control. However, there is no guidance as to the placement of portable changeable message signs (PCMS) relative to the location of the work zone taper to improve the effectiveness of zipper merge lane control.



Roadside PCMS for lane merge management

## Research Description

State department of transportation (DOT) practices for work zone lane merge control were synthesized through a review of DOT resources (e.g., typical applications, specifications, guidance, and outreach materials) and an agency survey that was developed and administered by the researchers. Survey responses were received from 45 DOTs, including all 9 SWZDI states.

A road user survey of drivers across the nine SWZDI states was also conducted to better understand road users' perceptions, familiarity, and comfort with early and zipper merge lane control and their perceptions of the safety and operational performance of select scenarios. Additionally, the survey assessed the impacts of the optional installation of PCMS to supplement standard static sign configuration. Regression models were estimated to understand drivers' preferred merging locations under various sign configurations and the behaviors of other drivers.

A series of field evaluations were performed in 2023 and 2024 at four freeway work zone lane closures (one in Missouri and three in Michigan) to assess lane utilization behavior under zipper merge lane control and evaluate strategies aimed at improving compliance in advance of single-lane closures. The study focused on the utilization of the soon-to-be-closed lane (measured as the proportion of all vehicles that were in that specific lane).

## Key Findings

### Key Findings from State DOT Survey

- Dynamic lane merge is most often implemented on urban freeways and for two-to-one lane drops in work zones.
- The most frequently considered factors when determining whether to implement dynamic lane merge are annual average daily traffic (AADT), peak-hour volumes, and duration of work. Other factors mentioned in DOT guidance include queuing and encroachment on upstream intersections or interchanges.

- Agencies most often utilize speed thresholds to activate or deactivate dynamic lane merge systems in work zones. These speed thresholds vary among DOTs but typically range from 20 to 40 mph. Dynamic lane merge is sometimes implemented along with other smart work zone technologies in work zones, such as end-of-queue warning systems (14 DOTs) and traveler information systems (13 DOTs).
- Among the responding DOTs that use dynamic lane merge, the factors perceived to be the most challenging to the implementation of dynamic lane merge in work zones are driver inattention, lack of perceived need, and the need for enforcement.
- DOTs generally consider queue length, delay, and speed as performance measures for dynamic lane merge in work zones.
- To educate a greater number of drivers about the zipper merge, nearly 42% of participants suggested using TV advertisements and newspapers, 28% suggested using social media, and 14% suggested using public meetings and driver's license handbooks.
- For outreach purposes, older drivers preferred TV advertising and newspapers while younger drivers preferred social media.

