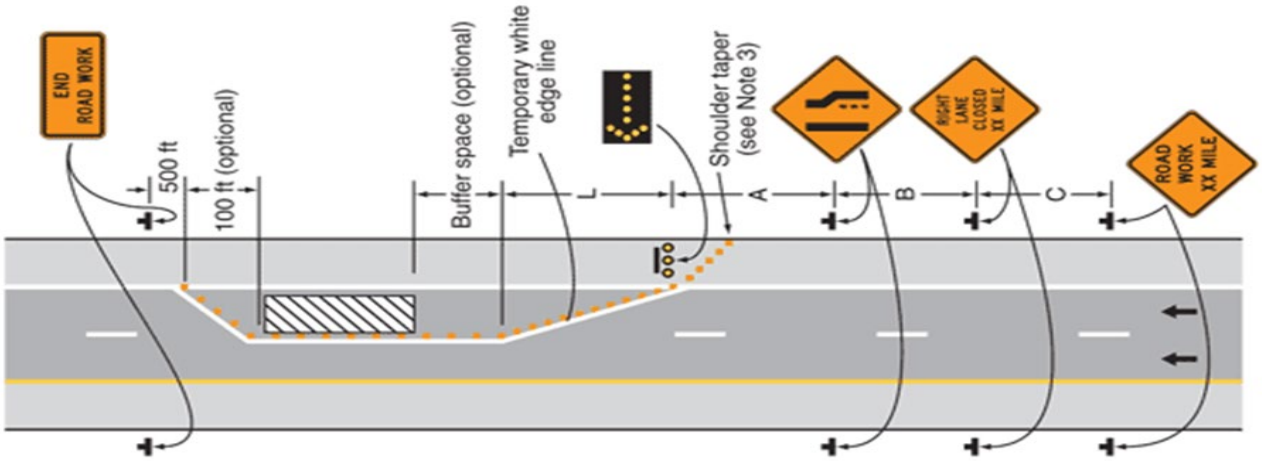
Optimizing Work Zone Zipper Merge Using Federated Driving Simulators



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PREPARED BY:

Carlos Sun, Ph.D., P.E., J.D.

Praveen Edara, Ph.D., P.E.

Sabreena Anowar, Ph.D.

Casey Canfield

University of Missouri-Columbia

PREPARED FOR:

Missouri Department of Transportation

Construction and Materials Division, Research Section

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16. Abstract
Several Departments of Transportation have implemented the zipper merge to counter the issues of wasted capacity and queue jumping that surface at early merge work zones. This project researched four issues related to zipper merge operations and offered practical suggestions for the deployment of zipper merge. A main result is that public education is vital since many drivers either do not understand zipper merge or are averse to changing from the long-held practice of early merging. Specific recommendations are provided for the deployment of educational materials, including video and written bulletins. Drivers prefer for zipper merge to operate under lower traffic speeds and higher traffic flow conditions. However, simulator results show that zipper merge works even under higher speeds and moderate traffic flow conditions. The placement of the last CMS sign in the zipper merge system near the taper is preferred to produce more desirable driver behavior. This placement can be specified in the MoDOT Engineering Policy Guide. The adoption of these recommendation supported by research could improve zipper merge acceptance and operations in Missouri.

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Optimizing Work Zone Zipper Merge

Using Federated Driving Simulators

MoDOT Research Project TR202009

Carlos Sun, Ph.D., P.E., J.D.
Professor
Civil and Environmental Engineering
University of Missouri-Columbia

Praveen Edara, Ph.D., P.E.
Professor
Civil and Environmental Engineering
University of Missouri-Columbia

Sabreena Anowar, Ph.D.
Assistant Professor
Civil and Environmental Engineering
University of Missouri-Columbia

Casey Canfield
Assistant Professor
Engineering Management & Systems Engineering
Missouri University of Science and Technology

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EXECUTIVE SUMMARY

Departments of Transportation (DOTs) are finding that early merge at work zone lane closures could have several drawbacks. One being wasted capacity of the closed lane leading to longer queues in the open lane(s) that could potentially extend beyond work zone signage. Another being queue jumping behavior described as some vehicles zooming past the queue and trying to cut in at the last minute. Such drawbacks could result in various problems such as moving roadblocks implemented by truckers upset at queue jumping, conflict and anger at queue jumping, and approaching traffic being surprised by the end of queue that extended beyond work zone signage. In response, several DOTs have begun to use the late merge or zipper merge system. Zipper merge has the potential to utilize wasted closed lane capacity, reduce congestion and queuing, and bring about uniformity at the merge point. There are several deployment factors of zipper merge that could be refined to bring about the most benefits. Some of these factors include the nature and importance of public education, effect of traffic speed, effect of traffic flow, and the placement location of the last Changeable Message Sign (CMS) of the zipper merge system. This research project is an effort to help refine zipper merge deployment by reviewing existing literature, conducting a simulator experiment, surveying human subjects, and analyzing educational materials. Practical recommendations are presented to MoDOT to aid in the deployment of zipper merge.

A major task of this project was a driving simulator study using human subjects. There are several advantages of using the simulator approach for studying zipper merge. One major advantage is the difficulty of obtaining heavily congested data over long periods of time in the field. The reason is because DOTs try to reduce congestion by applying various traffic management strategies. Another advantage is the ability to easily examine various factors since

the virtual world could easily be changed to isolate the effects of a specific factor. This flexibility is lacking from field studies where real-world conditions are often uncontrollable. An advantage related to safety is that human subjects are exposed to minimal risk in a simulator experiment. In fact, a simulator experiment complements field tests since it could help to refine field deployment strategies. A driving simulator experiment was completed successfully using 50 human subjects who are licensed Missouri drivers. These subjects also completed a survey that yielded insights into their behavior and attitudes.

One main finding of this project is that public education is vital to public compliance and the proper functioning of zipper merge. Of the 50 subjects that were surveyed, over 60% were not familiar with zipper merge. A survey question about zipper merge signage showed that there is significant potential for drivers to misinterpret the zipper merge sign package. Figure ES-1 shows one sign from the zipper merge system used in a question asking drivers for their interpretation of the sign. The responses were 10% for merge now, 42% for merge when reaching the work zone, 26% for following everyone else, and 22% for not understanding the sign. The results of the simulator study show a statistically significant difference between pre- and post-education driver behavior. As shown in Table ES-1, the difference in the distance to the work zone at first blinker use, a surrogate for the intention to merge, and at merge were 570 feet and 747 feet. In other words, drivers signaled and merged much closer to the taper after education.

Figure ES-1 Zipper Merge Signage

Table ES-1 Comparison Between Pre and Post Education

		Distance to Work Zone at Blinker Use	Distance to Work Zone at Merge Maneuver
mean	pre	2027.70	1833.62
	post	1457.41	1086.70
	diff	570.29	746.92
std. dev.	pre	1502.38	1572.46
	post	1225.39	1231.39
	ratio	1.23	1.28
t-test		0.00	0.00

While some subjects were confused about zipper merge operations, most appreciated the concept. Over 80% of the subjects surveyed agreed that the zipper merge concept was good. And only a little over 30% indicated that zipper merge could cause anxiety at a work zone. Again, public education could be used to help convince drivers of the value of zipper merge.

Another finding involving public education was that effective public education does not have to be elaborate or lengthy. With both the simulator and the survey, a short, concise message explaining zipper merge was presented to human subjects. Such a short message was effective to generate proper understanding and behavior from subjects. As shown in Figure ES-2, the percentage of respondents that said the zipper merge explanation was helpful was 94%. Survey subjects also approved of the sample educational video. The survey results show that either written or video educational materials can be effective in educating the general public.

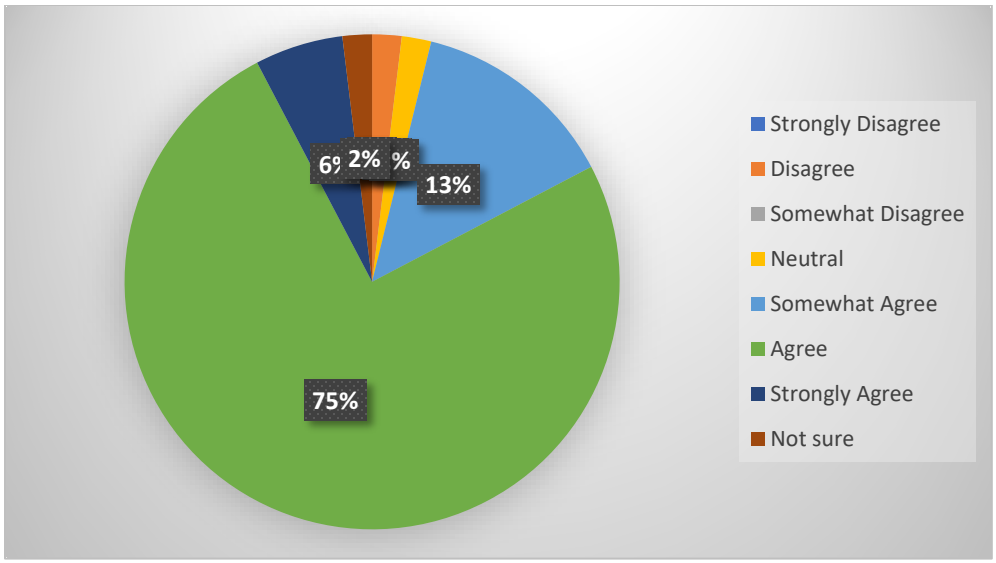

Figure ES-2 Survey Response to Helpfulness of Zipper Merge Education

The challenge with education appears to be one of reaching the vast driver population in Missouri and using education to counter the ingrained habit of merging early. The existing educational materials from several DOTs were examined. Appeals to reason and emotion were especially popular. In terms of content there was not a single video or news release that was superior to others. A good example of an effective video is one produced by North Dakota DOT where multiple behavioral strategies were used. Based on survey results and social behavioral science, a recommendation is offered to chunk (i.e., group information into smaller, easily digestible sections) the current MoDOT zipper merge web page. The goal of chunking is to present information in a way so that a person can quickly identify and process the main points related to zipper merge.

The literature, simulator, and survey offered slightly different recommendations in terms of the traffic speed at which the zipper merge could be effective. The literature and the survey results both suggest that lower speeds were preferred. In the simulator experiment there was not

a significant difference between background traffic traveling at 55 mph and 40 mph. The small difference in distances, 68.8 feet at first blinker use and 64.2 feet at merge, were not statistically significant. The practical conclusion is that zipper merge could work well even at higher speeds even though the preference is for lower speeds.

The literature, simulator, and survey also offered slightly different recommendations in terms of the traffic flow at which the zipper merge could be effective. The literature and the survey (70%) results both indicate a preference for high traffic volumes. The results of the simulator study showed that zipper merge could work well even under moderate flows. The simulator experiments had medium traffic flows of approximately 700 vehicles per hour per lane at 55 mph and 500 vehicles per hour per lane at 40 mph. The high traffic flow conditions were approximately 1400 vehicles per hour per lane at 55 mph and 1000 vehicles per hour per lane at 40 mph. The results showed very little difference in terms of driver behavior between medium and high traffic flows. The practical conclusion is that zipper merge could work well even at lower flow conditions even though the stated driver preference is for higher traffic.

The simulator results showed clear evidence that the placement of the CMS should be closer to the taper. There were statistically significant differences under the post-education condition where the distance decreased at first blinker by 295 feet and at merge by 236 feet for the 300 feet placement. Even though the magnitudes in the differences are not as large compared to the pre- versus post-education results, the decreased distance here is with respect to the location near the taper. In other words, this decrease is localized to the area near the CMS. The practical recommendation is to place the CMS closer to the taper to maximize the capacity in the closed lane. This recommendation can be promoted by specifying the CMS location in the MoDOT Engineering Policy Guide on zipper merge.

Finally, this research project was negatively impacted by the COVID-19 pandemic. A major portion of this project involved the design and conduct of human subject studies. The height of the pandemic was when human subject studies were to begin. The various health regulations at the federal, state, local, and University levels effectively shut down any type of simulator testing or development for nearly a year. Even when the simulator facility was reopened there as concern over the willingness of human subjects to participate in such a study. Fortunately, 50 human subjects were successfully recruited to complete the zipper merge experiment.

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Introduction

Overview

Work zones could involve lane closures where traffic is required to merge from a closed lane to an open lane. With the traditional early merge strategy, vehicles merge to the open lane right after encountering the lane closed ahead sign as part of work zone traffic control. Under congested conditions, this strategy could lead to several potential issues. An early merge results in increased queuing in the open lane while leaving capacity unused in the closed lane. The increased queuing could potentially extend beyond work zone warning signage surprising approaching traffic and increasing the risk of an end-of-queue crash. The unused capacity in the closed lane approaching the taper also allows the potential for queue jumping, where vehicles try and pass on the closed lane and cut in near the work zone. Queue jumping behavior could lead to motorist anger and friction at the taper. Several departments of transportation (DOTs) have been experimenting with the concept of late merge for several years. Late merge is also known as zipper merge since late merge involves vehicles taking turns merging at the taper like a zipper. The potential benefits of zipper merge include full use of the available capacity, more uniform merging at one location only, and fairness in taking turns one after another (Spiller et al., 2017). However, the support for zipper merge is not universal in the United States, and a Missouri study could help to improve education and public acceptance in the state of Missouri.

Simulator Study

MoDOT's policy of minimizing traffic impacts at work zones means that it is often difficult to obtain data involving sustained traffic congestion. Zipper merge is designed to operate best under congested traffic conditions and not free flow conditions. For example, in a field study of the dynamic late merge system in Laclede County, Missouri, the researchers obtained very little congested field data as work crews re-routed traffic once a backup was manifest (Bham et al., 2006). Congested conditions can be easily created in a simulator environment but are difficult to collect in the field in a sustained fashion. Another advantage of a simulator study is the ability to examine multiple factors. It is often difficult to examine multiple factors in a field study since one needs to control the effects of various factors in order to ascertain if a single factor was the cause of driver behavior change. In contrast, a simulator study allows the repeated testing of a similar scenario where only one factor is changed. This testing sequence allows the isolation of the effects from a single factor like traffic flow, prevailing speeds, public education, or location of the merge arrow sign. A simulator study also allows the collection of very detailed information such as vehicle kinematics and driver psychophysiology, neither of which can be obtained from the field except via a high-cost naturalistic driving study. In projects in which safety is a concern, a simulator allows experimentation with no risk of harm to human subjects. In a zipper merge study, there is no concern if a subject actually overruns the taper or cuts in front of another vehicle. In summary, a driving simulator study allows the safe and controlled investigation of zipper merge under congested conditions.

Literature Review

Evaluations of Applicable Zipper Merge Scenarios

Prior research recommends late merge for congested conditions and early merge for free flow conditions. In dynamic merge systems, a threshold is used for switching between these two merge strategies. This threshold then represents the threshold or the best conditions for applying zipper merge. Various traffic parameters have been used for determining this threshold, one being traffic flow. Several researchers recommend the use of approximately 1500 vehicles per hour as a threshold for switching between late and early merge (Datta et al., 2007; Grillo et al., 2008; Sperry et al., 2009). A related measure is volume-to-capacity ratio that takes into account the reduction in capacity at a work zone. A 2-to-1 lane closure differs from a 3-to-2 lane closure. Some recommend using an occupancy rate of around 15% (Kang et al., 2006). Another option, evaluated for three-to-two lane closures, used a speed threshold of around 50 mph (Meyer, 2004). Some studies suggest that the percentage of heavy vehicles is a significant factor in setting the switching threshold (Beacher et al., 2005; Harb et al., 2010; Hallmark et al., 2011). Under congested conditions, the growth of queues emanating from the work zone increases the crash risk of the approaching traffic upstream. Zipper merge could increase capacity and reduce the queue growth rate to mitigate upstream conflicts. Geometric design considerations also come in play. For example, horizontal and vertical curves reduce the available stopping sight distance making queue reduction a greater priority. Issues such as volume-to-capacity ratio, geometric design, and projected queue length are the factors that determined the simulator scenarios that were investigated.

Evaluation of Applicable Zipper Merge Sign Configurations

Signage must clearly indicate, to drivers approaching a lane closure, to perform a zipper merge at the merge point. NCDOT, for example, uses signs that use the word "zipper" and/or feature images depicting a closing zipper (Hoggard, 2016). Standard MUTCD signage for lane closures uses language, such as "RIGHT LANE CLOSED", that emphasizes the closure of a lane. Examples of signage in late-merge scenarios use language that emphasizes the act of merging. Late-merge signage uses language instructing drivers to utilize all the lanes of a road before the merge point and to take turns merging. Examples of signs, use phrases such as "USE BOTH LANES" and "TAKE TURNS" to prepare drivers entering a lane closure (Johnson, 2019). State DOTs use both types of wording at late-merge sites, in conjunction to MUTCD signs at late-merge sites. Other examples of DOT sign layouts have additional signs specifying distance from the merge point to prepare drivers for an upcoming merge. In addition, some DOTs post signs at the merge point to specify where the merge should take place, sometimes including a blinking arrow sign (Baumgarten, 2018; Beacher et al., 2005; NCDOT, 2019).

As discussed previously, the zipper merge is recommended for congested conditions. In some cases, DOTs use signs to specify to drivers that this is the case where a late merge is to be used. Examples of signs in these cases, such as "USE BOTH LANES DURING BACKUP", modifies the previously mentioned language (Lammers, 2019). In one case using this signage, MnDOT found that drivers were able to identify congested conditions and switched to late merge accordingly. This case was in a rural setting and MnDOT recommends a computerized system to determine when late merge should be used in urban areas, where volume and speed fluctuate greatly (MnDOT, 2008). In another case, NCDOT used dynamic signs that change to late-merge

instructions and do not rely on driver discretion. Furthermore, the dynamic signs also adapted to changing traffic conditions and changed the merge point depending on the level of congestion (NCDOT, 2019). In the simulator study, the MoDOT zipper merge system will be evaluated which uses signage similar to several other DOTs. In the post-simulator survey, additional signage options were examined.

Human Subject Study Procedures

Background

Institutional Review Board (IRB) is an entity, often part of a university, that reviews research proposals for human subject experiments. IRBs were established in 1974 by the Department of Health Education and Welfare to promulgate the regulations on the protection of human subjects. An IRB reviews the conduct of research to ensure that federal and local regulations, and ethical principles are followed. An IRB is staffed with experts who are able to evaluate proposals on both scientific and ethical bases.

Approval Process

The IRB review process involves the submission of an extensive set of materials. Some of the materials submitted for IRB approval are contained in Appendices B through F. They are the study protocol, recruitment flyer, consent form, post-simulator survey, and simulator sickness questionnaire. IRB also coordinates closely with accounting and information systems to ensure financial accountability, and data privacy and security. The IRB then weighs the risks and benefits of the research, issues modifications to the research, and approves if all concerns have been addressed. After a study has been approved for experimentation, the IRB continues to require researchers to monitor and report any issues. At the completion of the study, researchers are required to submit a final report to IRB confirming that proper procedures and protocols were followed throughout the study.

The human subject study protocol is a comprehensive document that describes the proposed research in sufficient detail so that IRB staff can adequately address any human subject concerns. The research purpose and objectives have to be clearly presented. In this project, the purpose is to investigate how drivers behave under different zipper merge implementations. The appropriate scientific rationale needs to be provided. The motivations for deploying zipper merge, such as improving efficiency, decreasing conflicts, and minimizing stress, are potential benefits. The study objectives are to identify the factors that would lead to optimal zipper merge deployment. The recruitment process needs to be described clearly, such as how and where will recruitment occur. The relevant communications materials for zipper merge study recruitment (e.g., flyer, email) were submitted to IRB. A key concept in ethical human study participation is the concept of informed consent. This concept involves subjects who are both willing participants and well-informed participants. The zipper merge consent form and the description of the consent process were submitted to demonstrate the adequacy of the consent process. IRB carefully reviews the population from which human subjects are drawn. For zipper merge, only Missouri-licensed adult drivers qualify for participation. The study design has to be described in detail. For the simulator study, the entire human subject trial is detailed, including the orientation, informed consent process, simulator warm up, simulator trial, post-simulator survey, and de-briefing.

