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Dynamic Merge Systems in Work Zones

Summary of Uses and Benefits

About

The ENTERPRISE Pooled Fund Program initiated a project to document the resources available as well as uses and benefits regarding dynamic merge systems in work zones. A detailed literature search was conducted to summarize work zone materials available related to dynamic merge technologies. In addition, intelligent work zone (IWZ) representatives from transportation agencies were contacted to provide details on recent related deployments and provide input to the project.

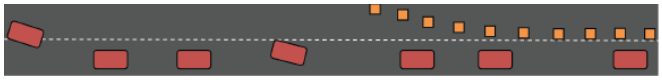
The purpose of the project was to understand the current status of work on IWZ activities by combining the resources gathered through a literature search with the information collected from the transportation agencies on recent deployments. Also included is a summary of dynamic merge systems in work zones including examples of successes, any guidance possible when technologies are most effective, and the configurations that demonstrated the best results.

While this summary is focused on dynamic merge systems in work zones, it is important to note that similar summaries were also developed by ENTERPRISE for variable speed limits, information describing conditions on alternate routes through work zones; and queue warning systems within work zones. These summaries are available on the ENTERPRISE Project Webpage.

Definition

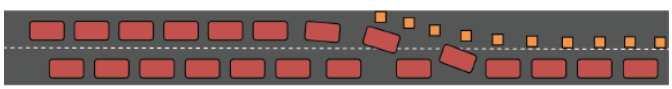
Typically IWZ dynamic merge applications consist of sensors and PCMS placed in advance of a lane closure. As congestion begins to form, the PCMS are activated to provide lane use instructions to drivers (e.g. TAKE YOUR TURN - MERGE HERE, USE BOTH LANES).

The America Traffic Safety Services Association (ATSSA) Guidance for the Use of Dynamic Lane Merging Strategies[1] identifies two dynamic merge strategies: Early and Late Merge. Early merging strategy advises drivers to move out of the closed lane well before the forced merge point and before traffic breaks down. To avoid congestion, the early merging strategy works best when there is a low traffic volume on the road combined with high average speeds.



Early Merge Concept Diagram (Source: ATSSA Guidance for the Use of Dynamic Lane Merging Strategies)

The late merging strategy that typically works best when the road has a high traffic volume and low average speed due to congestion. Drivers are instructed to remain in their respective lanes until they reach the designated merge point. This strategy ensures that both lanes are being used to their full capacity and minimizes unnecessary lane changes. Once vehicles reach the merge point, late merging encourages an alternating merging style, otherwise called zippered merging, in which vehicles take turns moving in the open lane.



Late Merge Concept Diagram (Source: ATSSA Guidance for the Use of Dynamic Lane Merging Strategies)

Resources

The following table includes resources that were reviewed related to dynamic merge systems. Information was gathered from available online resources (e.g. published reports, agency web pages, news articles) or through coordination with transportation agencies that have deployed queue warning systems. For those projects that an online hyperlink was not available, a brief summary of the information gathered for the project is provided at the end of this document.