## Key Findings from Field Evaluations

### Key Findings from Road User Survey

- Drivers typically prefer to merge early into the open lane regardless of the lane control strategy. However, providing information more conspicuously through PCMS increased compliance, as drivers were willing to merge closer to the taper when PCMS was used in addition to static signage.
- Drivers generally preferred signs that conveyed information both graphically and textually, followed by signs that used only text. Purely graphical signs generally showed lower preference among drivers, a result that is in contrast with some of the research literature.
- Generally speaking, drivers tend to slow down and allow other vehicles to merge. However, these trends varied depending on the merging strategy (early versus late/zipper) and the location of the merging maneuver with respect to the start of the taper.
- Respondents were more likely to continue driving at the same speed and use the soon-to-be-closed lane more effectively when the zipper merge was in place.
- Regardless of the lane merge control strategy, driver behavior was generally more aggressive closer to the taper compared to further upstream.
- An important and consistent finding was that both compliance with the zipper merge and the perceived benefits of the zipper merge increased as drivers' familiarity or comfortability with the zipper merge increased.
- Older people consistently showed lower compliance rates and poorer perceptions of the zipper merge. Because the success of zipper merge depends on drivers' understanding of and cooperation with zipper merge signage, drivers need to be educated about the expected behavior during zipper merge lane control.
- In general, introducing a PCMS increased lane utilization in the lane about to be closed. This effect was least pronounced at distances far upstream (2,500 ft or more) from the taper. The PCMS showed the most significant impacts at 1,200 to 2,000 ft, though results varied significantly across sites.
- The use of a PCMS is likely to provide marginal value at lower-volume sites. For example, the vast majority of traffic at the least congested field evaluation site had merged into the open lane more than 2,200 ft upstream of the taper. While the PCMS did show 1% to 2% increases here, congestion was generally not an issue in these volume ranges (average of approximately 940 vehicles/hour). This is consistent with the research literature, which suggests that zipper merge lane control works better at sites with moderate to high traffic volumes.
- The addition of a second PCMS near the start of the taper showed variable impacts at the two study locations where it was evaluated. At one of these sites, lane utilization was lowest in this scenario, while at the other site the combination of signs showed consistently higher lane utilization when the second sign was present.
- Optionally, a second PCMS closer to the taper may be appropriate at select locations, though further research is warranted to understand the scenarios under which this supplementary device is beneficial.
- Lane utilization improves with an increase in the density of open lanes.
- It is favorable for zipper merge compliance to have heavy vehicles in the open lane far upstream of the taper start.
- The effect of heavy vehicles on lane utilization gets more pronounced as the traffic density increases.
- For sites with higher AADT, such as those in Michigan, lane utilization tends to increase as traffic volume rises. Conversely, for sites with lower AADT, like that in Missouri, lane utilization decreases as traffic volume increases.
- The findings from the Missouri field study support the necessity of implementing zipper merge strategies in work zones, as drivers under early merge were prone to merge into the open lane earlier when traffic started to become congested.

## Conclusions and Recommendations

- When deployed in work zones, the primary purpose of a PCMS is to alert drivers of the need to stay in the lane they are driving in up to the start of the work zone taper. This will help to improve compliance with the zipper merge lane control strategy for freeway lane closures.
- The road user survey found that installing a PCMS upstream of the taper will likely increase utilization of the closed lane.
- Installing a PCMS 4,500 ft to 1 mile upstream of the taper generally provides sufficient advance notice under most scenarios. This PCMS is required to provide advance information to drivers about the lane merge control strategy and the necessary actions to take. The PCMS in this study was placed close to a static USE BOTH LANES DURING BACKUPS sign and displayed the same text but in two frames: USE BOTH LANES and DURING BACKUPS.
- If an additional PCMS is available, it should ideally be positioned within 500 to 1,000 ft upstream of the lane closure adjacent to a static sign displaying MERGE HERE TAKE TURNS. It is also recommended that this second PCMS display the same message in two frames: MERGE HERE and TAKE TURNS.
- Based on the results of the road user survey, it is recommended to use signs that convey information both graphically and textually over only graphical signs.
- Also based on the results of the road user survey, it is recommended to use a sign displaying a message along with a plaque that encourages drivers to stay in the closed lane as long as possible.
- It is recommended that TV advertising and newspapers be used to educate older people and that various social media platforms be used to educate younger drivers.



*Preferred sign (left) for encouraging drivers to use both lanes*

## Recommendations for Future Research

- In some cases, an additional PCMS closer to the taper may be beneficial, though further research is needed to determine under what conditions this supplementary device is effective.
- The latest edition of the MUTCD offers a range of alternative messages that can be displayed on PCMS in addition to the messages displayed in this study. Future research could investigate whether specific messages are more effective at improving capacity ahead of the lane closure.
- Research should explore variations in the placement of the PCMS relative to the taper. In this study, the location of the PCMS was influenced by site-specific factors.
- Further investigation is needed to assess how lane utilization rates differ between left-lane and right-lane closure scenarios.

## Implementation Readiness and Benefits

The findings from this study offer valuable insights to assist road agencies in deciding when, where, and how to implement static signs and PCMS for zipper merge scenarios. Recommendations on placement and messaging are summarized above and presented in more detail in the final report.

The road user survey provides important insights into drivers' understanding of lane merge scenarios and driver behavior when navigating both early and late/zipper merge control strategies at single-lane closures in freeway work zones. These findings can be used as a basis for education and outreach campaigns by road agencies to improve work zone knowledge and behavior.