An important part of the protocol evaluation is the balancing between potential risks and benefits. Managing risk is an integral part of human subject studies as there are always risks whenever human subjects are involved. Thankfully, simulator studies typically involve relatively mild risks and there is a small percentage of the subjects who experience discomfort or simulator

sickness. Simulator sickness is not well understood by the medical community even though some hypothesize that it is similar to motion sickness and may be caused by vection which is a mismatch between visual and motion cues received by the body. A longer study increases the risk for simulator sickness. Thus, this study was kept under 20 minutes of actual driving time and limited to 12 scenarios. Additional mitigation strategies included controlling the testing environment (e.g., cool temperature and multiple fans) and careful monitoring of human subjects. There were no subjects that dropped out for this project.

In order to incentivize human subject participation, researchers typically offer compensation. Here, $20 gift cards were issued to the 50 participants. As with the handling of other financial aspects of research grants, there are several steps that were taken to ensure financial accountability for our grantor, MoDOT. Gift cards were kept in a locked office accessed by a custodian. IRB requires that strict records be kept of the issuing of gift cards even for a small denomination. The names and addresses of the compensated party were submitted to accounting. Due to the small denomination, a waiver was issued by accounting to forgo the recording of the social security numbers of the subjects.

Data Privacy and Data Management

The protection of the privacy of participants is required for human subject studies. This is true even if an unauthorized release of data is not particularly embarrassing or harmful. Here, the videos of human subjects driving through work zones or survey answers do not contain embarrassing details. The ZouSim data management plan includes the following components. First, no personally identifiable information is stored in the data files such as the simulator

videos, derived data, and surveys. A unique identifier was assigned and used to link the participant data with the participant. The hash table linking participants with unique identifiers was locked in a locker inside the ZouSim laboratory. At the completion of each research day, data was compiled and locked inside the ZouSim laboratory. All the steps taken minimize the potential for any data breaches.

Complications Due to COVID-19

The COVID-19 pandemic caused major disruptions to the research project. Just when the ZouSim lab was readying for human subject trials, national, state, and local restrictions started to appear. These health restrictions shut down the entire University and specifically the ZouSim lab. Computing equipment was relocated off campus but the driving simulator could not be accessed for several months. The shutdown delayed various steps in the research including design and testing of the simulator scenarios, the calibration of the hardware for this experiment, alpha (or in-house) testing, and the human subject trials. There were additional procedures mandated by COVID rules such as social distancing, mask wearing, and cleaning of frequently contacted surfaces such as the steering wheel and door handles. There were even some changes in the preference for gift cards. Previously, most human subjects gladly accepted gift cards from local eateries such as Chipotle. However, since the advent of the pandemic, subject switched their preference to online shopping cards such as an Amazon gift card. The pre-purchased Chipotle gift cards were exchanged for Amazon ones which took a significant effort due to the compliance with accounting rules. With the easing of the pandemic restrictions, the conduct of human subject studies became possible even though there was still a general hesitancy of the

population to participate in human subject trials. After extensive recruiting efforts in the mid-Missouri area, the required number of subjects was attained.

Simulator Design and Methodology

Introduction

This chapter describes the design of the zipper merge simulator experiment. First, the instrumentation for human subject psychophysiological measurements is described. Second, the zipper merge education for human subjects is presented. Last, the details of the simulator layout and scenarios are described.

Psychophysiological Instrumentation

Eye tracking devices are receiving greater use in recent simulator studies. In simulator studies, an eye tracker tracks the movement of a participant's pupil, capturing the frequency and time of participants glance at specific spots. This is useful to examine designs involving position configurations, signage, or a multi-media information platform. An eye tracker can act as an indicator for when a participant has identified an object in the simulator world. Eye tracking data can be combined with other information to infer driver intention. For example, if a driver glances at a "MERGE HERE" sign and then proceeds to merge, then it could be inferred that the driver understood the message and proceeded to follow the message.

Zipper Merge Education for Simulator Study

As part of the simulator study, zipper merge education was introduced. A script was followed so that the education was done uniformly for all human subjects. The host said the following setence to each human subject:

Zipper merge means drivers use both lanes and take turns merging at the point of the lane closure, alternating with every other car, so that the road capacity is fully utilized.

The following diagram (Figure 4-1) was shown to each human participant.

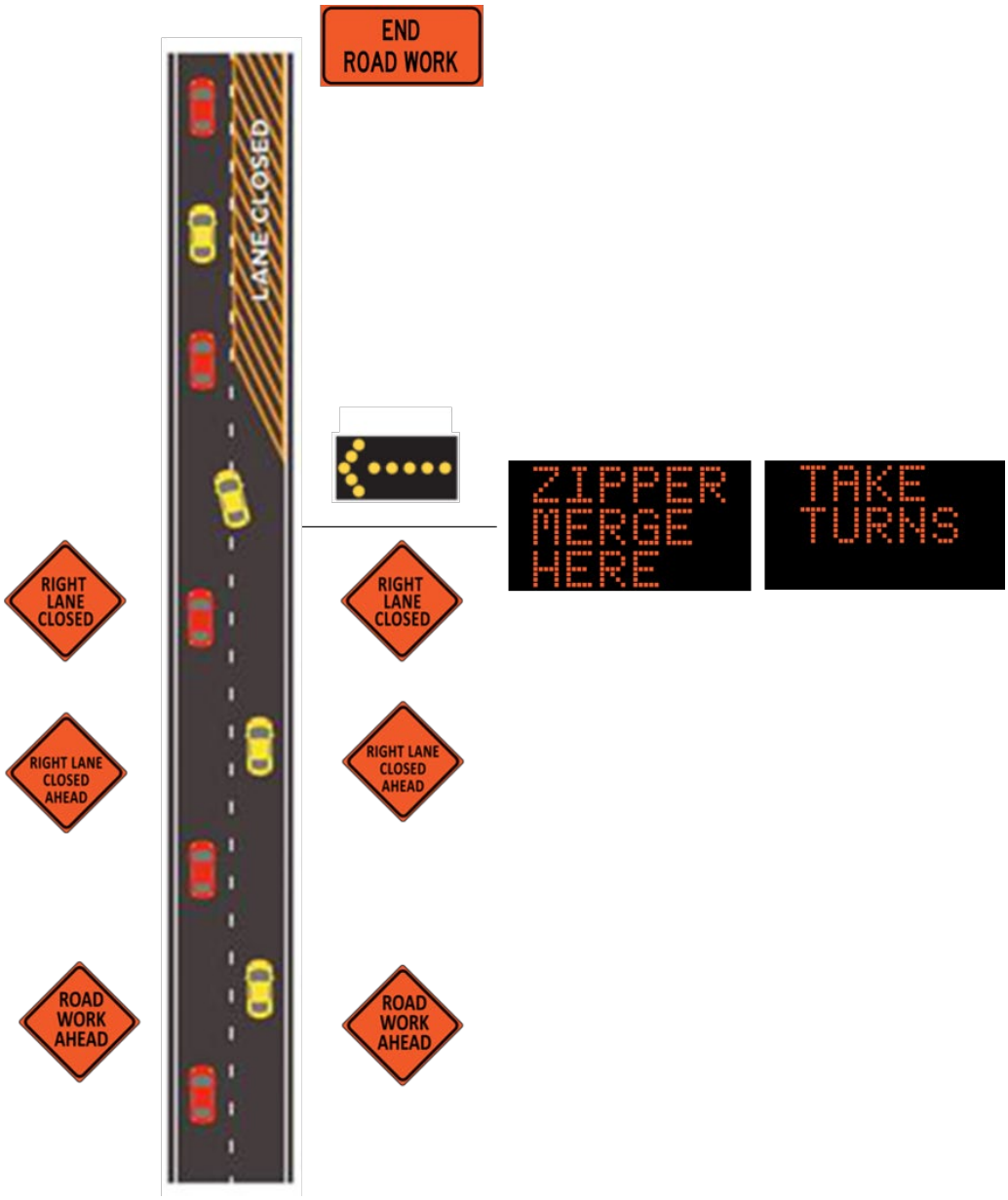

Figure 4-1 Diagram for Human Subject Education

Simulator Study

This simulator study utilizes the ZouSim driving simulator. ZouSim is a suite of networked transportation simulators that allows the safe and effective investigation of various transportation modes, including the interaction among multiple modes. Currently, ZouSim is capable of simulating driving, trucking, walking, bicycling, wheeling, and e-scootering. Figure 4-2 shows the ZouSim driving simulator. This simulator is a medium-fidelity simulator built around the half-cab of a sedan. The active instrumentation in the vehicles includes a force-feedback steering wheel, brake and acceleration pedals, turn signals, and engine vibration generator. The ZouSim simulator environment has been used for various projects sponsored by agencies such as FHWA, MoDOT, FAA, and the City of Columbia. ZouSim has been utilized extensively for examining work zone safety and efficiency issues. Examples of recent ZouSim work zone studies include the use of green lights on truck mounted attenuators (Brown et al., 2018), automated flaggers (Zhang et al., 2019), and alternative work zone signage (Edara et. al., 2019). Other examples of recent ZouSim experiments include bicycle signage and markings (Sun and Qing, 2018), geometric design of J-turns (Sun et al., 2017), autonomous vehicle interactions with pedestrians (Qing et al., 2019), and wheelchair accessibility at airports (Qing et al., 2019).

Figure 4-2 ZouSim Driving Simulator

The work zone and road section designed for the study is a two-way four-lane divided highway with a closure on the right lane. The work zone follows the MUTCD (FHWA 2009) Typical Application 33 which is a stationary lane closure on a divided highway. Figure 4-3 shows the diagram of the basic layout and signage without any zipper merge components. The road is intentionally designed straight so that road curvature does not influence driver behavior. Also, the road is designed as a typical Missouri highway without replicating an actual road section; the non-descript nature of the road is intentional to prevent human subjects from using their memory of actual roadways to influence their simulator behavior. Figure 4-4 shows the MoDOT zipper merge system with the additional signage communicating the late merge procedures.

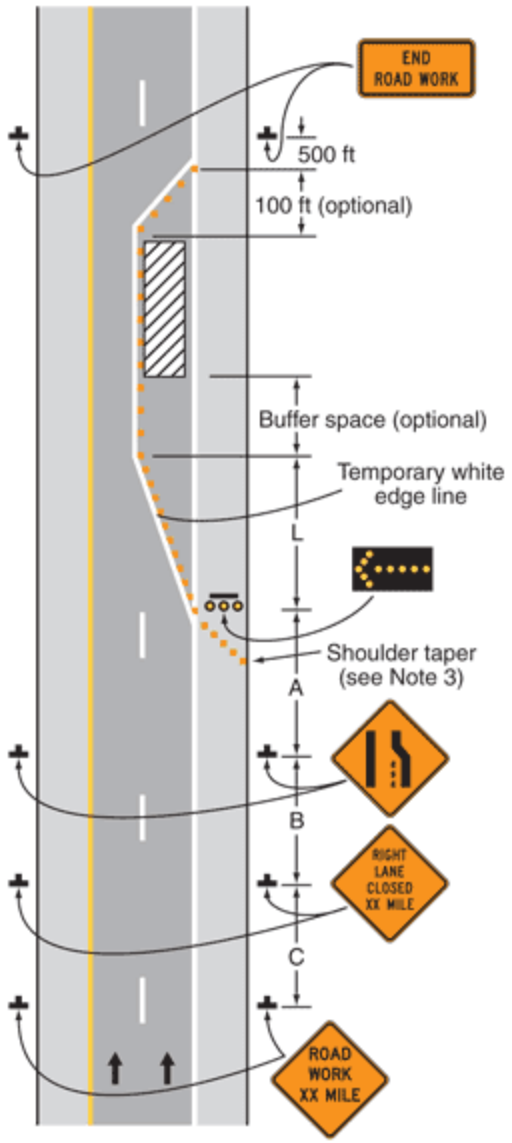

Figure 4-3 MUTCD Typical Application 33 (FHWA 2009)

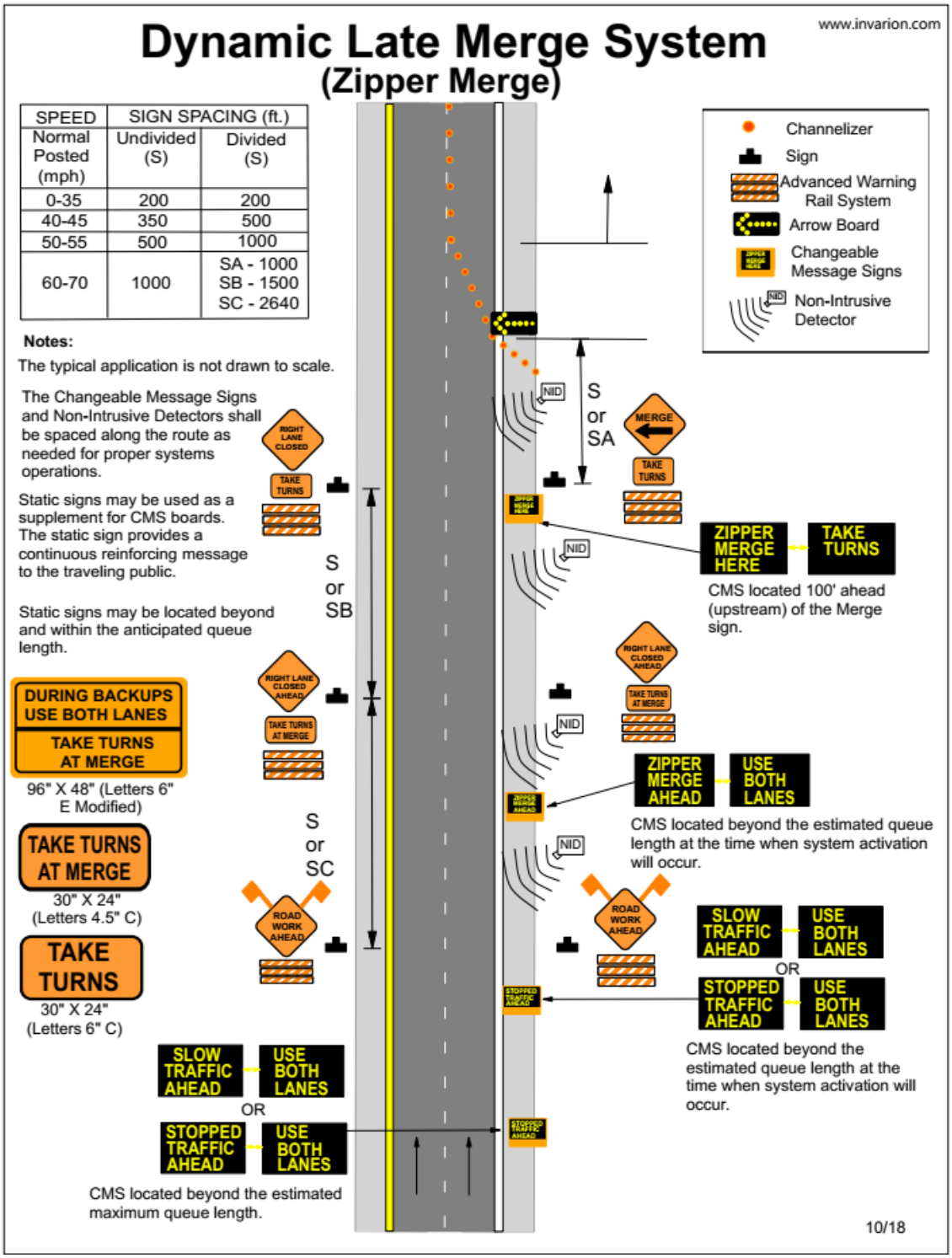

Figure 4-4 MoDOT Zipper Merge (MoDOT EPG 616.13.6.3)

There were four factors that were included in the human subject trials: (1) education, (2), traffic speed, (3), traffic flow, and (4) location of the merge sign with respect to the taper. Education refers to the host explaining to subjects the meaning of zipper merge. Therefore, the sequence of scenarios has to begin with all the pre-education scenarios. All the pre-education scenarios were randomized so that human subjects do not experience the same order. This randomization is often utilized in simulator studies to reduce the influence of learning or sequence bias. All the post-education scenarios were similarly randomized.

Traffic speed refers to the average traffic speed proceeding through the work zone. Two speeds were chosen for testing: 40 mph and 55 mph. An even lower speed would not be useful as such low speeds would not reveal as much since drivers would be constrained by the congested conditions and would not have a choice. Neither would higher speeds be useful since long headways under high-speed conditions would work against the purported benefit of zipper merge or maximizing roadway capacity. Traffic flow refers to the average flow of the background traffic. Two levels of traffic were tested, medium and high. The traffic flow factor is similar to traffic speed in that traffic flow near breakdown or free flow would not be useful. Near breakdown, driver choice is eliminated as vehicles inch toward the taper. At free flow, there would not be enough vehicles taking turns merging at the taper. The goal is to investigate the traffic flow values that could serve as the threshold value for when zipper merge becomes effective. The last factor is the location of the MUTCD-specified arrow board near the taper. The TAC explained that currently there is no clear guidance on the placement of merge arrow sign for zipper merge. The goal is to identify the best location so that the arrow board could best

complement the zipper merge system. These four factors were recommended by the MoDOT TAC as the most useful factors to examine.

The complete number of scenarios required for 4 factors is 2^4 or 16. Due to concerns about an overly long simulator study that could induce simulator sickness, the number of scenarios was reduced down to 12. The scenarios involving after education with slow speeds were not expected to yield interesting data and were eliminated from the study. The driving simulator trial is composed of 12 distinct scenarios. In other words, each human subject drives through 12 separate scenarios. Table 4-1 shows the summary of the 12 scenarios. The scenarios were designed so that only one factor was changed while the rest remained the same. The goal is to clearly discern the driver behavior change due to that one factor alone.

Table 4-1 Simulator Scenarios

Scenario	Education	Speed	Flow	Merge Sign Location
1	pre	55mph	medium	700ft
2	pre	55mph	medium	300ft
3	pre	55mph	high	700ft
4	pre	55mph	high	300ft
5	pre	40mph	medium	700ft
6	pre	40mph	medium	300ft
7	pre	40mph	high	700ft
8	pre	40mph	high	300ft
9	after	55mph	medium	700ft
10	after	55mph	medium	300ft
11	after	55mph	high	700ft
12	after	55mph	high	300ft

Simulator Data Analysis

Simulator Data Reduction Process

Each of the 50 human subjects generated a set of non-personally identifiable data. The data involves multiple types. One is the video recording of the virtual world as the subject navigates through the 12 scenarios. This recording also contains kinematic information on the vehicle driven by the human subject including instantaneous speed and location/distance from the work zone. Another type of data contains the eye tracking information showing the instantaneous location where the pupil is glancing.

Simulator data contains very detailed information on driver behavior at every instant of the human subject trial; therefore, significant labor is required to convert this detailed information into quantitative measures that could be analyzed statistically. The following is an overview of the data reduction process. Due to the labor-intensive nature, there were five research assistants that were trained for this task. A consistent data reduction process was implemented so that the resulting data was uniform among all five research assistants.

Each research assistant reviewed the main simulator file from each subject. The assistant tracked each driver from the beginning of each scenario until the end noting all the critical data measurements at key instances. Figure 5-1 shows a screen capture of the main video display. Vehicle kinematic data such as speed and distance are overlayed onto the driver's field of view. In addition, the location of the pupil glance is also overlayed onto the driver's field of view. Thus, all different types of data are fully synchronized so that at any instant in time, all the details of a driver's behavior is fully known. The Avidemux video player was used for

processing the video files. This player allows very precise control over the time code in the video even down to the millisecond.

Figure 5-1 Example of Video File Snapshot

Several important measurements were taken from the video for each scenario driven by a human subject. One measure is the whether the subject used a turn signal while merging onto the freeway. Figure 5-2 shows the on-screen blinker indication. A measure derived from the eye tracker is whether a subject glanced at the speed limit sign or not. Figure 5-3 shows an example of how the eye tracking software indicates when a subject moved the pupil to glance at the speed limit sign. Similarly, the eye tracking software also indicates if any road work signage was glanced at by the subject. Figure 5-4 shows an example of a driver glancing at the road work sign though it was far away. Even though the pupil was not centered at the sign itself, it was clear that the subject was glancing at the sign by watching how the pupil intentionally moved from the center to the location of the road sign. An important measure is whether or not the subject glanced at the Changeable Message Sign (CMS) instructing on zipper merge. Figure 5-5 shows how a subject glanced at the CMS even though the pupil was not fully centered on the CMS. All the above measures were binary, i.e., yes or no.