Dynamic Merge Systems Related Resources

State/Resource	Document/Intelligent Work Zone Deployment
American Traffic Safety Services Association (ATSSA)	• Online Resource: Guidance for the Use of Dynamic Lane Merging Strategies[1] (2012) - Document introducing innovative merging strategies and when to implement the strategies. • Online Resource: ITS Safety and Mobility Solutions – Improving Travel Through America's Work Zones[2] (2008) - ITS resource manual from ATSSA on multiple parts of improving safety and efficiency of traffic in work zones.
Colorado	• Online Resource: Colorado DOT adds signs asking drivers to merge late[3] (2013) TheDenverChannel.com - News article discussing Colorado DOT's use of late merge signs. • Online Resource: You Tube Video Demonstrating Late Merge[4] (2013) - Colorado DOT YouTube video discussing merge late in construction zones.
Florida	• Online Resource: Evaluating Variable Speed Limits and Dynamic Lane Merging Systems in Work Zones: A Simulation Study[5] (2012) -Study simulating a two-to-one work zone lane closure configuration under different Maintenance of Traffic (MOT) plans and comparing work zone throughputs and travel times across MOTs including early and late Dynamic Lane Merge and VSL combinations. • Online Resource: Dynamic Early Merge and Dynamic Late Merge at Work Zone Lane Closure[6] (2009) - Research suggesting two simplified lane merging schemes to be applied and tested on short term work zones. • Online Resource: Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida[7] (2009) - Study compares the effectiveness of both forms of Simplified Dynamic Lane Merging Systems (SDLMS) to the conventional MOT plan. • Online Resource: Two Simplified Dynamic Lane Merging Systems (SDLMS) for Short Term Work Zones[8] (2009) - Comparison of the effectiveness of SDLMS to the conventional MOT plans during a lane reduction on I-95.
Indiana	• Online Resource: Indiana Lane Merge System – Warrants for Use [9] (2000) - Study proposing a new method of combining crashes and conflicts using an integrated model analysis. • Online Resource: Manual of the Lane Merge Control System[10] (1998) - Manual for persons involved in the utilization of layout and parameter settings of the Lane Merge Control System on rural two-lane freeways.
Iowa	• Online Resource: Effectiveness of Dynamic Messaging on Driver Behavior for Late Merge Lane Road Closures[11] (2009) - Evaluation of Iowa DOT's system of dynamic message signs for construction on I-80 and recommendations for future use of the system based on results.

	• Online Resource: Traffic Management Strategies for Merge Areas in Rural Interstate Work Zones[12] (1999) - Report seeks to better understand traffic flow behavior at rural interstate highway work zones and to estimate traffic carrying capacity of lane closure.
Kansas	• Online Resource: Construction Area Late Merge (CALM) System[13] (2004) - Study results underscore the importance of considering site characteristics very carefully when selecting sites for deployment of dynamic systems and/or late merge systems.
Maryland	• Online Resource: Use of Intelligent Transportation Systems in Work Zones[14] (2005) – Work Zone Safety toolbox for ITS in work zones.
Michigan	• Deployment Summary: EB I-96 near Mile Marker 9 in Ottawa County (2013) • Online Resource: Late Merging Drives Beware: MDOT Dynamic Merge Lanes Designed to Encourage Safer Driving Around Construction Zones[15] (2013) – mLIVE news article on Michigan DOT's use of dynamic merge lanes. • Online Resource: Evaluation of the Dynamic Late Lane Merge System (DLLMS) at Freeway Construction Work Zones[16] (2007) - Based on the travel time characteristics, queue, merge locations, and throughput the effectiveness of the DLLMS was evaluated by the research group. • Online Resource: Development and Evaluation of an Advanced Dynamic Lane Merge Traffic Control System for 3 to 2 Lane Transition Areas in Work Zones[17] (2004) - Advanced dynamic early lane merge traffic control system for 3 to 2 lane transition in work zones. • Online Resource: ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zone Merges in Michigan[18] (2004) - Case Study from Michigan: document from a series of products to provide ITS solutions to meet local and regional transportation needs. • Online Resource: US-131 Kalamazoo, Michigan[19] (2004) - Case Study of a dynamic late merge system used in a work zone in Kalamazoo, MI and findings and tips from the project. • Online Resource: Assessing the Impacts of the Dynamic Early Lane Merge Traffic Control System[20] (2003) - Study, analysis, and results on testing of early merge traffic control system. • Online Resource: Development and Evaluation of the Lane Merge Traffic Control System at Construction Work Zones[21] (2001) - Report on a pilot project to study the effectiveness of a lane merge traffic control system in Michigan.
Minnesota	• Online Resource: Evaluation of 2004 Dynamic Late Merge System[22] (2004) - Evaluation report was created from the deployment of the DLMS on US 10 in Anoka, MN. • Online Resource: Zipper Merge Still Tough Sell for Minnesota Drivers, MnDOT[23] (2013) – StarTribune.com news article discussing the difficulties of zipper merge in Minnesota. • Online Resource: Dynamic Late Merge System Evaluation – Initial Deployment on US-10[24] (2003) - Report on the development, testing, and evaluation of a traffic control system that incorporates the best aspects of both the early and late merge systems.
National Work Zone Safety Information Clearinghouse	• Online Resource: Simulation Trials on an Unconventional Alternative to Congestion Mitigation and Traffic Control at Highway Work-Zone Bottlenecks using Advanced Technologies (2008)[25] - Paper presents a method to integrate the DLM with a merge

	metering via wireless communication area of a work zone, termed as Dynamic Merge Metering Traffic Control System (DMM-Tracs) for highway work-zone bottlenecks.
Nebraska	• Online Resource: Dynamic Late Merge Control Concept for Work Zones on Rural Freeways[26] (2004) - Report discusses when to use different merging strategies on rural freeways.
Street Smart Rental	• Online Resource: Dynamic Late Merge Deployment Criteria Considerations[27] - Short webpage on deployment criteria and anticipated system effects of dynamic late merge.
Texas	• Online Resource: Understanding Road Rage: Evaluation of Promising Mitigation Measures[28] (2001) - Report documents literature review, focus groups, telephone survey, and evaluation of 3 mitigation measures aimed at reducing driver stress that can lead to aggressive driving.
Transportation Research Board	• Online Resource: Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy[29] (2007) - Operational effects of the late merge were evaluated and findings are documented in this study. • Online Resource: Dynamic Late Merge Control at Highway Work Zones: Evaluations, Observations and Suggestions[30] (2007) - Study that evaluates the result of dynamic late merge system for highway work zone operations and focuses on operational efficiency.
USDOT Federal Highway Administration	• Online Resource: Work Zone Intelligent Transportation Systems Implementation Guide[31] (2014) - Document to provide guidance on implementing ITS in work zones to assist public agencies, firms, developers, etc. • Online Resource: Work Zone Public Information and Outreach Strategies[32] (2005) - This guide is designed to help transportation agencies plan and implement effective public information and outreach campaigns to mitigate the negative effects of road construction work zones.
Virginia	• Online Resource: Evaluation of the Late Merge Work Zone Traffic Control Strategy[33] (2004) - Study to determine when, if at all, deployment of the late merge is beneficial.
Wisconsin	• Online Resource: Evaluation of Dynamic Late Merge System in Highway Work Zones[34] (2006) - Study researched speed characteristics with and without DLMS, measured the effectiveness of the DLMS, and determined traffic conditions where the DLMS will be efficient. • Online Resource: I-94 Eastbound – Waukesha County Dynamic Late Merge System[35] - Wisconsin DOT website discussing the I-95 re-pavement project and the use of dynamic late merge system.

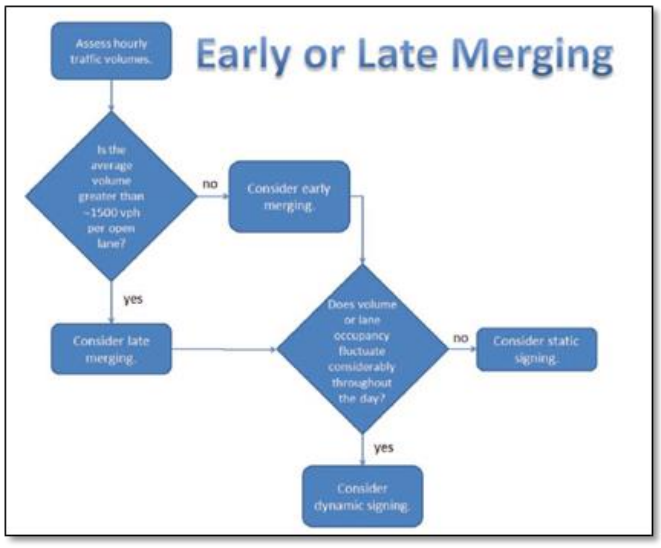
Typical System Use

Dynamic merge systems are typically used in work zones that experience fluctuating traffic demand. The technology typically used for a dynamic merge system can be programmed to change the message and merging strategy based on measurements of real-time traffic conditions such as speed, density, and occupancy. Early and late merging can also use static signage and is most effective when there is a steady flow of traffic because they always display the same message throughout the duration of the lane closure.