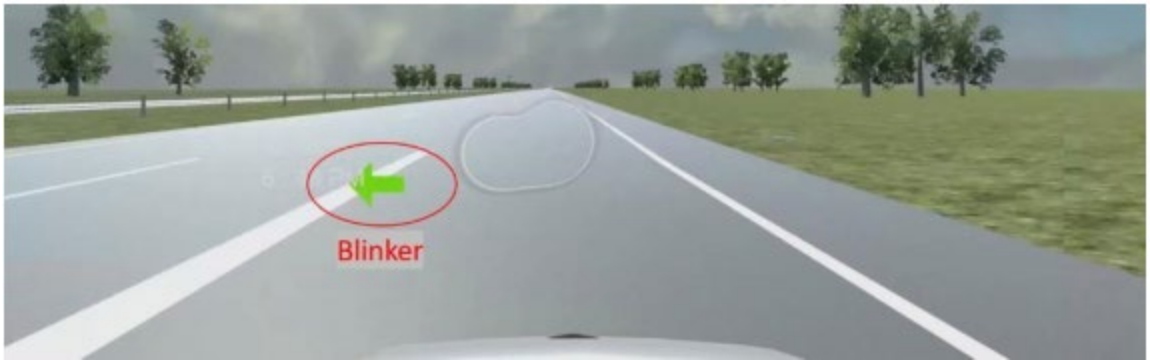

Figure 5-2 Example of Blinker Usage

Figure 5-3 Example of Speed Limit Detection

Figure 5-4 Example of a Glance at Road Work Sign

Figure 5-5 Example of a Glance at CMS

In addition to binary measures, many quantitative measures were recorded related to human subject performance. One important point in driving through a zipper merge work zone is when a subject first uses a blinker while approaching the work zone taper. This is important because it indicates an intention to start the merging maneuver. When the use of the turn signal is detected, all the associated measures are recorded such as the time stamp, car speed, distance from the work zone, and the distance to the trailing vehicle in the open lane, a surrogate for the gap accepted. Another important point is when the vehicle merges to the open lane. The same associated measures are also recorded. Figure 5-6 shows an example of the quantitative measures relevant to the initiation of the merge maneuver. The example shows the time stamp at merge maneuver as 00:04:43.433, a vehicle speed of 52 mph, the distance from the work zone as 185 feet, and the distance to the trailing vehicle as 23 feet. All the aforementioned measures were used to assess the effectiveness of various treatments at a zipper merge; the critical result being whether a subject complied with the zipper merge instructions by merging near the taper.

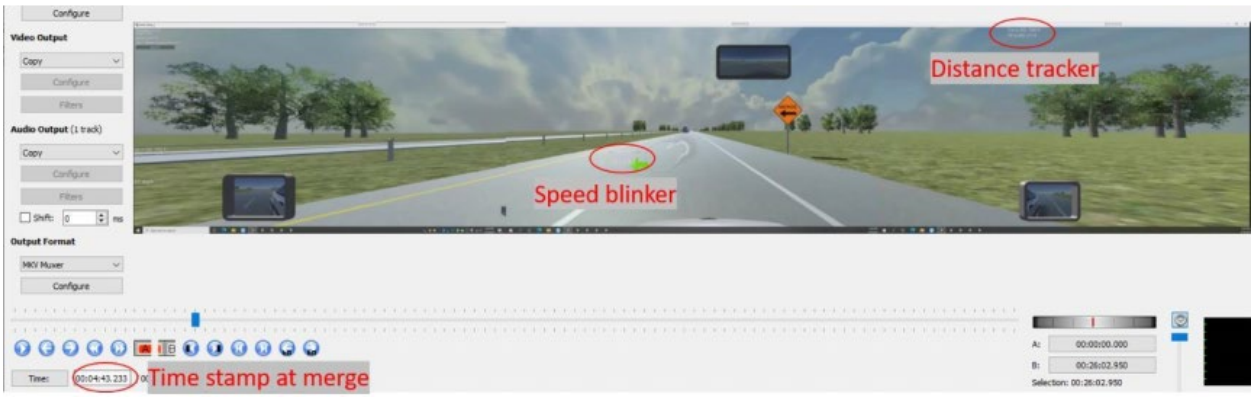

Figure 5-6 Example of Measures Relevant to Signaling

Simulator Data Results

In analyzing the results pertaining to each of the four factors, all the scenarios were grouped together except for the relevant factor. For example, all the pre-education scenarios were grouped together, and all the post-education scenarios were grouped together. Thus, a comparison was made between pre- and post-education. Recall that Table 4-1 Simulator Scenarios lists the various scenarios tested for each human subject. These scenarios reflect the four factors of education, speed, traffic flow, and location of the merge arrow sign. The results for each factor are presented in tables in similar formats. The explanations for the rows are as follows. Three rows involve the average values; two rows are the averages of the factor, and the third row is the difference between the two values. For example, the first row is the average value of the pre-education condition, and the second row is the average value of the post-education condition. A third row presents the difference between the two conditions. The next three rows involve standard deviations. For example, the first row is the standard deviation of the pre-education condition, and the second row is the standard deviation value of the post-education

condition. A third row presents the ratio between the two standard deviations. The last row is the examination of the statistical significance in the difference between the two averages.

The columns represent the quantitative measures of driver behavior at various points along the drive to a work zone. The “at first blinker” column refers to the moment when a driver first uses the blinker, presumably to start a lane change maneuver from the closed to the open lane. The speed refers to the instantaneous speed of the vehicle. The distance is with respect to the work zone. The headway is the distance between the subject vehicle and the trailing vehicle in the open lane; it is related to the gap accepted by the human subject when merging to the open lane. The measures of speed distance and headway are defined the same for all three points, i.e., at first blinker, at merge, and at taper. The “at merge” columns refer to the start of the actual merging maneuver. The “at taper” columns refer to the arrival at the work zone.

Pre- Versus Post-Education

The comparison between pre- and post-education shows clearly the effect of education on zipper merge behavior. The post education vehicle speed increased by 6.3 mph (p=0.00) at the first use of the blinker, 6.14 mph (p=0.00) at merge, and 7.56 mph (p=0.00) at passing of work zone. The p-value presented in the parenthesis is the significance level or reciprocal of the confidence level. So, for example, a p-value of 0.001 is equivalent to having a 99.9% statistical confidence. The increase in speed appears to be desirable as an indication that drivers understand that they could reach the taper in order to merge into the open lane instead of merging early into the traffic stream. As highlighted in Table 5-1, the difference in distance at the first blinker use and at merge were 570 feet (p=0.00) and 747 feet (p=0.000). In other words, drivers signaled and

merged much closer to the taper after education. This decrease in distance is desirable for zipper merge as it results in the greater use of the capacity of the open lane.

The variability in the distances also decreased between pre- and post-education. The standard deviation of distance decreased from 1502 feet to 1225 feet at first blinker and from 1572 feet to 1231feet at merge. A decrease in the standard deviation means that there is less driver variability or more uniformity among drivers after education. Headways between the subject vehicle and the trailing background traffic increased at all three points by 14 feet (p=0.09), 9 feet (p=0.15), and 4.6 fee (p=0.28). The headway results provide evidence that drivers used larger gaps after education, though the p-values are not very small, i.e., less statistical confidence.

The result that education significantly improved driver behavior at zipper merges demonstrates the importance of having an effective educational campaign. Conversely, the results caution against trusting that drivers who are unfamiliar with zipper merge to fully comply with the zipper merge sign package. Because drivers follow the behavior of nearby drivers, even the education of a subset of drivers can help to improve the overall behavior at zipper merges.

Table 5-1 Comparison Between Pre- and Post-Education

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	pre	52.75	2027.70	151.41	50.74	1833.62	145.13	47.60	136.51
	post	59.05	1457.41	165.33	56.88	1086.70	154.13	55.16	141.13
	diff	-6.30	570.29	-13.92	-6.14	746.92	-9.00	-7.56	-4.62
dev	pre	9.72	1502.38	104.92	9.71	1572.46	97.39	9.86	88.93
	post	8.11	1225.39	113.86	10.16	1231.39	100.08	9.40	91.79
	ratio	1.20	1.23	0.92	0.96	1.28	0.97	1.05	0.97
t-test		0.00	0.00	0.09	0.00	0.00	0.15	0.00	0.28

Pre-Education Comparison Between 55 mph and 40 mph

The pre-education comparison between 55 mph and 40 mph background traffic did not result in any interesting differences. The quantitative results are shown in Table 5-2. The statistically significant decreases in speeds at the first blinker (7.6 mph/p=0.00), at merge (7.9 mph/p=0.00), and at taper (13.8/p=0.00) are all function of the large difference in background traffic speeds between 55 mph and 40 mph. In other words, drivers were simply driving close to the speed of the traffic. The small difference in distances 68.8 feet (p=0.34) and 64.2 feet (p=0.34) were not statistically significant. The lack of significant differences between the 55 mph and 40 mph scenarios could be an indication that zipper merge could operate well under various speeds and that another traffic parameter, such as traffic flow, could be a better threshold for switching between early and late merge behaviors.

Table 5-2 Pre-Education Comparison, 55 mph and 40 mph

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	55 mph	56.62	2062.51	154.17	56.01	1801.50	152.45	54.50	131.35
	40 mph	48.97	1993.72	148.72	45.47	1865.73	137.82	40.70	141.67
	diff	7.65	68.79	5.44	10.54	-64.23	14.63	13.80	-10.32
dev	55 mph	7.78	1566.88	99.51	7.93	1580.17	93.82	7.07	77.41
	40 mph	9.93	1464.50	108.64	8.15	1585.32	97.19	6.44	99.05
	ratio	0.78	1.07	0.92	0.97	1.00	0.97	1.10	0.78
t-test		0.00	0.34	0.32	0.00	0.34	0.07	0.00	0.12

Pre- and Post-Education Comparison Between Medium and High Traffic

Two traffic flow levels were selected based on literature and in-house testing of the simulators. For the 55 mph scenarios, the medium traffic flow was approximately 700 vehicle

per hour per lane, and the high traffic flow was approximately 1400 vehicles per hour per lane. For the 40 mph scenarios, the medium traffic flow was approximately 500 vehicle per hour per lane, and the high traffic flow was approximately 1000 vehicles per hour per lane. The low flow or free flow scenario is uninteresting and not tested because there is not enough traffic to zipper merge.

The quantitative results for pre-education are presented in Table 5-3 and the results for post-education is presented in Table 5-4. For pre-education, there is very little difference (p=0.32 at first blinker and p=0.29 at merge) in driver compliance with zipper merge at either traffic level. The distance at merge was far from the taper near 2000 ft away. At both traffic levels, the distance at merge was much shorter post-education at around 1000 ft, although the difference between the traffic levels was not statistically significant (p=0.22 at first blinker and p=0.30 at merge). This result seems to indicate that zipper merge operates well at both traffic levels as long as the public is properly educated.

The headways differed significantly between medium and high traffic for both pre- and post-education conditions. For pre-education, the headway differences were 101 feet (p=0.00) at first blinker, 94 feet (p=0.00), and 84 feet (p=0.00) at taper. For post-education, the headway differences were 137 feet (p=0.00) at first blinker, 132 feet (p=0.00), and 119 feet (p=0.00) at taper. These differences can be attributed to the difference in traffic level and do not necessary yield any insights into improvements in driver behavior. In other words, the space headways result from the open lane gaps which are directly related to the inverse of the flow rate or the time headways. Thus, the headway measure reflects the traffic flow demand and is not very informative about driver behavior.

Table 5-3 Pre-Education Comparison, Medium and High Traffic

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	medium	54.74	1988.37	202.57	51.92	1789.61	192.39	47.88	178.61
	high	50.81	2066.08	101.48	49.56	1877.18	98.34	47.31	94.83
	diff	3.93	-77.70	101.09	2.36	-87.58	94.05	0.58	83.79
dev	medium	7.69	1464.95	117.16	8.90	1556.30	109.88	9.52	98.60
	high	11.04	1541.48	57.83	10.33	1590.99	50.47	10.20	51.41
	ratio	0.70	0.95	2.03	0.86	0.98	2.18	0.93	1.92
t-test		0.00	0.32	0.00	0.01	0.29	0.00	0.28	0.00

Table 5-4 Post-Education Comparison, Medium and High Traffic

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	medium	59.67	1384.45	234.48	57.52	1041.54	220.48	55.82	200.54
	high	58.39	1534.77	97.71	56.17	1134.21	88.46	54.54	81.51
	diff	1.29	-150.33	136.77	1.35	-92.67	132.02	1.28	119.03
dev	medium	8.51	1207.00	115.29	10.33	1215.84	93.53	9.56	87.76
	high	7.75	1246.15	61.00	10.04	1251.22	51.63	9.15	45.57
	ratio	1.10	0.97	1.89	1.03	0.97	1.81	1.04	1.93
t-test		0.15	0.22	0.00	0.17	0.30	0.00	0.17	0.00

Pre and Post-Education Comparison Between 700 Feet and 300 Feet CMS Placement

The 700ft means the distance between CMS and taper/arrow board is 700ft, and 300ft means CMS is 300ft away from taper/arrow board. According to MoDOT's zipper merge guidance (MoDOT EPG 616.13.6.3) the merge sign should be placed within a distance of 1000 feet from the arrow board at the taper for roads with posted speed limits of between 60 and 70 mph. And the zipper merge CMS closest to the work zone should be located 100 feet ahead of the merge sign. Since there is discretion on where the merge sign is placed, this same discretion extends to the location of the CMS. In the simulator study, two different placements of the CMS, at 700 feet and 300 feet, were tested.

For the pre-education condition, there does not appear to be significant differences between the 700 feet and 300 feet CMS placements. The confidence levels are around 85% or lower for all quantitative results. However, there are statistically significant difference under the post-education condition where the distance decreased at first blinker by 295 feet (p=0.06) and at merge by 236 feet (p=0.09). Even though the magnitudes in the differences are not large, it represents some evidence that placing the CMS closer to the taper improves zipper merge behavior. Therefore, the recommendation is for the zipper merge system to locate the CMS closer to the taper.

Table 5-5 Pre-Education Comparison, 700 ft and 300 ft

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	700 ft	53.36	2065.28	146.64	50.77	1905.70	140.28	48.06	131.93
	300 ft	52.13	1989.66	156.24	50.71	1762.24	149.94	47.13	141.04
	diff	1.22	75.62	-9.59	0.06	143.46	-9.66	0.93	-9.12
dev	700 ft	8.99	1445.16	105.99	9.89	1542.09	97.99	9.68	87.94
	300 ft	10.40	1561.68	103.93	9.54	1602.62	96.80	10.05	89.89
	ratio	0.86	0.93	1.02	1.04	0.96	1.01	0.96	0.98
t-test		0.13	0.32	0.20	0.47	0.18	0.16	0.17	0.15

Table 5-6 Post-Education Comparison, 700 ft and 300 ft

		At First Blinker			At Merge			At Taper	
		Speed	Distance	Headway	Speed	Distance	Headway	Speed	Headway
mean	700 ft	59.14	1604.47	172.73	57.50	1206.00	156.88	56.11	144.02
	300 ft	59.22	1309.29	156.48	56.37	970.38	151.46	54.34	138.38
	diff	-0.07	295.18	16.25	1.13	235.62	5.42	1.77	5.64
dev	700 ft	8.49	1299.53	116.41	10.19	1292.70	100.83	9.11	92.75
	300 ft	7.67	1143.23	112.43	10.22	1172.50	100.68	9.57	92.07
	ratio	1.11	1.14	1.04	1.00	1.10	1.00	0.95	1.01
t-test		0.48	0.06	0.18	0.22	0.09	0.35	0.09	0.33

Human Subject Survey Results

Each human subject that participated in the simulator trial was given a post-simulator survey. The survey is complementary to the simulator study. Instead of observing driver behavior, drivers were asked directly to give their preferences for different aspects of zipper merge such as signage and operating conditions. Open-ended questions allow subjects to explain their answers further, giving more insights into the reasons for the answers. The full survey is included as Appendix E. The following are discussions on the survey results and the related insights into zipper merge operations.

Introductory and Education Questions

The first question involves assessing human subject familiarity with zipper merge. As shown in Figure 6-1, the percentage of respondents that was not familiar with zipper merge (choices 1 or 2) was ~60%. Thus, a majority of the respondents answered the survey from a fresh perspective.

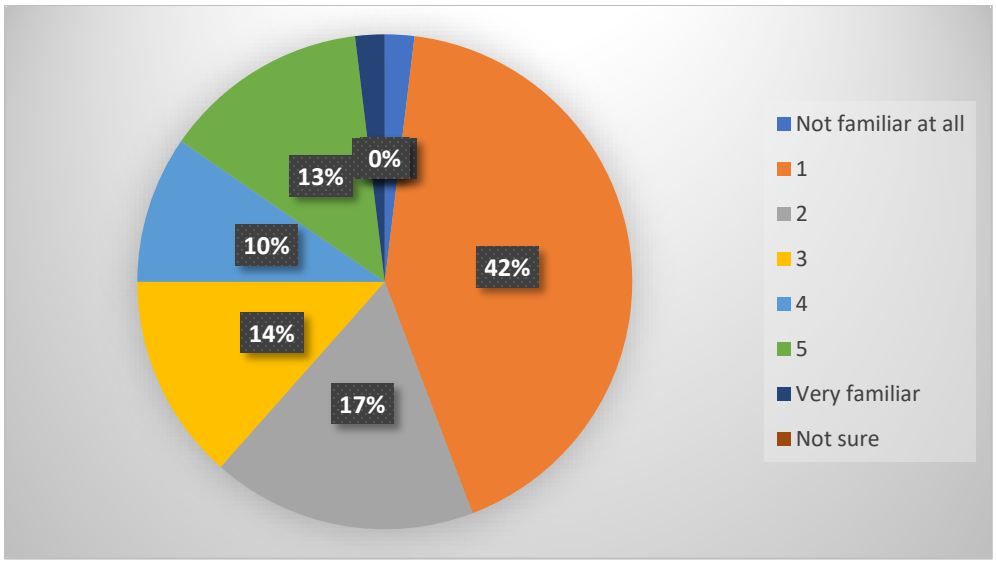

Figure 6-1 Zipper Merge Familiarity

Questions 2 and 3 related to a simple written explanation of zipper merge that includes a sentence description and a diagram (Figure 6-2). The sentence says, "zipper merge means drivers fill both lanes and take turns merging every other car at the point of the lane closure, so that we could fully utilize the road capacity and enhance efficiency." The percentage of respondents that said the zipper merge explanation was helpful was over 96% (answers 4 and 5). The percentage that said the zipper merge explanation enabled the proper understanding of zipper merge behavior was over 94% (answers 4 and 5). The results from Questions 2 and 3 show that a simple description can be effective for explaining zipper merge operations.

Figure 6-2 Zipper Merge Explanation

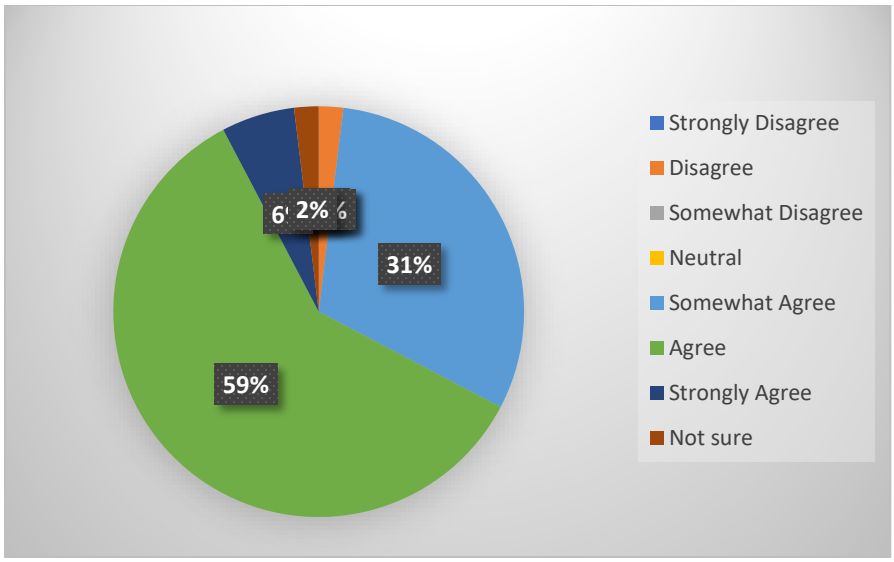

Figure 6-3 Helpfulness of Zipper Merge Explanation

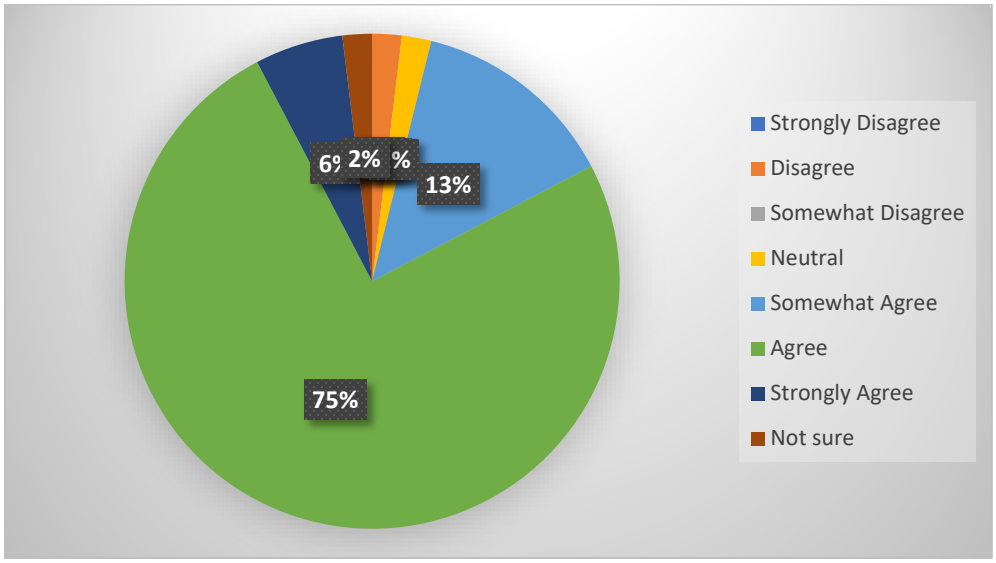

Figure 6-4 Understanding of Zipper Merge Explanation

Questions 4 and 5 related to an instructional video produced by the Minnesota Department of Transportation (MNDOT) that is shown to subjects. Figure 6-5 is a screen capture of the opening scene of the two-minute-long instructional video. This is a non-narrated video that uses field scenes of traffic conditions with and without zipper merge. Scenes are labeled using large letters at the bottom of the screen. When zipper merge is not used (e.g., Figure 6-6) the scenes show how traffic backs up when only a single lane is used. Several scenes show how zipper merge is implemented using changeable message signs that indicate there is a merge ahead and to use both lanes. When zipper merge is used (e.g., Figure 6-7) the scenes show how both lanes are fully utilized leading to smoother and safer operations.

Figure 6-5 MNDOT Zipper Merge Instructional

Figure 6-6 Without Zipper Merge

Figure 6-7 With Zipper Merge

Question 4 asks about the helpfulness of the video and Question 5 asks about driver understanding of zipper merge. The percentage of respondents that agreed with the video's helpfulness was over 86% (see Figure 6-8). The percentage of respondents that agreed that the video enabled understanding of zipper merge was over 90% (see Figure 6-9). Questions 4 and 5 show that a simple two-minute video can help improve public understanding of zipper merge. Question 6 asks respondents to compare between the video and the written information. As shown in Figure 6-10, over 70% of the respondents prefer the video to the written material, even though the overwhelmingly positive response of the simple written educational material (96%) was even better than the response to an educational video (86%). More discussions on educational material will be presented in a subsequent dedicated chapter.

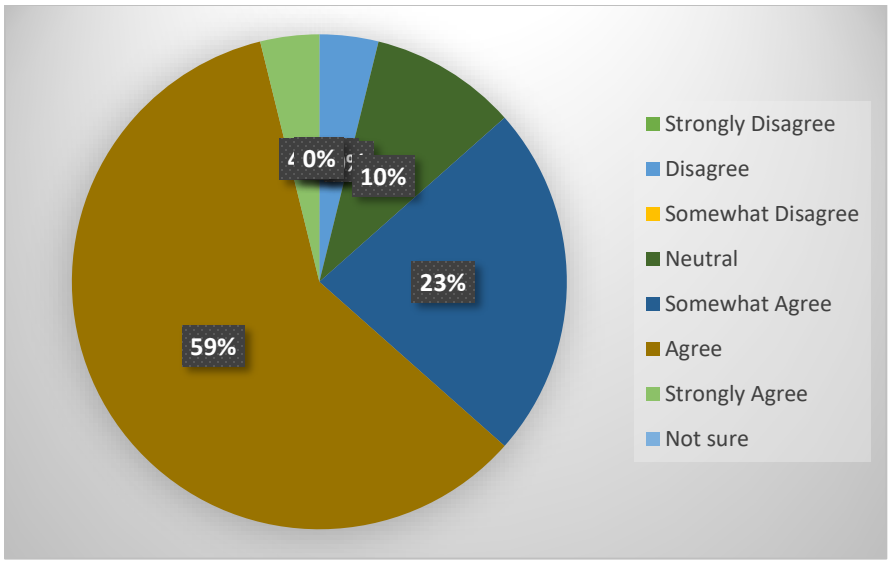

Figure 6-8 Video Helpfulness

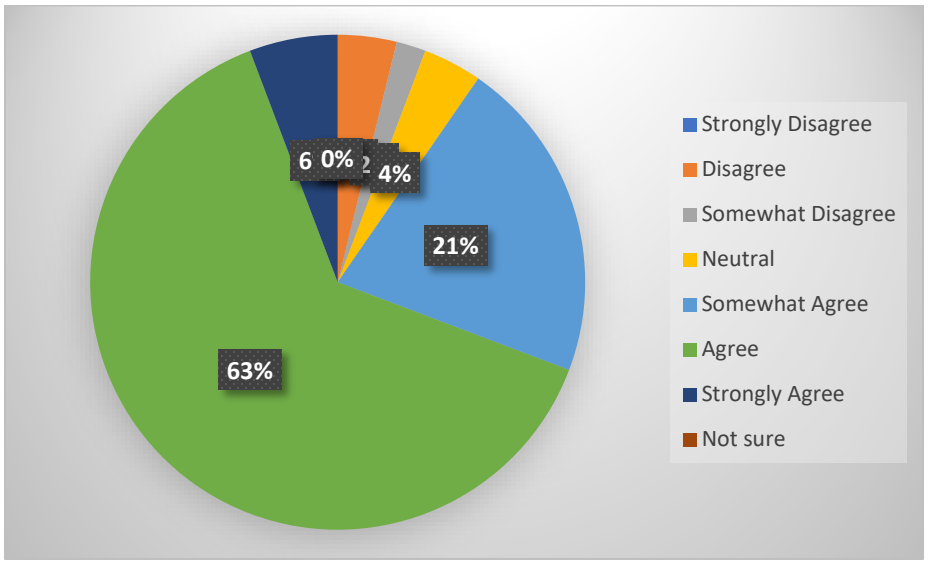

Figure 6-9 Video Understanding

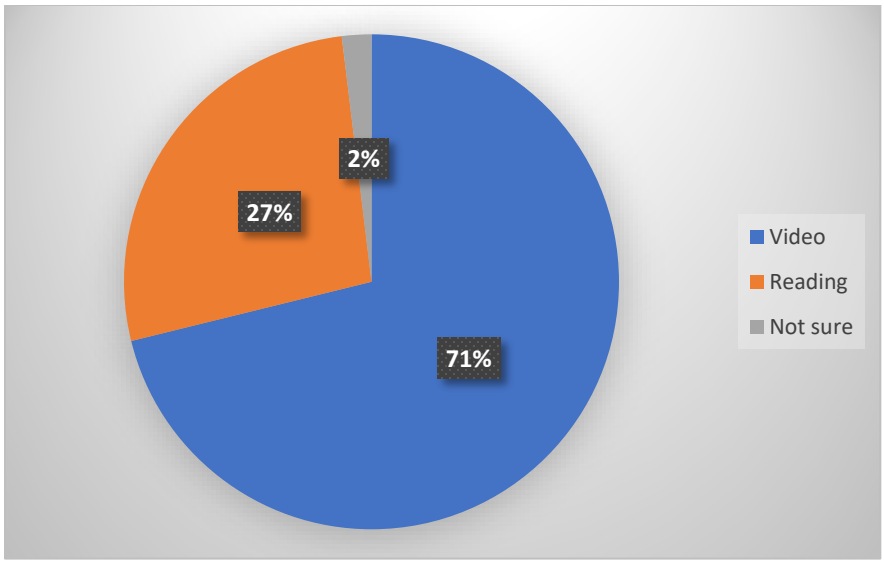

Figure 6-10 Educational Material Preference

Operational Conditions

Questions 7 through 9 concerns operational conditions and user anxiety. Question 7 (Figure 6-11) asks respondents to state the preference for the speed at which zipper merge should be implemented. Over 80% selected the lower speed of 40 mph instead of 60 mph. Question 8 (Figure 6-12) is about respondent preference for the traffic condition for deployed zipper merge. Over 70% preferred high traffic volumes. The responses to Questions 7 and 8 show that drivers have good intuition for when zipper merge should be utilized, i.e., under low speed and high traffic conditions. Question 9 (Figure 6-13) asks if zipper merge causes anxiety at a work zone, and only a little over 30% indicated that they felt anxious.

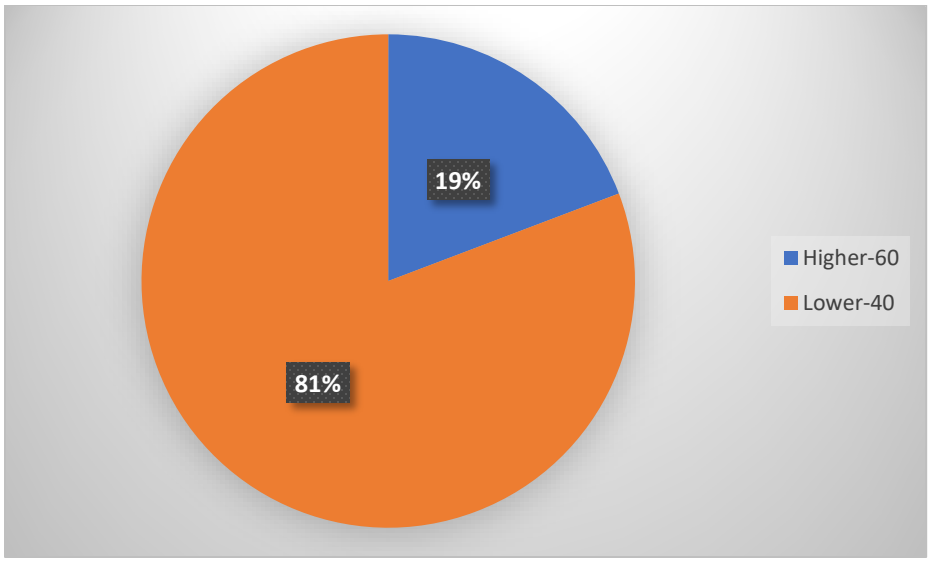

Figure 6-11 Traffic Speed

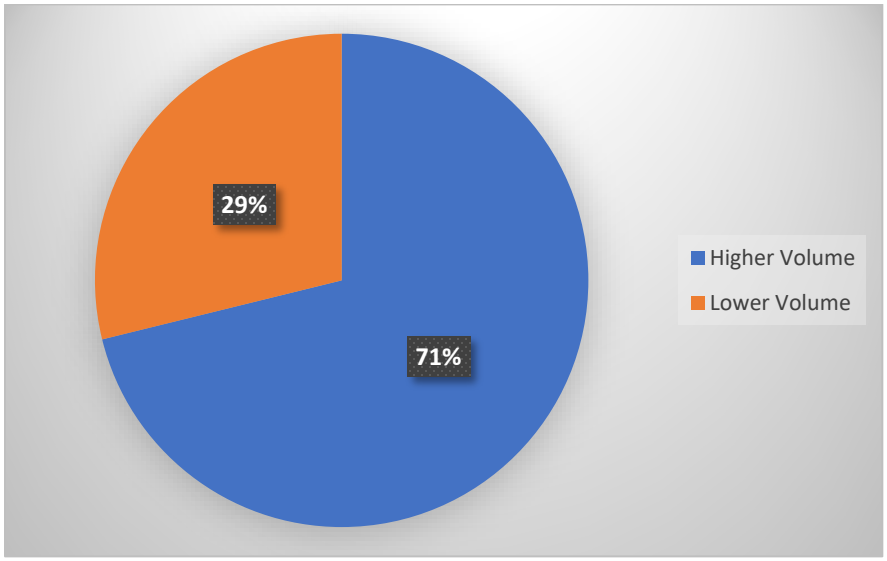

Figure 6-12 Traffic Volume

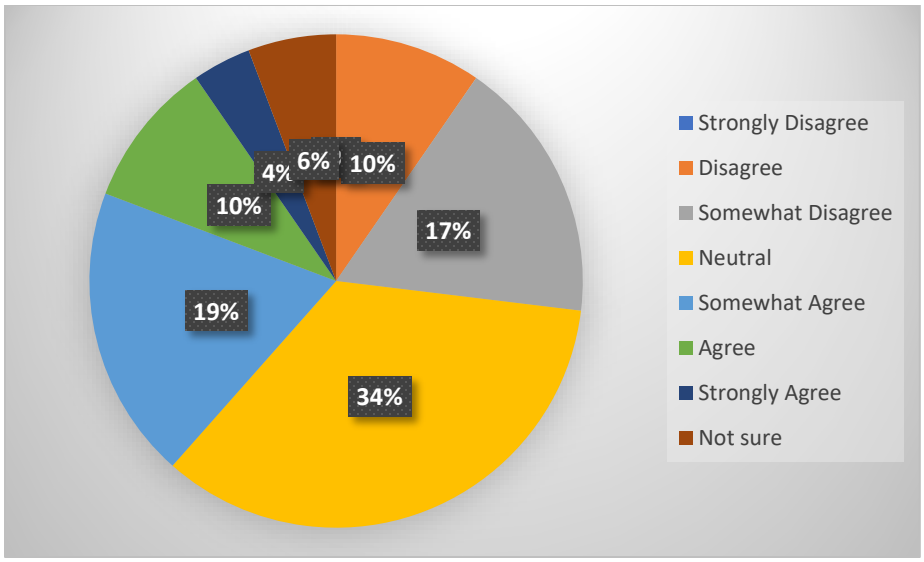

Figure 6-13 Driver Anxiety

Zipper Merge Signage

The review of multiple state departments of transportation showed that different signage options are currently used for implementing zipper merge. Variations on wording of signs occur for signage at different points while approaching the work zone taper. A series of questions asks a driver to imagine he or she is approaching the work zone and to indicate the preferred signage from the options shown. For each question, the MUTCD typical application signage deployment is shown along with a yellow vehicle approaching the work zone (see Figure 6-14). Question 10 asks drivers to indicate their preference for the signage at the work zone beginning. The two options are shown in Figure 6-15. Over 68% of the respondents preferred option B.

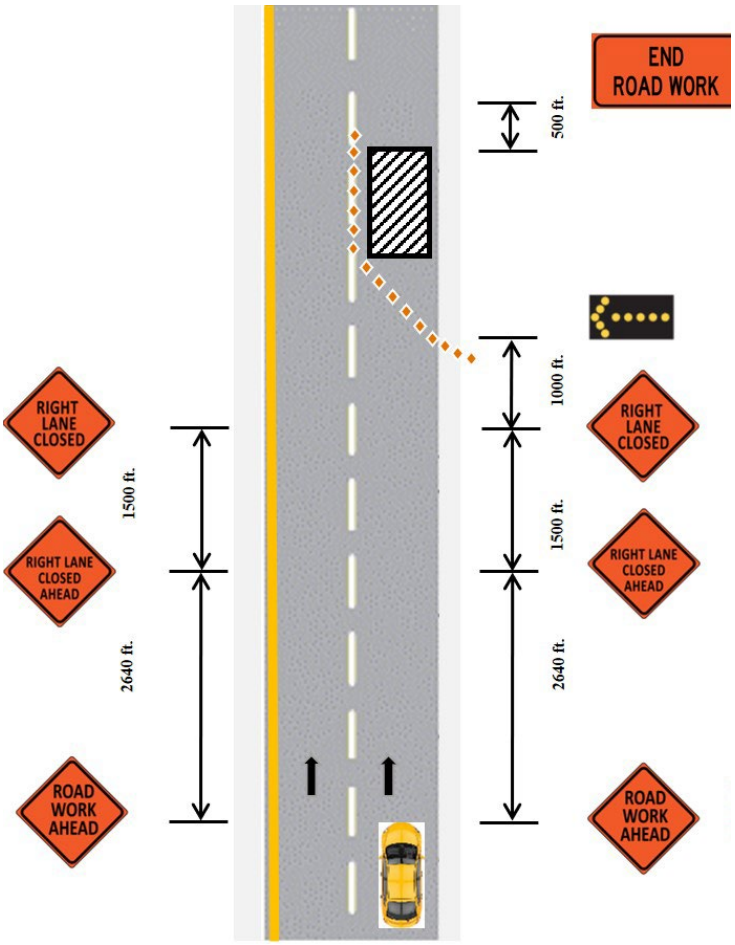

Figure 6-14 MUTCD Work Zone Setup

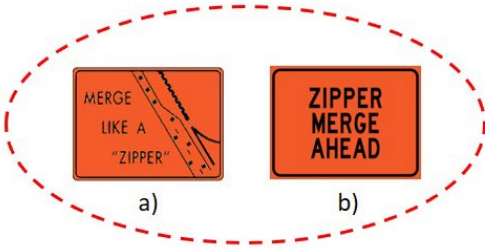

Figure 6-15 Signage at Work Zone Beginning

Question 11 involved three sign options on the way to the work zone as shown in Figure 6-16. The three signs are almost equally preferred with 36% for option A, 26% for option B, and 38% for option C. Option C is a static sign specified in MoDOT EPG 616.13.6.3. Question 12

asks respondents to declare how they would behave after observing Option C. The responses were 10% for merge now, 42% for merge when reaching the work zone, 26% for following everyone else, and 22% for not understanding the sign. Even though 42% selected the correct response, it is concerning that 10% chose merge now and 22% did not understand the sign. These responses point to the importance of educating the public. Question 13 asks respondents to declare how they would behave after observing a changeable message sign (CMS) with the messages "MERGE AHEAD" and "USE BOTH LANES". The responses were 28% for merge now, 58% for merge when reaching the work zone, 12% for following everyone else, and 2% for not understanding the sign. There was a higher percentage of the correct answer for the CMS sign (Question 13) compared to the static sign (Question 12). Question 14 asked respondents to compare the static and the CMS sign. Seventy-two percent preferred the CMS compared with the static sign.

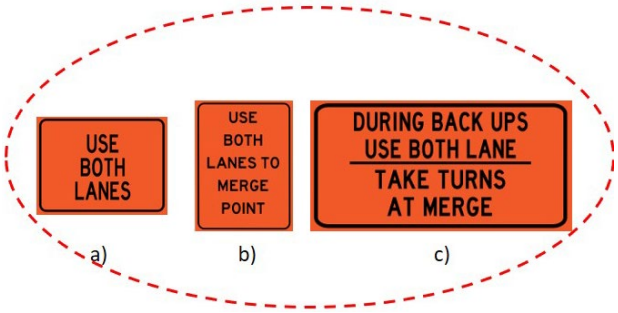

Figure 6-16 Signage on the Way to Work Zone

Question 15 asks about driver preference between two signs at the start of the taper as shown in Figure 6-17. The preference was equally divided between the two signs. Question 16 asked respondents to compare between a static and a CMS sign. The preference for the CMS sign was slightly higher (48.1%) than the static sign (42.3%). Question 17 asks whether the

zipper merge concept is a good idea, and over 82% agreed that it was a good idea as shown in Figure 6-19.