A brochure developed by ATSSA, ITS Safety and Mobility Solutions[2], advises that the dynamic early merge is effective for longer passing zone and lower volumes of traffic; when the work zone requires a two-to-one or three-to-two lane drop; when peak hour traffic demand is between 2,000 and 3,000 vehicles per hour (two-to-one lane closure) and between 3,000 and 3,800 (three-to-two lane closure). Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida[7], a study conducted by the Florida DOT, found that dynamic early merge performs better than late merge with volumes ranging between 0 and 500 veh/hr and 501 and 1000 veh/hr. The same study found that for volumes ranging between 1001 and 1500 veh/hr the dynamic late merge exhibits the highest performance compared to the early merge. In addition, the early merge can be considered for situations when the length of queue is not expected to extend beyond the start of work zone signing; when there is commuter traffic and sufficient project duration to allow adaptation to the system; when travel speed is high; when aggressive, repeat drivers attempt to "jump the queue" by remaining in the dropped lane up to the merge point.

The dynamic late merge is effective for higher volumes of traffic and a definite merge point. In addition, the late merge should be considered in situations when the work zone requires a two-to-one lane drop; when traffic demand exceeds the capacity of the open lane; when traffic demand could create an extensive queue length which may affect other access points or may extend beyond reasonable placement of advance warning signage; and when congestion caused by lane closures varies many times throughout a work day. A study conducted by the Virginia DOT in 2004, Evaluation of the Late Merge Work Zone Traffic Control Strategy[33], concluded that the late merge should be considered for 3-to-1 lane closure configurations but not until a sound methodology for deployment has been developed and tested in the field. For the 2-to-1 and 3-to-2 configurations, the late merge should be implemented only when the percentage of heavy vehicles is a t least 20 percent.

ATSSA, Guidance for the Use of Dynamic Lane Merging Strategies[1], provides a flow chart to determine which merging strategy to use; however, a common thread in the projects researched was a recommendation that the use of engineering judgment and site evaluation be conducted along with the suggestions in this report because of the range of options and combinations for dynamic merge applications.



Flow chart diagram indicating guidelines for when to use various merging strategies for either two-to-one lane closures or three-to-two lane closures (ATSSA, Guidance for the Use of Dynamic Lane Merging Strategies[1])

Public Outreach

There are several strategies to improve public compliance with the dynamic merge techniques. An example of this type of public education outreach was done by Colorado DOT in 2013 for two projects using dynamic late merge. Colorado DOT utilized news outlets and created a YouTube Video Demonstrating Late Merge[4] to educate drivers about how to understand the signage and use dynamic late merge appropriately.

Screenshot of YouTube Video Demonstrating Late Merge

A project conducted by Michigan DOT in 2004, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zones in Michigan[18], found it beneficial to identify stakeholders early in the planning stage as one of the key steps to a successful implementation. Michigan DOT held several meetings with key stakeholders, including the law enforcement community, to keep them involved and aware of the project's intent.

It is also important to provide motorists with real-time information at appropriate locations because drivers prioritize information and will discard the information that seems irrelevant or unimportant. The time gap between information is critical to a driver in order for him/her to retain the relevant information, and to take appropriate action at the correct time. A study conducted by Michigan DOT, Assessing the Impacts of the Dynamic Early Merge Traffic Control System[20], assessed the effectiveness of dynamic merge system and driver understanding and concluded that driver non-compliance or understanding is because of non-optimal system layout and settings, inappropriate spacing between dynamic signs, the sign messages being new and unfamiliar, and the installation of the system when not warranted that can all lead to non-compliance.

Dynamic Sign and Trailer Used in Michigan[20]

Typical System Components

Dynamic merging systems in work zones can alternate which merging technique it displays by using real-time traffic monitoring and conveys instructions to motorists using PCMS. Based on site-specific algorithms, once a dynamic merging system detects a change in traffic conditions, it switches from early to late merge or vice versa to accommodate traffic. Guidance for the Use of Dynamic Lane Merging Strategies[1], developed by ATSSA compiled a list from various practitioners and researchers that have used the following to test, evaluate, and implement dynamic lane merging strategies: microwave signals to identify traffic volume; video analysis to track traffic volume, lane occupancy, and queue; Doppler radar to determine average speed; pneumatic tubes to calculate traffic volume; computer simulations to optimize dynamic merging algorithms.