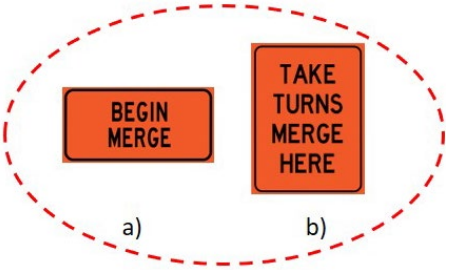

Figure 6-17 Signage at the Taper

Figure 6-18 Static vs. CMS Sign

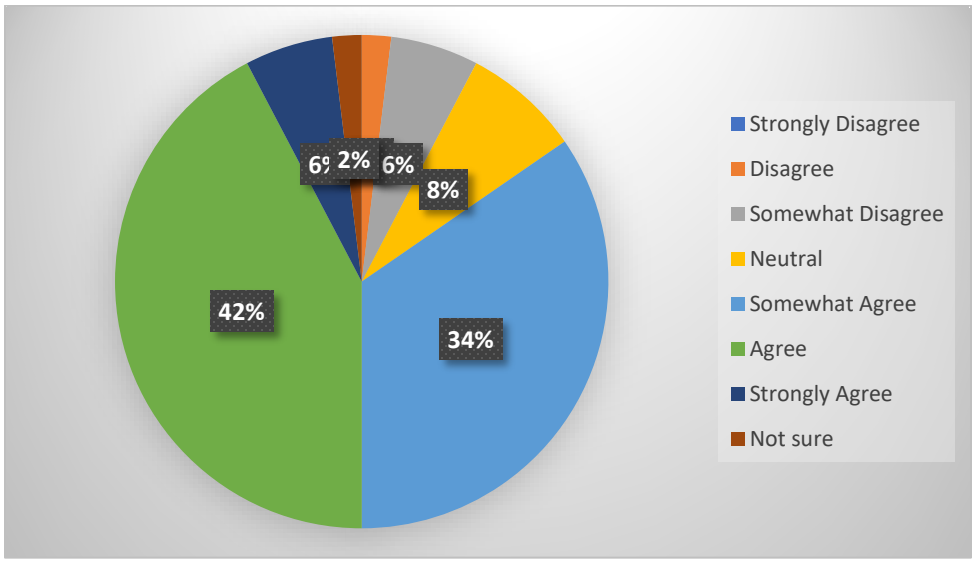

Figure 6-19 Zipper Merge is a Good Idea

Fidelity and Demographics

Questions 18 through 20 relate to simulator fidelity. These questions are typically included to confirm the validity of driving simulators. Question 18 asked if the drivers felt like they were actually driving on a highway. A large majority, 64% agreed, while only 23% disagreed. Question 19 asked if drivers could drive around freely. Forty-six percent agreed while 29% disagreed. Question 20 asked if drivers encountered any problems. Over 67% reported no problems. It is unclear why the results from all three questions are lower than the results from previous surveys that utilized the ZouSim driving simulator. One possible reason is the set of complications arising from the COVID-19 pandemic. One complication is the complete shutdown of the ZouSim lab. Restarting the simulator involved recalibration of various hardware components including the driving wheel, the projection screens, and the overall lab setup. Another complication involved the recruitment of human subjects. Due to the difficulty in recruiting subjects, it was difficult to obtain a sample representing a wide range of population demographics. Furthermore, it is unknown if the subjects' frame of mind was affected by challenges of being quarantined and subject to various health restrictions for a long time. The investigation of the psychological and social impacts of COVID-19 is beyond the scope of this project. Another complication is the issue of the steering wheel. The fine-tuning of the steering wheel is extremely important for achieving a high level of simulator fidelity. If the steering is not sensitive enough, then the vehicle will seem to be lagging to driver input. But if the steering is too sensitive, then oversteering could become a problem.

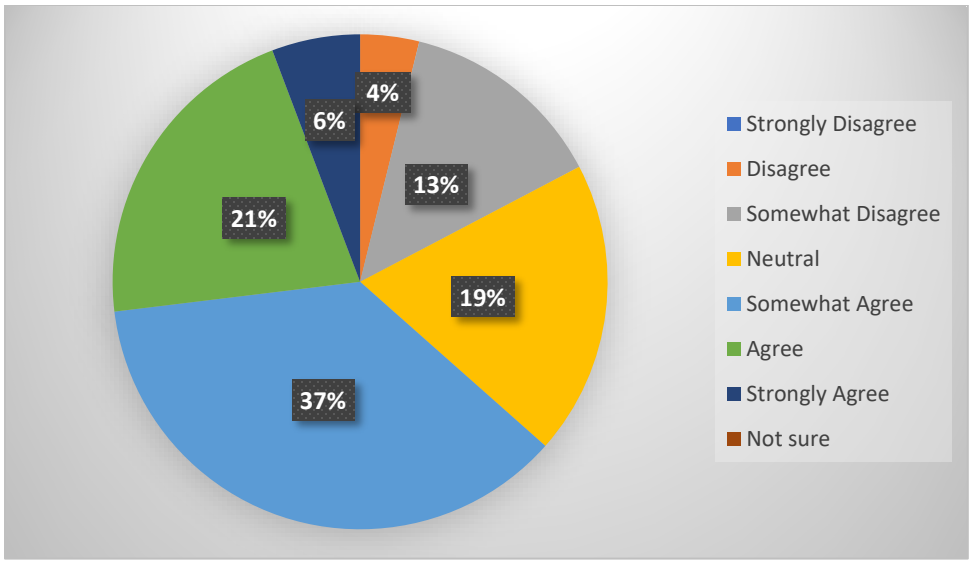

Figure 6-20 Felt Like Highway

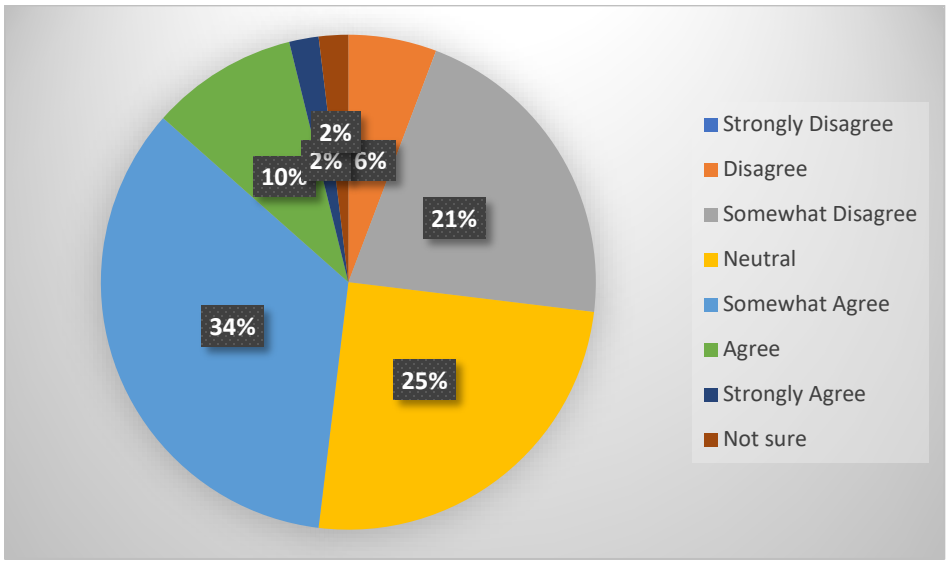

Figure 6-21 Could Drive Freely

Questions 21 through 24 involve respondent demographics. As shown in Figure 6-22, the age distribution of the subjects was skewed towards younger drivers. The age distribution was most likely affected by COVID-19 where the older population were more concerned about exposure and risk and were less willing to participate. The gender distribution was fairly balanced with 55% male and 45% female. Subjects were mostly urban (78%) with 22% rural.

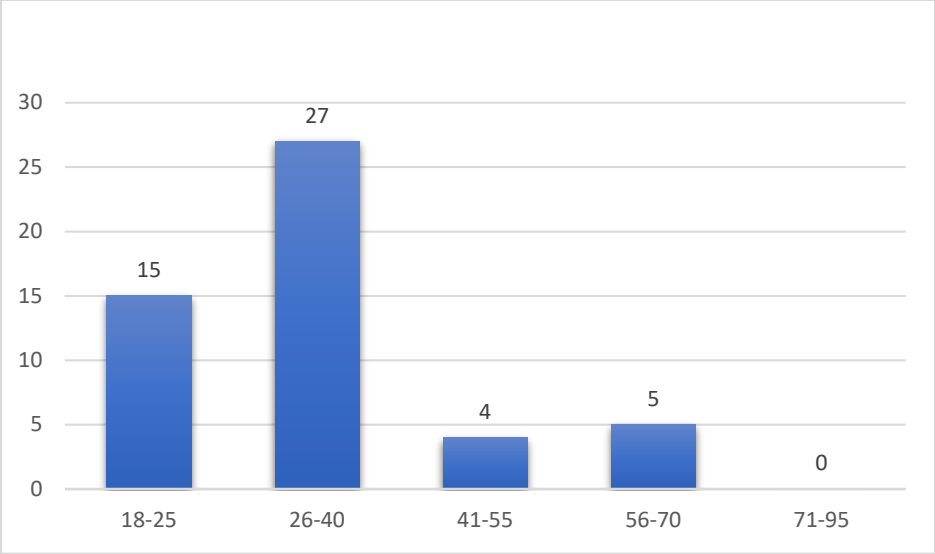

Figure 6-22 Age Distribution

Zipper Merge Education

Educational Material Literature Review

Various entities such as public agencies and news media have generated educational material on the zipper merge. A popular type of educational media is a video. For example, MoDOT produced a video featuring kids educating adults, and MnDOT uses a video to show what to do and not to at when approaching a work zone taper. The news media has also been a partner in educating the public about zipper merge. Local news stations produce short segments explaining zipper merge operations while capturing driver perspectives. Even educational YouTube channels get into the act of making zipper merge videos. There are too many videos to list them exhaustively in this report. Some videos have similar characteristics, such as providing videos of field conditions or the use of graphics for illustrating merging behaviors. News or YouTube channels tend to embed video clips from DOT educational videos. The goal of this chapter is to review enough educational materials to offer recommendations to MoDOT for the types of materials that would be the most effective.

The following are examples of zipper merge educational videos. Figure 7-1 shows a screen capture of a Public Service Announcement (PSA) for educating on zipper merge. As seen in Figure 7-1, this three-minute-long video is a joint effort between MnDOT and the MN State Patrol. They start with the phrase, "Right Thing to Do?" And they go on explaining the proper driving behavior as well as the benefits of zipper merge.

https://www.youtube.com/watch?v=vLVMW8KnfBE

Figure 7-1 MnDOT Public Service Announcement

Figure 7-2 shows a screenshot of a minute-long educational video produced by WSDOT. This narrated video uses animated vehicles to illustrate the desired merging behavior.

https://www.youtube.com/watch?v=0ypWx8PEFXI

Figure 7-2 WSDOT Educational Video

Figure 7-3 shows a screenshot of an approximately two-minute-long video educating on zipper merge. A unique character of this video produced by MoDOT is the use of kids and adults in cardboard cars simulating behavior at zipper merge.

https://www.youtube.com/watch?v=TLAISm1XuHQ

Figure 7-3 MoDOT Educational Video Using Humor

Figure 7-4 shows a screenshot of a three-and-a-half-minute long local news report on zipper merge in the Grand Rapids area. As is common in news reports, local residents are asked about their perspectives on traveling through a zipper merge.

https://www.youtube.com/watch?v=36L_Ld6CB5Y

Figure 7-4 Local News Report

Figure 7-5 shows a screen capture of a video produced by the channel Cheddar. The website seeks to answer various questions of public interest. The channel uses clips from various sources, including news clips, to explain the zipper merge background, rationale, and operations. This four-and-a-half-minute long video is one of the longer educational videos.

https://www.youtube.com/watch?v=35byJxDIX88

Figure 7-5 Example of YouTube Channel

Even car sellers get into the act of producing educational videos. Figure 7-6 shows a screenshot of a video produced by the cars.com website which is a marketplace for buying and selling vehicles. This one-minute-and-a-half long video uses clips, such as a MNDOT animation, to discuss driver behavior in the zipper merge area.

https://www.youtube.com/watch?v=X0dGyG1tqHM

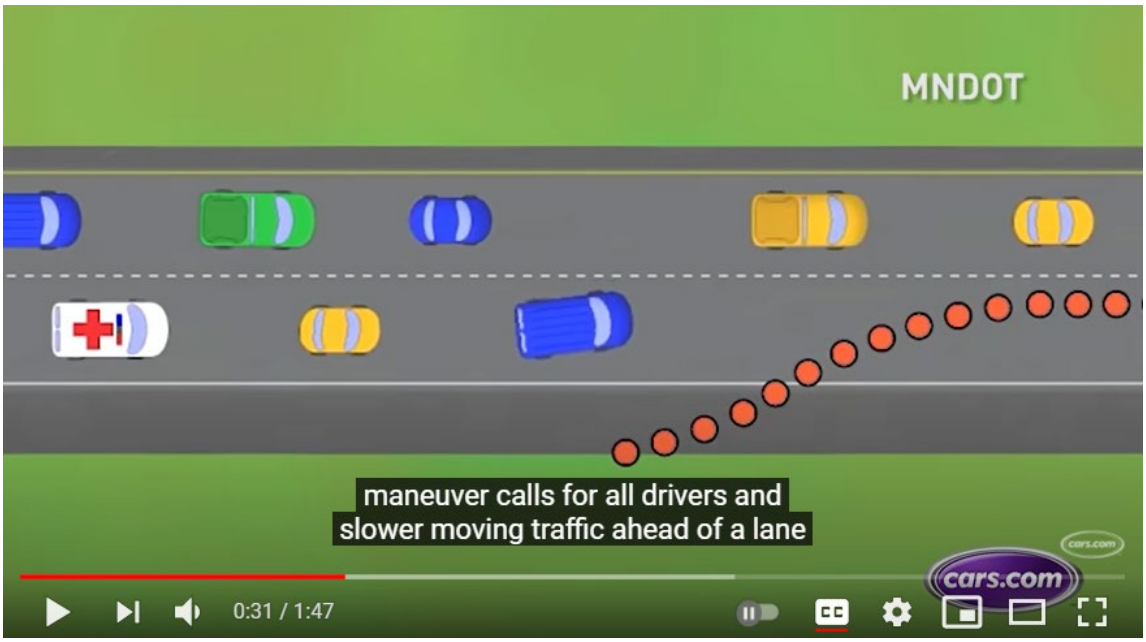

Figure 7-6 cars.com Driving Video

Other educational materials include web pages, guidebooks, and other social media. DOTs have web pages dedicated to explaining the zipper merge (e.g. MoDOT's Zipper Merge page https://www.modot.org/zipper-merge). FHWA provides a guidebook to help educate agencies on work zone best practices such as the use of the zipper merge (FHWA, 2013). DOTs also utilize other social media such as Facebook and Twitter using hashtags such as #MergeLikeAZipper and #TakeTurns.

Examining Educational Materials Using Behavioral Science

Behavioral science strategies, such as social norms, positive framing, and negative framing, were used to evaluate educational material. Behavioral science has been used to encourage tax compliance (Cialdini, Martin, & Goldstein, 2015), increase energy efficiency behavior (Allcott & Mullainathan, 2010), and reduce cybersecurity risk (Pfleeger & Caputo, 2012). Across these scenarios, researchers are able to leverage behavioral theories to design

communications that encourage desirable behaviors. An example of social norms language (i.e., emphasizing the desired behavior is normal) is "Use Both Lanes to Help All." An example of positive framing language (i.e., focus on achieving positive outcome) is "Travel Faster Use Both Lanes." An example of negative framing language (i.e., focus on avoiding negative outcome) is "Avoid Congestion Use Both Lanes." Research on loss aversion suggests that the negative framing language may be the most effective at encouraging the desired behavior (Tversky & Kahneman, 1981).

Materials

Public-facing state-level DOT communications were collected by searching '"zipper merge" OR "late merge"' on each U.S. state's website. These materials included all public-facing documents that included an announcement of zipper merge implementation, a description of how to do one, or information about zipper merge specific signs. Excluded materials included construction updates that mentioned zipper merges but provided no information for the public about what to expect from a zipper merge, such as how to zipper merge or signs to look for. Materials were also excluded that mentioned zipper merge but were obviously not public facing, such as transcripts of department planning meetings or documents from inter-departments presentations. The materials span the years from 2011-2020. For a summary of the details of the individual materials from the various DOTs, see Appendix G.

This analysis separates communications that describe signs used at zipper merge locations and any public communication to inform the public about zipper merges in general or the implementation of a zipper merge in a particular location. Communications that describe signs were almost exclusively construction updates intended to inform the public about a particular

zipper merge location and what signals and instructions to watch for. Public communications more broadly include press releases, radio ads, videos, and articles that explain what a zipper merge is, how to do it, and how or where the department intended to implement them.

Analysis

Using a deductive approach, we characterized the use of behavioral science strategies based on existing theories. Based on the literature review, we developed a coding scheme that included seven categories, (1) instructions, (2) information, (3) social norms, (4) appeals to reason, (5) emotional appeals, (6) humor, and (7) activators summarized in Table 7-1. The coding was performed by two independent coders and any disagreements were resolved by a third member of the research team.

Table 7-1 Summary of the Coding Scheme for Behavioral Science Strategies

Strategy	Definition	Example
Knowledge Deficit Model (Scheufele, 2013; Sturgis & Allum, 2004)		
Instructions	Signs that explicitly tell drivers what to do	Merge in ½ Mile, Merge Here
Information	Signs that only provide drivers with information	Roadwork Ahead
Social Cognitive Theory (Allcott & Mullainathan, 2010; Schultz et al., 2007)		
Social Norms	Promoting or working against a pressure felt because of a societal expectation, real or imagined, to engage in a behavior	"People generally think the polite thing to do is to merge early"
Elaboration Likelihood Model (Bator & Cialdini, 2000; Slater & Rouner, 2002)		
Appeals to Reason	Appealing to rationality by describing either benefits to be received by engaging in the behavior or costs to be received by not engaging in it	Moving faster, Fewer accidents, Less back-ups
Emotional Appeals	Appealing to a person's feelings or emotions via messages related to generosity, which appeal to their sense of rightness or fairness and desire for the general welfare, and commiseration, which attempt to win people over by identifying with their struggle	Take Turns, "We've all been there"
Humor	Making audience more receptive to a message or making it more memorable by presenting it in a funny way	A talking traffic cone
Activators	Using mnemonic or other devices to help drivers remember what a zipper merge is and how to do it when they encounter it	Mnemonics (rhymes), Visual Metaphors (like a zipper)

Results of Behavioral Science Analysis

The analysis is composed of the following three sections: (1) types of existing zipper merge communications, (2) use of behavioral science strategies, and (3) comparisons between states.

Types of Zipper Merge Communications

The first state to release zipper merge communications was Minnesota in 2011, followed soon by Colorado and Vermont in 2013. Table 7-2 shows how zipper merge communications dramatically increased in 2016.

Table 7-2 Timeline of the Introduction of Zipper Merging Communications by State

Year	State
2011	Minnesota
2013	Colorado, Vermont
2016	Arizona, Kansas, Michigan, Missouri, Nebraska, Pennsylvania, Wisconsin
2017	North Dakota
2018	Montana, Virginia
2019	North Carolina, Washington
2020	Oregon

Across the 16 states that had zipper merge materials, we found three items on average (*Median* = 2, *SD* = 2.46) as shown in Figure 7-7. Most states had a small number of communication materials, with only one state exceeding five communication types.