Benefits

There are a number of benefits from deployment of dynamic merge systems in work zones. The nature of work zones and lane closures indicate that some delay is inevitable; however, some lane closure and merging techniques are able to improve operations, reduce delay, and increase safety when used appropriately.

ITS Safety and Mobility Solutions[2], a brochure developed by ATSSA, suggests that the early dynamic merge systems can reduce aggressive driving and unsafe merge maneuvers, provide significant advanced warning to allow drivers an adequate distance to merge, and gives drivers positive instructions on lane usage, which helps reduce road rage. A study conducted by the Michigan DOT, Assessing the Impacts of the Dynamic Early Lane Merge Traffic Control System[20], found that with the use of the dynamic early merge it significantly reduced aggressive driver behavior, lane violations and delay, as well as a slight improvement in traffic flow on a two-lane to one-lane suburban freeway work zone.

The late merge system allows the queue to "stack" in multiple lanes, which reduces the overall queue length by approximately half; and reduces the differential in speed between lanes, which provides for safer lane changes. A project conducted by Michigan DOT, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput at Work Zones in Michigan[18], found that using the dynamic late merge decreased the average number of aggressive driving maneuvers per travel time run from 2.88 to 0.55 during the afternoon peak period.

Sign Messages and Thresholds

Messages can either be displayed on static signs or on PCMS systems to alert motorists of required merging and reduced speeds. Typically the messages displayed for early merge say DO NOT PASS with flashing strobes to indicate to motorists to merge right away. A late merge generally shows a sign with USE BOTH LANES TO MERGE POINT to indicate to wait to merge until the merge point. These messages and thresholds vary depending on the type of dynamic merge used.

Contracting

There are many different contracting options for IWZ projects. In the US DOT FHWA Work Zone ITS Implementation Guide[31], an overview of procurement approaches (direct or indirect) are provided as well as information to consider to determine the procurement award mechanism, issuing a request for proposals and selecting the preferred vendors, consultant or contractor.

A project conducted on I-94 in Michigan, ITS in Work Zones – A Case Study – Dynamic Lane Merge System – Reducing Aggressive Driving and Optimizing Throughput At Work Zones in Michigan[18], found it beneficial for contracting to add specifications for the dynamic late merge system components as pay items in the prime construction contract after award, as a modification to the contract. The prime construction contractor hired two subcontractors to design, install, and integrate the system components based on the specifications that Michigan DOT provided in the contract modification. Michigan DOT wrote the specifications for temporary use of the system so that they could deploy DLM without having to perform equipment maintenance or store the system after construction was completed. Because these were not permanent installations, Michigan DOT's subcontractor leased all of the system components and Michigan DOT continues to use the lease option to benefit from the latest in rapidly changing technology.

Dynamic Merge System Deployment Example

Following is a Dynamic Merge System deployment example project summary.

Dynamic Merge Deployment Summary: EB I-96 near MM – Ottawa County, Michigan

During 2013 EB I-96 underwent the removal of two bridges and replacement with two, pre-stressed concrete box beam bridges, hot mix asphalt road reconstruction, cold milling and resurfacing, new interchange construction, bridge rehabilitation on two bridges, deep overlay on one bridge, water main relocation, guardrail and drainage improvements, signing, pavement markings, and restoration on I-96 from west of GTW Railroad (Abandoned) east to east of 112th Avenue, Ottawa County. This project includes two 5 year materials and workmanship pavement warranties and a 2 year bridge painting warranty. 4 traffic sensors, communication devices, 5 sets-flashers, signs, 5 trailers, 5 sets- solar power equipment and batteries, and PCMS were utilized. The message board with the merge and arrow symbol was removed because traffic was merging prior to them needing to merge. The project indicated very good success with the dynamic merge. A lot of positive feedback from motorists and police enforcing agencies. Traffic is merging properly and not having many motorists "cheat" and pass everyone and merge at the arrow board. As long as you enforce the system with police the motorists are obeying the signs. The key to success is having enough enforcement.

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