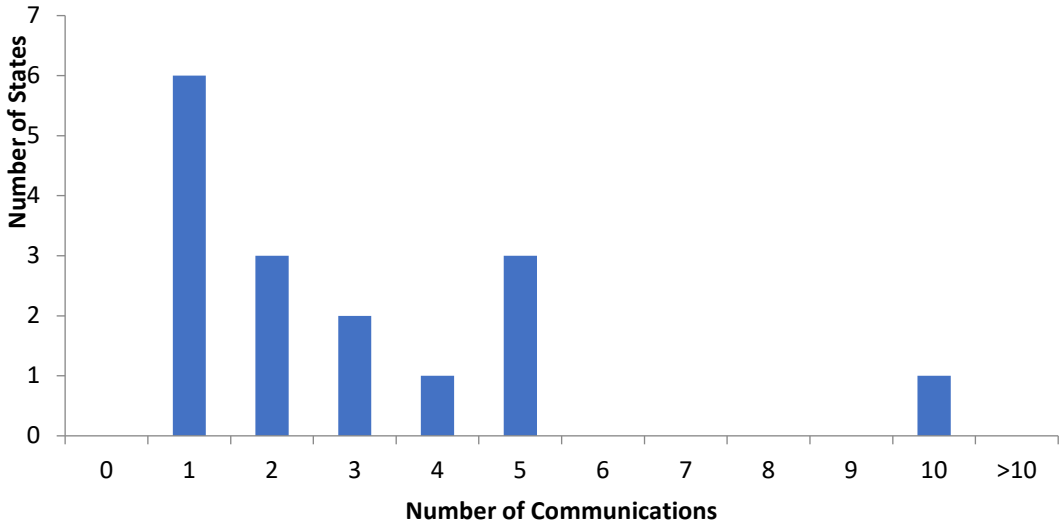

Figure 7-7 Number of Zipper Merge Communications per State

States varied widely in the types of media that they used for zipper merge communications. Broadly, these types fell into four categories, (1) signs, (2) written, (3) audio, and (4) social media communications. Even though signs are actual traffic control devices used in the deployment of zipper merge, they use words and symbols that can also be analyzed. Therefore, they are included along with other types of communications. As summarized in Table 7-3, of the 16 states that had zipper merge communications, almost all used static signs and written articles. Dynamic signs and videos were also very popular and used by 9 of the 16 (56%) states. Few states used audio materials via podcasts or radio.

Table 7-3 Media Types Used

Media Type		Number of States	Description
Signs	Static	16 (100%)	Messages do not change
	Dynamic	9 (56%)	Messages may flash or change over time
Written	Article	15 (94%)	Announcements, updates, or explanations
Audio	Podcast	1 (6%)	State DOT sponsored podcast or podcast featuring a State DOT representative
	Radio	1 (6%)	Advertisements on the radio
Social Media	Video	9 (56%)	Videos produced and marketed by State DOTs

Use of Behavioral Science Strategies

The use of behavioral science in analyzing signs is done separately from other communications. By their nature, signs are typically limited to simple messages, and they are part of the zipper merge deployment.

Signs

Two types of signs were used at construction sites to instruct drivers regarding upcoming zipper merges. Static signs are those that are fixed, stationary, and unchanging. Changeable or variable message signs are electronic, portable signs that can be programmed to display many different messages and can have a flexible location. Changeable message signs (CMS) are particularly useful for zipper merge because the message can be changed to encourage zipper merging under high traffic conditions when zipper merging is more effective. Studies suggest that

dynamic signs yield higher zipper merge compliance because they respond to current conditions (Grillo, Datta, & Hartner, 2008).

Signs were categorized as information or instructions. Informational signs conveyed updates, such as “Road Closed Ahead” or “Lane Ends 1 Mile”, to drivers without indicating how they should respond. Instructional signs, conveyed commands to drivers such as “Take Turns”, “Merge Here,” or “Merge in 1 Mile.” Most states heavily utilized instructional rather than informational signs. In some cases, there are indirect uses of other behavioral strategies. For example, some signs say, “Do Not Merge Here,” acknowledging the existence of the social norm that pressures drivers to early merge.

Public Communications

Written, audio, and visual public communications were categorized as Social Norms, Appeals to Reason, Emotional Appeals, Humor, and Activators. In the DOT communications, social norms are used in slogans or phrases that DOTs create to assist their campaign in increasing zipper merge compliance. One example of this is Minnesota’s catchphrase, “Resist the Urge to Merge Early.” This acknowledges the existing social norm surrounding merging and encourages Minnesota motorists to re-think their merging strategy. Another way DOTs use the social norm is by citing other states who have implemented zipper merging on their roadways, thereby creating a positive social norm surrounding zipper merging for their citizens.

Appeals to reason increase zipper merge compliance by engaging drivers’ rational and logical faculties. These would include such appeals as “zipper merges are faster, safer, and make your commute less stressful.” These are not used in signs but are used frequently in other DOT public materials. Articles or videos encouraging drivers to zipper merge usually include several

appeals to reason. Appeals to reason are, in fact, very rarely used individually in this application. They are almost always used in groups of two or more and frequently paired with an emotional appeal.

Emotional appeals appear frequently in both signs and other public communications. The most common usage are appeals to generosity. This is a situation in which an attempt is made to win drivers over to the zipper merge by means of appealing to their sense of generosity or their responsibility to contribute to the common good. This would include signs such as "Take Turns," and urge for drivers to zipper merge because it is good for everybody. Usually, emotional appeals are used in conjunction with appeals to reason.

Humor was not used frequently in the DOT communications, but when it does appear, it is used in videos to make them more engaging. Sometimes this was manifested in the eyes through which zipper merging was narrated. For example, one state had an informational video on zipper merging where a talking traffic cone was used to discuss the process and merits of zipper merging. In other situations, humor was expressed through a funny or unique twist on the presentation of the material; a MoDOT video showed children and adults in cardboard cars doing early merging and zipper merging.

Activators make the messaging more memorable or recognizable. They appeared more frequently in educational materials than in signs. Some states created a slogan that would appear consistently on their zipper merge educational materials. Minnesota's "Zip the Urge to Merge Early" is one such recognizable message that appeared quite frequently in all their materials. It was common among these slogans for mnemonics such as rhyming to be employed, or for the same picture to be used in all their publications. These pictures were deemed "visual metaphors" because they used visuals such as a zipper to reinforce the concept of a zipper merge in the

minds of their viewers. Figure 7-8 Example of Visual Metaphor shows an example of one such visual metaphor from an educational public communication. Research on loss aversion suggests that the negative framing language may be the most effective at encouraging the desired behavior (Tversky & Kahneman, 1981). The effectiveness of some of these strategies was also tested in the post-simulator survey.

Figure 7-8 Example of Visual Metaphor

Because of the abundance of educational materials, it is efficient to recommend good examples of existing materials instead of reinventing the wheel. Nonetheless, it is difficult to determine one that is universally the best as different members of the public react differently to the various behavioral science strategies. Several DOTs have produced videos that are effective in using different behavioral science strategies. "ADOT piloting 'Zipper Merge'" (AZDOT 2016) uses a combination of animation, field footage, and interviews to explain the zipper merge pilot at Quad Projects. The project-specific nature of the video makes it unsuitable to be transferred for use to another state. "How to Zipper Merge" (KSDOT 2016) uses humor via two talking delineators explaining zipper merge operations and benefits. The banter between the delineators could be effective for some but distracting for others. "Zipper Merge: Kids, Adults in Cardboard Cars and Taking Turns" (MoDOT 2016) uses humor by having kids explain the

zipper merge. The use of kids results in a very friendly presentation; however, actual field footage or realistic animation could illustrate traffic concepts in a clearer fashion than illustrating using cardboard cars. "Do the Zipper Merge! Transportation Tidbit" (NDOT 2016) uses animation to contrast the early merge strategy with the late merge (zipper merge) strategy. One drawback of this video is that significant time is spent explaining the early merge strategy. "NDDOT – zipper merge" (NDDOT 2017) relies on effective animation to educate on the use of zipper merge and to explain the benefits of less congestion, fewer crashes, and lower stress. "Driver's 'Ed'iquette: The Zipper Merge" (VDOT 2019) is a highly animated video with frequent cutaways. Such a presentation may connect well with younger generations but may not be as effective for other populations. "WSDOT Zipper Merge: Merge late, cooperate!" (WSDOT 2019) is an effective zipper merge video that combines field footage with work zone animation. However, it is a project-specific video about zipper merge at the Southbound US-101 construction near Steamboat Island. A MNDOT zipper merge video was previously discussed as part of the survey results in Section 6.1. Though this video was excellent it did not involve any audio narration. In summary, the NDDOT video stands out as a concise but effective video on zipper merge. The video used a combination of appeal to reason and emotional appeal. It clearly presented the benefits of the zipper merge while making the emotional appeal that it's "good for everybody." The MNDOT video received good responses from the surveyed subjects and is also an effective video if the lack of audio is not a concern.

MoDOT's web page on zipper merge (https://www.modot.org/zipper-merge) explains the ideal zipper merge behavior at lane closures, discusses the problems of early merge under congestion, and then summarizes the early merge situation versus the zipper merge situation with bullet points. The page links to an informative video using kids and humor to explain zipper

merge. This web page communicates important concepts effectively. One possible improvement is to simplify the language and format the information. For example, the Nebraska DOT's web page uses shorter paragraphs and the concept of chunking. Chunking is a learning strategy in which information is grouped into smaller meaningful groups or chunks to increase learning efficiency and capacity (Fountain and Doyle 2012). A recommendation is to rewrite and re-format the opening four paragraphs into labelled chunks. Here is a suggested chunking of the MoDOT web page: how to merge safely, problems with early merge, and benefits of zipper merge.

Conclusion

On the average, states had 2.46 zipper merge educational materials per state. The mode or highest number of states used only one type of material. Nine of 16 states produced a video to educate on zipper merge. A more important issue, which was infeasible to assess under the current project, is how many citizens were reached by DOT education in each state.

Patterns are discernable in states' uses of behavioral science strategies in zipper merge communications. States noticeably gravitate towards similar strategies and phrases used in their signs and educational materials. Appeals to reason and emotional appeals were especially popular and by far the most commonly used across the board. The literature review, however, revealed that in other traffic communication applications, social norms are frequently used and predicted to be effective (Geller, 1988; Guttman, 2015). Although this review is limited to materials that were currently available on state DOT websites, this represents the breadth (if not the frequency) of existing zipper merge communications.

Because several DOTs have produced various educational materials over the years, it would be efficient for MoDOT to use or adapt existing materials instead of starting from scratch. The NDDOT and MNDOT videos are examples of an effective video that used multiple behavioral strategies in communicating both the use and benefits of zipper merge. Several other DOTs also developed effective videos, but they were tied to specific projects. In terms of web communications, chunking is recommended to transform MoDOT's existing zipper merge web page into more easily digestible groups so that a person can quickly identify and process the main points related to zipper merge. Learning styles vary widely among people, so it is difficult to identify a video or an article that is universally best. However, the recommended NDDOT video and changes to the MoDOT zipper web page could work well for a diverse audience.

There are many opportunities to increase the use of behavioral science strategies in zipper merge communications. However, evidence is needed to determine which strategies are more effective. Future research could focus on conducting human subject experiments to measure the effectiveness of behaviorally informed communications. Online experiments would be helpful in gaining a general understanding of how drivers might respond to different messaging schemes. Simulator experiments would help gain a more specific understanding of how drivers might react in real situations, but are limited in the length of testing and the number of subjects due to the simulator's capacity limits. Given the effectiveness of behavioral communications in other domains, there is high potential for increasing zipper merge compliance with behavioral science.

Conclusion

Even though not all DOTs are in agreement regarding zipper merge, there are a significant group of DOTs who are widely deploying such a strategy. The reasons for doing so are due to the problems that have resulted from early merging such as wasted capacity, excessive queuing of the open lane, the potential for queues to grow beyond warning signs, and queue jumping and the associated conflicts and safety risks. In contrast, zipper merge has the potential to reduce queuing and reduce conflicts at the merging area.

Even though there is significant research on zipper merge, there are several issues that require research. The issues examined in this project include the role and manner of education, operation under different traffic speeds, operation under different traffic volumes, and the placement of the CMS closest to the taper. These were the issues that the MoDOT technical advisory committee identified. The way to resolve these issues was through reviewing existing literature, conducting a simulator experiment, surveying human subjects, and analyzing educational materials from various DOTs across the United States.

The ZouSim driving simulator is a flexible and effective tool for analyzing traffic operational applications like the zipper merge. The simulator enabled the creation of congested work zone traffic data that is often fleeting since DOTs seek to minimize traffic impacts at work zones. Furthermore, the traffic and geometric conditions were tightly controlled in a simulation so that each human subject experienced the same scenarios. A simulator allows excellent control over all aspects of the experiment. Despite the challenges and delays posed by the COVID-19 pandemic, the human subject experiments were completed with 50 subjects.

A clear finding of this project is that public education is vital to public compliance and understanding of zipper merge. Many of the subjects were not familiar with zipper merge and

offered a perspective of the novel driver. The results revealed that there is significant potential for drivers to misinterpret the zipper merge sign package. Despite driver misunderstanding, most still support the use of zipper merge and do not think that it is stressful to drive through a zipper merge. The results of the simulator study show a statistically significant difference between pre- and post-education driver behavior. After education, drivers merged much closer to the taper, the desired behavior for zipper merge.

The project found that the content of public educations materials does not have to be overly long or detailed. Concise messages were used in the simulator study and the post-simulator survey. Both were effective in eliciting the proper behavior and response from drivers. Respondents preferred video over written educational materials. The abundance of existing educational materials, such as the NDDOT video, means that existing materials can be adapted for use in Missouri. However, the greater challenge is to provide sufficient coverage so that the drivers who are educated on zipper merge could help to overcome the long-ingrained behavior of merging early.

The results show that there is driver preference for the use of zipper merge under lower traffic speeds and higher traffic flow conditions. However, simulator results show that zipper merge could operate well even at higher traffic speeds and moderate traffic flow conditions. The results show that the last zipper merge CMS should be located closer to the taper to reduced early merging. By adopting strategies validated through research, zipper merge operation could operate more efficiently, and driver experience could be improved.

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Appendix A. Institutional Review Board Approval of Human Subject Study

Institutional Review Board
University of Missouri-Columbia
FWA Number: 00002876
IRB Registration Numbers: 00000731, 00009014

482 McReynolds Hall
Columbia, MO 65211
573-882-3181
irb@missouri.edu

January 31, 2020

Principal Investigator: Carlos Chung Sun

Department: Civil/Environmental Engr

Your IRB Application to project entitled Optimizing Work Zone zipper merge Operations Using Driving Simulators was reviewed and approved by the MU Institutional Review Board according to the terms and conditions described below:

IRB Project Number	2016962
IRB Review Number	253120
Funding Source	Missouri Department of Transportation
Initial Application Approval Date	January 31, 2020
IRB Expiration Date	January 31, 2021
Level of Review	Expedited
Application Status	Approved
Project Status	Active - Open to Enrollment
Expedited Categories	45 CFR 46.110.a(f)(4) 45 CFR 46.110.a(f)(7)
Risk Level	Minimal Risk
Type of Consent	Written Consent
HIPAA Category	No HIPAA
External Funding	External Grant (ex. Federal funding, foundation funding)

Approved Documents	IRB Approved Consent Document corrected title and changed version number to v2 and date on Section 4.5 A & B written script survey recruitment flyer recruitment email

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

1. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
2. All unanticipated problems must be reported to the IRB on the Event Report within 5 business days of becoming aware of the problem. Unanticipated problems are defined as events that are unexpected, related or possibly related to the research, and suggests the research places subjects or others at a greater risk of harm than was previously known or recognized. If the unanticipated problem was a death, this is reportable to the IRB within 24 hours on the Death Report.
3. On-site deaths that are not unanticipated problems must be reported within 5 days of awareness on the Death Report, unless the study is such that you have no way of knowing a death has occurred, or an individual dies more than 30 days after s/he has stopped or completed all study procedures/interventions and required follow-up.
4. All deviations (non-compliance) must be reported to the IRB on the Event Report within 5 business days of becoming aware of the deviation.
5. All changes must be IRB approved prior to implementation unless they are intended to reduce immediate risk. All changes must be submitted on the Amendment Form.
6. All recruitment materials and methods must be approved by the IRB prior to being used.
7. The project-generated annual report must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date. If the study is complete, the Completion/ Withdrawal Form may be submitted in lieu of the annual report.
8. Securely maintain all research records for a period of seven years from the project completion date or longer depending on the sponsor's record keeping requirements.
9. Utilize the IRB stamped consent documents and other approved research documents located within the document storage section of eCompliance. These documents are highlighted green. If you are offering subject payments and would like more information about research participant payments, please click here to view the MU Business Policy and Procedure: http://bppm.missouri.edu/chapter2/2_250.html

If you have any questions, please contact the IRB at 573-882-3181 or irb@missouri.edu.

Thank you,

MU Institutional Review Board

Appendix B. Human Subject Study Protocol

SOCIAL/BEHAVIORAL/EDUCATIONAL RESEARCH PROTOCOL

UNIVERSITY OF MISSOURI

Project Title: Optimizing Work Zone zipper merge Using Driving Simulators

IRB Number: 2016962

Version Number: 1

Version Date: 12/10/19

Principal Investigator: Carlos Sun

Funding Source: Missouri Department of Transportation

I. Research Objectives/Background

1. Describe the purpose, specific aims, or objectives. State the hypothesis to be tested or the research questions that will guide the study.

Work zones could involve lane closures where traffic is required to merge from a closed lane to an open lane. With the traditional early merge strategy, vehicles merge to the open lane right after encountering the lane closed ahead sign as part of work zone traffic control. The purpose is to study the late or zipper merge strategy. The objectives are to review existing zipper merge practices, evaluate different sign configurations, analyze public educational material, and develop policy guidance for public agencies. The hypothesis to be tested via the human subject simulator studies is whether drivers behave differently under different signage (NC vs. MD), traffic level (medium vs. high), and information (none versus education).

2. Provide the scientific or scholarly background for, rationale for, and significance of the proposed research based on the existing literature and how it will add to existing knowledge.

Detailed references and citations are provided in Section XII, References.

Work zones could involve lane closures. With the traditional early merge strategy and under congested conditions, this strategy could lead to several potential issues. An early merge results in increased queuing in the open lane while leaving capacity unused in the closed. The increased queuing could potentially extend beyond work zone warning signage surprising approaching traffic and increasing the risk of an end-of-queue crash. The unused capacity in the closed lane approaching the taper also allows the potential for queue jumping, where vehicles try to zoom past on the closed lane and cut in at the last minute. Queue jumping behavior could lead to motorist anger and friction at the taper. Several departments of transportation (DOTs) have been experimenting with the concept of late merge for several years. Late merge is also known as zipper merge since late merge involves vehicles taking turns merging at the taper. The potential benefits of zipper merge include full use of the available capacity, more uniform merging at one location only, and fairness in taking turns one after another (Spiller et al., 2017). However, the support for zipper merge is not universal, and a Missouri study could help to improve education and public acceptance in the state of Missouri.

II. Recruitment Process

1. Describe the recruitment process.

Human participants will be recruited formally via flyers sent to College of Engineering staff and students, and informally via personal invitations using the same flyers or emails. The flyer describes the purpose of the study, provides the study details such as the location and dates,

explains the benefits and risks, and presents the compensation provided. The email is a condensed version of the flyer. Both the flyer and the email provide the contact information for the Principal Investigator, Carlos Sun.

2. Describe how and where recruitment will take place.

Recruitment will occur via electronic and face to face invitations in Lafferre Hall and in the City of Columbia.

III. Consent Process

1. Describe the consent process; including who will be asked to consent and what type of consent will be obtained from each subject population, if there is more than one.

After a participant arrives in Lafferre 1510, the orientation process starts with the consent process. The informed consent process will involve study hosts asking participants to read the consent form and to sign if they agree. A copy of the form will be given the participant.

The consent form will not be emailed beforehand to subjects. Subjects will be given ample time to review the consent form when they arrive for orientation. Subjects will have the opportunity to ask any questions before the simulator orientation process start.

IV. Inclusion/Exclusion Criteria

1. List all inclusion and exclusion criteria.

The study participants will be U.S. adult drivers and will be College of Engineering students and staff, as well as city of Columbia residents.

2. List any restrictions on participation and appropriate screening procedures to ensure that the restrictions are maintained.

The recruiting flyer will clearly state that this is a driving simulator study and that a participant needs to be a licensed adult driver in the U.S.

V. Number of Subjects

1. Include the anticipated enrollment number in this study. Include a break-down in numbers if there is more than one subject population.

The anticipated enrollment is 50 participants.

2. Include the statistical analysis or other justification for the number of subjects enrolled.

Due to the detailed information captured in simulator studies, a sample size of 50 is a commonly accepted size. Some simulator studies have used as few as 15 participants.

VI. Study Procedures/Study Design

1. Include a detailed description of the procedures and/or design to be followed (what will subjects be asked to do), and describe each intervention and/or interaction with the subjects and/or their data.

The study involves two major subtasks. The first subtask involves the design of the simulator experiment and the refining of the experiment through testing. Testing is typically conducted using alpha (in-house) and beta (external) testers. As is typical in simulator studies, the design of the post-simulator survey is often included in this subtask. The second subtask involves all the steps required to successfully conduct a human subject study. The first step is to secure approval from the Institutional Review Board. This entails the approval of several required documents,

including the experiment protocol, request for human subject incentive, data safety plan, recruitment flyer, and informed consent form. The recruitment step involves advertising the study and recruiting a representative sample from the Missouri driving population. A representative sample requires a balanced distribution among demographic characteristics such as age and gender. A minimum sample size of 50 participants is planned. A standard human subject hosting protocol and script is then developed and all experiment hosts are trained in order to host each human subject in a uniform manner. The conduct of driving simulator trials involves providing an orientation, obtaining informed consent, instructing on the use of federated driving simulator, monitoring the well-being of the human subject, administering the post-simulator study, delivering the gift card incentive, and checking the human subjects out.

The steps for designing the simulator experiment are further explained as follows. Simulators require careful validation in order to elicit realistic human behavior. ZouSim driving simulators have been validated using several comparison methods. One is the comparison of actual speeds between the simulator and real-world. The real-world data are typically collected from on-road videos (Sun et al., 2017) and the manufacturer's manual (e.g., maximum acceleration and braking rates) (Zhang, 2018). Another is the visual comparison of the 3D models with field videos (Sun et al., 2017). This comparison ensures visual fidelity of the simulator scenarios. Figure 1 shows an example of how a truck-mounted attenuator with a dynamic message board was validated using images captured at controlled distances. For relative validity, driver behavior observed in the driving simulator was compared with driver behavior observed in field studies (e.g., Brown et al., 2018). Even though drivers did not behave identically, the general behavior trends were consistent between simulator and field results.

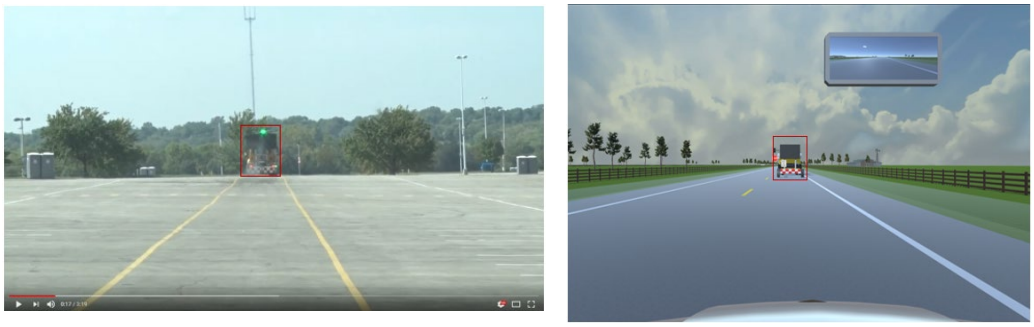


Figure 1. Example of Visual Calibration

The zipper merge simulator experiment is a specific scenario that a human participant is asked to drive. The ZouSim driving simulator is developed with the Unity simulation engine, which contains a realistic physics engine, three-dimensional capabilities, animation tools, and compatibility with popular three-dimensional computer-aided design software (e.g., Microstation), which allows accurate modeling of the road design. Surfaces will be textured or painted with the appropriate colors, striping, and markings that conform to the MUTCD (FHWA, 2009). The static objects modeled in scenes included road signs, trees, and grass. The zipper merge scenario, developed jointly by the researchers and the TAC, will be implemented in Unity.

2. Describe the time commitment involved.

The simulator portion of the study will take approximately 20 minutes. Including orientation, simulator warm up, post-simulator survey, and wrap up, the total time commitment approximately 45 minutes.

3. Include whether the procedure/item listed is research-only (occurring only because they are a participant in the research) or routine care/activity (it would occur regardless of the research and you are requesting to collect that data to include in your data analysis).

The procedure is research-only.

4. A table of events may be helpful in this section.

Table 1. Table of study events

Event	**Description**	**~Time (minutes)**
Orientation	Greet participant Obtain informed consent Offer water, restroom break	5
Simulator warm up	Familiarize participant with simulator Free driving	6
Simulator trial	Drive all scenarios	20
Post survey	Complete post simulator survey	8
Wrap up	Check on participant wellness Offer water again Deliver gift card	5

VII. Potential Risks

1. Describe any reasonably foreseeable risks or discomforts to the subjects and the steps to minimize risks.

Even though the probability of experiencing simulator sickness is low, there is a potential for some participants to experience general discomfort, eye strain, dizziness, and/or nausea. This risk is minimized by keeping the simulator portion short, e.g., 20 minutes or less and ventilating the lab well with double fans. We will also monitor participants closely and inquire about their comfort between simulator scenarios.

2. Include the plan for reporting unanticipated problems or deviations to the IRB. This plan must include a five-day reporting requirement to the IRB once becoming aware of an event.

At the conclusion of each participant trial, the host will report any problems or deviations to the principal investigator and the team. The team will then devise ways to address or prevent problems and to adjust the study accordingly. Once changes are devised, they will be reported to IRB within the five-day period.

VIII. Anticipated Benefits

1. Describe both direct and indirect benefits for either the individual or society.

The results of the study will benefit the state of Missouri and the nation by analyzing driving behavior at zipper merges. The results can be included into public agency policies and procedures, and public information/education on zipper merge.

IX. Compensation

1. Describe the amount, method, and timing of disbursement. This includes checks, cash, gifts, extra/course credit, etc.

A $20 gift card to Chipotle/Amazon will be delivered to the participant at the conclusion of the simulator session or when a participant elects to drop out. A participant may drop out at any time during the study without any penalty or loss of benefits.

X. Data Safety Monitoring Plan

Describe the plan to monitor the data, if necessary. A plan is required for treatment and/or intervention studies, sensitive data are being collected, or there is a possibility for subjects to experience adverse events, etc.

1. The plan should include when something needs to be reported
2. The frequency of the monitoring, such as points in time or after a specific number of participants are enrolled
3. Who will conduct the monitoring, such as a data board, medical monitor, investigator, independent physician; the specific data to be monitored?
4. Procedures for analysis and interpretation of the data
5. Actions to be taken upon specific events or end points (early stopping rules)
6. Procedures for communication from the data monitor to this site.

1) The data safety monitoring plan exists to ensure that personally identifiable information is kept secure and confidential. There will not be any personally identifiable information stored in the simulator videos, derived data, and surveys. A unique identifier will be assigned and used to link the participant data with the participant. The hash table linking participants with unique identifiers will be locked in a locker inside the locked E1511 laboratory. In case there has been a breach in data security, the event will be reported to IRB and to the affected participants.
2) At the completion of each research day, data will be compiled and locked inside E1511 in Lafferre Hall.

3) The security of data will be monitored by the entire research team, including the principal investigator. The data to be monitored consists of the simulator videos and logs, and the post-simulator surveys.

4) Data will be processed by research assistants. They will review each simulator trial video and log, and derive the necessary measures such as speed and headway at lane change, distance to the taper, and acceleration rate. Statistical analysis will be used to assess passenger car driver behavior differences under different alternatives (i.e., signage, education, traffic). Data will be stored in an external hard drive in Lafferre E1511 in a locker along with the paper surveys.

5) The host shall monitor participants carefully and interrupt the study whenever there is evidence of participant discomfort. Whenever a host discovers that a participant experiences discomfort, the host shall immediately offer to stop the study (early stop) and remind the participant that there will be no loss of compensation. The host shall also offer bottled water to the participant, and offer a place for the participant to sit and rest.

6) The data monitor, Dr. Sun, will email or telephone IRB (irb@missouri.edu) directly with information on problems.

XI. Multiple Sites

1. Specify who is the lead site and describe the roles of each site in the study.

There is only one study site: Lafferre Hall, E1510 (ZouSim Laboratory), at the University of Missouri (MU).

2. Indicate whether all required approvals are already in place or will be in place at each site prior to project implementation. If the study will utilize a reliance agreement or a single IRB, please describe which institution(s) will be relying on another IRB for review, and which institution will be responsible for the IRB oversight of the relying IRB(s).

Only IRB at MU will be involved.

3. Describe the plan that is in place to manage information obtained from multiple sites that may be relevant to the protection of human subjects such as reporting unanticipated problems, protocol modifications, and interim results.

Not applicable.

XII. References

1. Findings from a literature search or pilot study must be outlined including appropriate detailed references to earlier studies and data.
2. If necessary, additional references to supporting data or additional information may be included in an appendix.

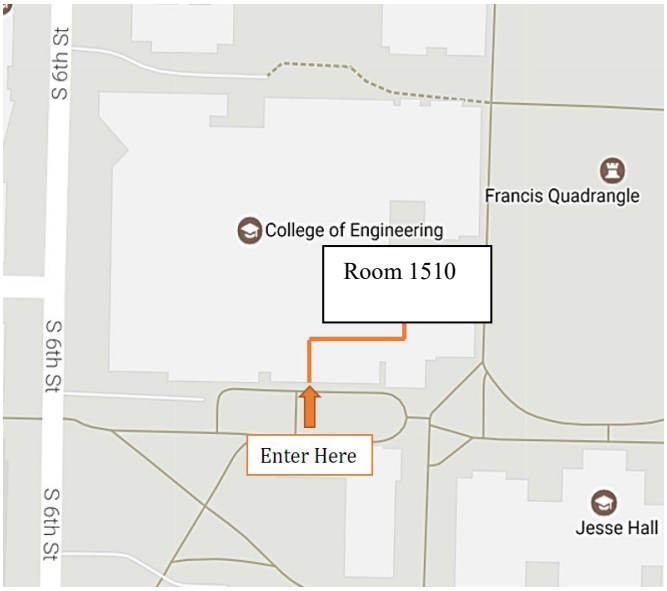
Prior research recommends late merge for congested conditions and early merge for free flow conditions. In dynamic merge systems, a threshold is used for switching between these two merge strategies. This threshold then represents the threshold, or the best conditions, for applying zipper merge. Various traffic parameters have been used for determining this threshold. Several researchers recommend the use of approximately 1500 vehicles per hour as a threshold for switching between late and early merge (Datta et al., 2007; Grillo et al., 2008; Sperry et al., 2009). A related measure would be volume-to-capacity ratio which takes into account the reduction in capacity at a work zone. Thus, a 2-to-1 lane closure differs from a 3-to-2 lane closure. Some recommend using an occupancy rate of around 15% (Kang et al., 2006). Another option, evaluated for three-to-two lane closures, used a speed threshold of around 50 mph (Meyer, 2004). Some studies suggest that the percentage of heavy vehicles is a significant factor in setting the switching threshold (Beacher et al., 2004; Harb et al., 2010; Hallmark et al., 2011). Under congested conditions, the growth of queues emanating from the work zone increases the crash risk of the approaching traffic upstream. The proposed study adds to the body of

knowledge by providing actual human behavioral data to support the implementation of zipper merge strategies. None of the previous literature sought to analyze driver behavior explicitly.

Appendix C. Human Subject Study Recruitment Flyer

Optimizing Work Zone zipper merge Using Federated Driving Simulators

What: You are warmly invited to participate in a driving simulator research study at the University of Missouri to help enhance traffic safety. Participants will drive on a simulated freeway and give their opinions on vehicles merging in work zones. The study will take approximately 45 mins.



Where: The study will take place in the ZouSim Lab in E1510 Lafferre Hall
- Enter through the south door into Overholser Atrium.
- Turn right down the hallway to the small staircase
- Go up staircase and the room will be on the left side.
- Street metered parking available near Lafferre Hall

When: Spring-Summer, 2020

Benefits: Your feedback will help to improve traffic safety in Missouri.

Risks: A small percentage of participants may experience some simulator discomfort such as eye strain or dizziness.

Compensation: A participant may withdraw from participation at any time for any reason without losing the $20 gift certificate to Chipotle.

Confidentiality: Personal identifying information will be kept confidential.

Thank you for your help in improving traffic safety in Missouri. Participants must be 18 years of age and a licensed U.S. driver.

If you are interested in participating in this study, please contact Dr. Carlos Sun in the Department of Civil and Environmental Engineering at csun@missouri.edu or 573-884-6330.

Appendix D. Human Subject Study Informed Consent Form

OPTIMIZING WORK ZONE ZIPPER MERGE OPERATIONS USING DRIVING SIMULATORS

PARTICIPANT CONSENT FORM

You are being asked to take part in a research study involving the zipper merge at work zones. We are asking you to take part in this study to obtain your feedback about driving near work zones. Please read this form carefully and ask any questions you may have before agreeing to take part in the study. Participants must be 18 years of age and a licensed driver in the U.S. The number of participants in the study is 50.

What the study is about: The purpose of this study is to learn about driver preferences near work zones.
What we will ask you to do: If you agree to be in this study, we will ask you to drive a car simulator through a sample road freeway network. We will collect data from the simulator trip to help us evaluate how to best formulate work zone policy. Upon completion of the simulator trip, we will ask you to take a brief survey of four pages. The survey will ask you about your preferences while merging in work zones. The entire study, including orientation, will take approximately 45 minutes.
Risks and benefits: Even though the probability of experiencing simulator sickness is low, there is a potential for some participants to experience general discomfort, eye strain, dizziness, and/or nausea. The results of the study will benefit the state of Missouri learning about zipper merge near work zones.
Compensation: A $20 gift card to Chipotle, will be offered. <u>If the subject refuses to participate, there is not loss of benefits to the subject.</u>
Your answers will be confidential. In any type of report we make public, we will not include any information that will make it possible to identify you individually. Research records will be kept in a locked file; only the researchers will have access to the records.
Taking part is voluntary: Taking part in this study is completely voluntary. You may skip any survey questions that you do not want to answer. If you decide to take part in this study, you are free to withdraw at any time without the loss of compensation.
If you have questions: The researcher conducting this study is Dr. Carlos Sun. Please ask any questions you have now. If you have questions later, you may contact Dr. Sun at csun@missouri.edu or 573-884-6330. If you want to talk privately about your rights or any issues related to your participation in this study, you can contact University of Missouri Research Participant Advocacy by calling 888-280-5002 (a free call), or emailing muresearchrpa@missouri.edu. If you have any questions or concerns regarding your rights as a participant in this study, you may contact the Institutional Review Board (IRB) at 573-882-3181. You will be given a copy of this form to keep for your records. The information we collect from you for this study will not be used or shared with other investigators for future research studies.

Statement of Consent: I have read the above information, and have received answers to any questions I asked. I voluntarily consent to take part in the study.

Your Signature _____ Date _____

Your Name (printed) _____

Appendix E. Zipper Merge Survey

Participant #: ___ Date _____

Optimizing Work Zone zipper merge Using Federated Driving Simulators

Thank you for sharing your opinions to help us improve safety and efficiency at work zones. To reduce congestion and enhance efficiency at work zones, the Missouri Department of Transportation (MoDOT) is promoting the policy of zipper merge. This policy instructs motorists to use both lanes of traffic on a two lane road until reaching the lane closure and then allowing vehicles to take turns merging.

1. **Before participating in this study, how familiar were you with zipper merges?**

Not familiar at all [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Very Familiar | [ ] Not sure

Please read the following material and answer the following questions. Please note that this was the material shown earlier during the simulator trial.

zipper merge means drivers fill both lanes and take turns merging every other car at the point of the lane closure, so that we could fully utilize the road capacity and enhance efficiency.

2. **The explanation was helpful to understand zipper merge concept in the work zone.**

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

3. **After reading this paragraph, I understand how to merge at a zipper merge.**

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

Watch this video and answer the following questions.

https://www.youtube.com/watch?v=ZcPby71TNC0&sns=em

4. **This video was helpful to understand zipper merge signs at a work zone.**

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

5. **After watching this video, I understand how to merge at a zipper merge.**

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

6. **Which educational material do you prefer?**

[ ] Video [ ] Reading (Paragraph linked to Question 2 and 3) [ ] Not sure

7. **Under which situation do you think zipper merge should be used?**

[ ] Higher traffic speed (60 mph) [ ] Lower traffic speed (40 mph)

8. **Under what situation do you think zipper merge should be used?**

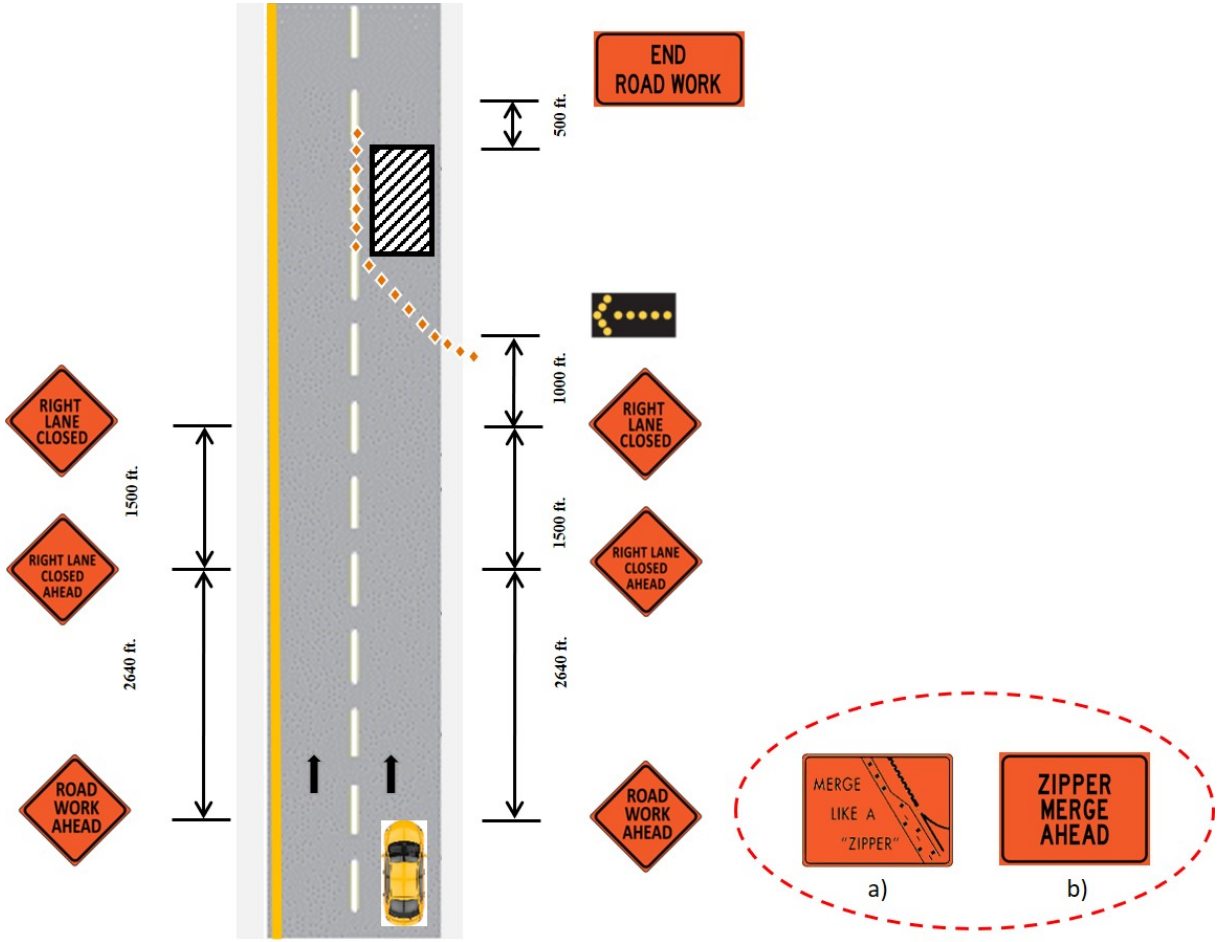
[ ] Higher traffic volume [ ] Lower traffic volume

9. **I feel more anxiety if a zipper merge is required at a work zone.**

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

For the next set of questions, please imagine that you are the yellow car driver, approaching a work zone and there is a lot of traffic. You are approximately 1 mile from the work zone.

10. Assume you are approaching a zipper merge work zone in the yellow car. Choose your preference for signs at the beginning of the work zone area. Choose either (a) or (b).



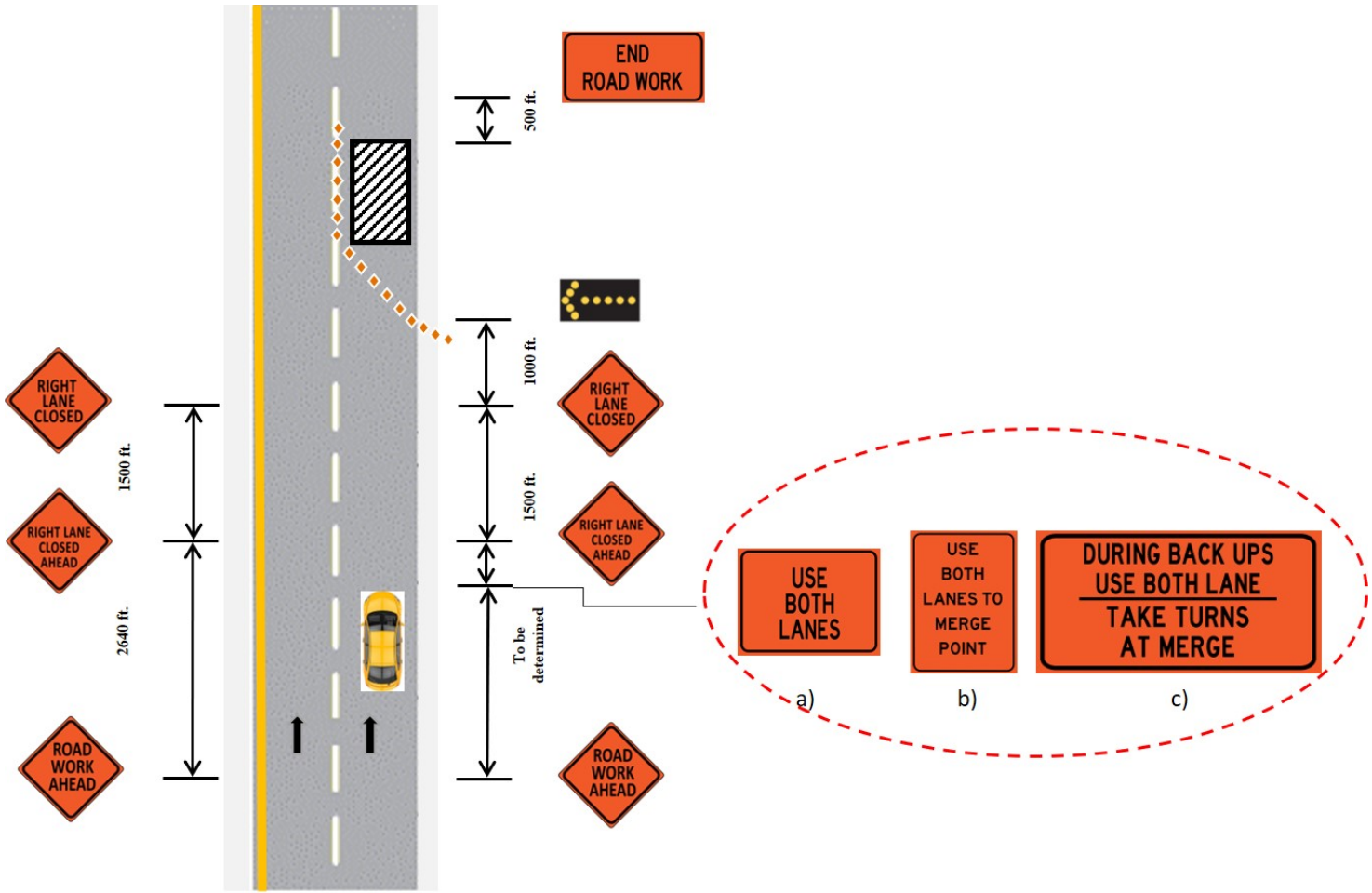
[ ] Sign a) 

[ ] Sign b) 

[ ] Not sure

Explain your choice:_____

11. **Assume you are approaching a zipper merge work zone in the yellow car. Choose your preference for signs located on the way to the work zone. Choose the wording of either (a), (b), or (c)**



[ ] Sign a)

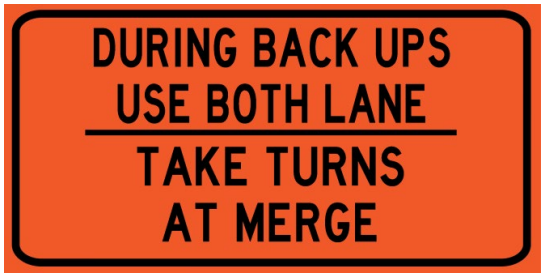
[ ] Sign b)

[ ] Sign c)

[ ] Not sure

Explain your choice: _____

12. How would you react when you see this sign?



a) Merge right now

b) Merge when I reach the work zone

c) I will do the same thing as everyone else

d) The sign makes no sense

13. In the same scenario, how would you react if you saw this sign?

a) Merge right now

b) Merge when I reach the work zone

c) I will do the same thing as everyone else

d) The sign makes no sense

14. Of the two signs you have seen so far, which one do you prefer?

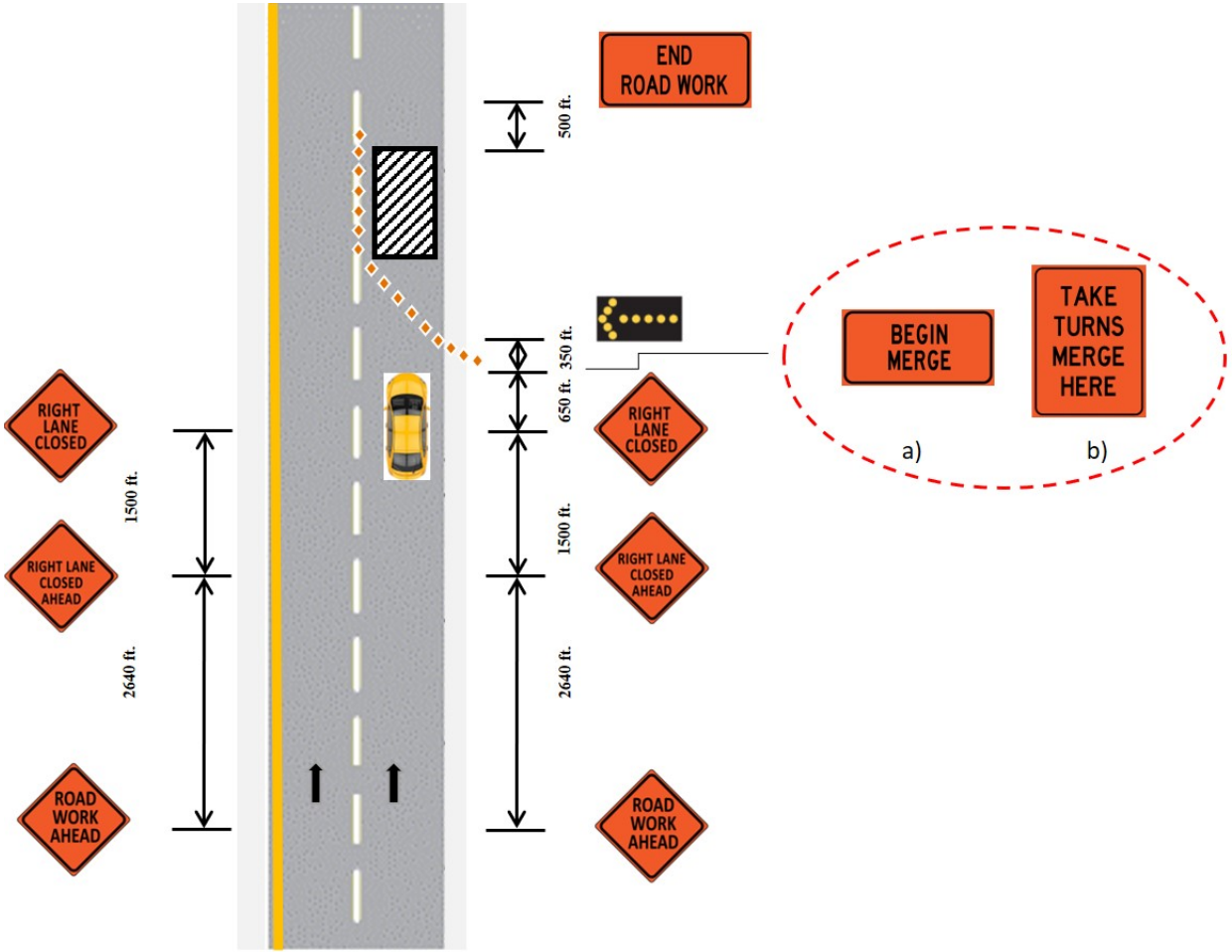
[ ] sign a)

[ ] sign b)

[ ] Not sure

Explain your choice _____

15. **Assuming you are approaching a zipper merge work zone in the yellow car. Choose your preference for signs located at merge point. Choose the wording of either (a), (b), or (c)**



[ ] Sign 

a) [

] Sign b) [ ] Not sure

Explain your choice:_____

16. Of the two signs below, which one do you prefer?

[ ] sign a) 

[ ] sign b) 

[ ] Not sure

Explain your choice: _____

17. The concept of zipper merge is a good idea.

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

Explain: _____

18. While driving in the simulator, I felt like I was actually there on the highway.

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

19. While driving the simulator, I felt like I could drive around freely.

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

20. Did any issues arise during the use of the simulator?

[ ] Yes [ ] No

If yes, please explain the issue(s) that you experienced:

_____

_____

Please answer the following demographic questions.

21. What is your age range?

[ ] 18-25 [ ] 26-40 [ ] 41-55 [ ] 56-70 [ ] 71-95

22. What is your gender?

[ ] Male [ ] Female

23. What is your residency?

[ ] Urban [ ] Rural

24. What is your regular vehicle type?

[ ] Passenger Car [ ] Vehicle towing trailer [ ] Delivery/Moving Truck

[ ] Tractor trailer truck [ ] Bus

25. Please enter any additional comments you may have regarding this study.

_____

_____

If you are interested in participating in a future simulator study, please write your email address here:

Please feel free to invite your family and friends for the next simulator study.

Appendix F. Simulator Sickness Questionnaire

Simulator Sickness Questionnaire

Instructions: Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficult focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe

10. Fullness of the head	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eye closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Please contact Dr. Carlos Sun (csun@missouri.edu) for additional comments, concerns or information on this survey. Thank you for completing this survey! We greatly appreciate your time!

Appendix G. Summary of Select Educational Materials

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
Arizona	Article - Zipper merge: In the right situations, two lanes can be better than one	4/20/2017	An article on ADOT's website addressing what the zipper merge is, how to do it, where it has been and where it is being currently implemented in Arizona		Merge Here	Take Turns Merging	Zipper merging shortens back-ups	List other states using zipper merge		
Arizona	Article - ADOT tries out a different method for merging	2/11/2016	Engineers and other members of ADOT explain how the zipper merge is working well in certain construction zones in Arizona, as well as what the zipper merge is and how it works				Minimizes traffic congestion, reduced queues	there's nothing rude about this method" tries to assuage fears that the zipper merge may be rude, as that's how we've been taught to think about merging	Static and dynamic	

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
Arizona	ADOT piloting "Zipper Merge"	2/11/2016	Accompanying video to the article above		Merge Here, Merge Ahead, Use Both Lanes					
Colorado	Late Merge Video	N/A	A take on zipper merging from a child's perspective	Delays Ahead	Merge Here, Just Wait, Use Both Lanes, Take Turns, Merge Late	Take Turns, "I wish grownups knew how to take turns, we do this in school everyday" "people need to be courteous everywhere, especially on the road"	Easier, safer, and more polite		dynamic	Humor tactic
Colorado	CDOT Seeks Reduction of Project Traffic Delays	7/10/2013	Announcement of the commencement of the use of the zipper merge at construction zones.		Use Both Lanes During Congestion, Use Both Lanes to Merge Point, Take Turns		Improve traffic flow, reduce queues by as much as 35%, reduce frustration, reduce confusion		static and dynamic	

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
					Merge Here					
Colorado	Construction Update	10/19/2019	A construction update on a project in which CDOT asks public to zipper merge.		Use Both Lanes During Congestion, Use Both Lanes to Merge Point, Take Turns Merge Here					
Colorado	Construction Update	11/25/2019	A construction update on a project in which CDOT asks public to zipper merge.		Use Both Lanes During Congestion, Use Both Lanes to Merge Point, Take Turns Merge Here					

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
Colorado	Construction Update	N/A	Announcement of upcoming construction and a description of the zipper merge and recommendation to use it	Lane Closed Ahead			Decrease dangerous lane switching, crashes, and road rage			
Kansas	Construction Update	2016	Announcement by KDOT of first use of zipper merge in upcoming construction, along with a video and direction about how to zipper merge			Take turns, be considerat e	Shorter lines, safer, more fair, less driver frustration, Can be ticketed for obstructing zipper merging	Mentions other states using the zipper merge, specificall y Minnesota Dot and MoDOT		
Kansas	How to Zipper Merge	3/23/2016	Video released along with above article			Take turns	Shorter lines, safer, more fair	"Zip the urge to merge"		Humor tactic
Kansas	Zipper Merge Use Announcement	5/24/2016	Article detailing what to expect at zipper merge on highway at construction site							
Kansas	Translines Express	6/1/2016	KDOT's newsletter, which mentions the implementation of the zipper merge		"two lanes are both meant to be used while travelling", "follow the signs"	Don't block fellow drivers		Mentions Minnesota and Washingto n using the zipper merge, "zip the		

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
								urge to merge"		
Kansas	Translines Express	12/7/2017	KDOT's newsletter, which gives update on zipper merge and mentions the success of their video, which has was picked up by many US news outlets and even the London Mirror internationally.							
Michigan	Work Zone Safety	10/30/2016	Transcript of episode of podcast Talking Michigan Transportation, produced by MDOT, discussing recent road worker deaths and construction zone safety, including touching on zipper merges and how they facilitate this. Mentions using PCM's to control messages being given around work zones. Discusses that zipper merges most appropriate				Less back-up, safer	Zipper merge has been successful in other states		

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
			when going from 2 lanes to 1, and under congested circumstances, "Human behavior is a big part of what you deal with"							
Minnesota	How To Video	5/12/2011	MnDOT video detailing the benefits of zipper merges, also touches on what NOT to do, but mostly seems focused on benefits		Merge Here, Use Both Lanes, Merge Ahead	Take Turns	Shows video of traffic with zipper merge, vocalizes positive effects of it, Shows video of traffic without zipper merge and vocalizes adverse effects	@ 1:31 "Resist the urge to merge early" acknowledges acceptable social norm	Adjustable	

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
Minnesota	Instructional PSA	10/25/2011	MnDOT traffic engineer and state patrol member talk about how/why to zipper merge		Instructs that when traffic is light, merge early, but when traffic is heavy, zipper merge	Makes appeal to zipper merge on behalf of others, including construction workers	Lists 5 benefits of zipper merge, States fines that can occur for those blocking lanes or otherwise impeding traffic during a zipper merge	@ 0:59 "Resist the urge to merge early", seems like MnDOT's catchphrase		
Minnesota	Merge PSA	6/9/2011	A quick 15 second ad-type promotion of the zipper merge			"the correct, safe, and polite way to merge"		@0:05 "Resist the urge to merge early"		
Minnesota	Radio Spot	N/A	Radio ad for zipper merging		"use both lanes, follow the signs"	"the correct, safe, and polite way to merge"		@0:12 "Resist the urge to merge early"		
Missouri	Zipper Merge	2016?	Article introducing the zipper merge in Missouri. Specifically states conditions to continue early merging (light traffic/congestion) and when to zipper		Merge Like a Zipper. Wait to Merge. Take Turns		Reduce difference in speed between 2 lanes. Reduce length of back-ups.	Resist the urge to merge.		

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
			merge (heavy traffic/congestion).				Reduce road rage.			
Missouri	Zipper Merge: Kids, Adults in Cardboard Cars and Taking Turns	7/5/2016	Video included in article above illustrating how to do the zipper merge. Includes comments from kids watching adults demonstrate different types of merges in cardboard cars			"why don't they take turns?"	"they're moving a lot faster"			Humor
Montana	Zipper Merges	7/5/2018	Video accompanying article above	Signs included below	Signs included below	"zipper merges, the nicest way to handle merging"	"merging right away means more stress, more accidents, and...it slows everybody down"	"most people want to be nice, when you see a sign to merge you merge right away"	dynamic	Humor
Nebraska	Do the Zipper Merge!	11/1/2016	Article describing the zipper merge, stating how and when to do it, when not to do it, and the			Creates a sense of fairness and equality,	Reduces differences in speeds b/t 2 lanes, reduces backup,		dynamic	

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
			benefits that it can produce				reduces congestion			
Nebraska	Do the Zipper Merge!	11/1/2016	Video released along with above article	Left Lane Closed 1/2 Mile		"everyone benefits"	Reduces backups, reduces accidents, reduces road rage			
Nebraska	Zipper Merge Use Announcement	11/1/2016	Detailed description of zipper merge process in certain construction project and what drivers should expect		Use Both Lanes to Merge, Merge Here	Take Turns	"improve traffic flow", Reduce congestion, reduce confusion			
North Carolina	Dynamic Zipper Merge	2019/2020	Description of the Dynamic ZM, what it is, how to do it, and why it is beneficial	Traffic Has Stopped 2 Miles Ahead, Slowed Traffic Is A Mile Ahead	Use Both Lanes To Merge Point, Merge Here Take Turns		Safer, Less backups		dynamic	
North Carolina	Safety & Mobility	N/A	Update regarding measures to improve safety and efficiency in NC traffic, links to Dynamic ZM page and has short description of it				Smoother merging conditions, Reduced backups			

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
North Dakota	NDDOT - zipper merge	9/13/2017	Video explaining the zipper merge.	Merge Ahead	Merge Left, Take Turns, Use Both Lanes		Less congestion, less crashes, less stress		dynamic	
Oregon	Construction Update - Beltline Highway weekend lane closures	1/31/2020	Includes instructions on how to zipper merge, a link to a how-to video, and including a reference to signs.		Use both lanes	Take turns at the merge point	Faster, safer			
Pennsylvania	PennDOT Announces Change in Traffic Pattern on I-99 Project	6/14/2018	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging, not allowing other drivers to late merge may result in citations			
Pennsylvania	Zipper Merge Graphic	N/A	Zipper merge graphic			Take turns Merge here				
Pennsylvania	PennDOT Announces 2016 Lawrence County Highway and	3/20/2017	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce			

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
	Bridge Improvement Projects						aggressive merging			
Pennsylvania	PennDOT Announces 2016 Beaver County Highway and Bridge Improvement Projects	3/9/2016	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Pennsylvania	PennDOT Announces 2018 Lawrence County Highway and Bridge Improvement Projects	3/5/2018	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Pennsylvania	PennDOT Announces 2018 Beaver County Highway and Bridge Improvement Projects	3/5/2018	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Pennsylvania	2019 Lawrence County Highway and Bridge	N/A	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce			

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
	Improvement Projects						aggressive merging			
Pennsylvania	PennDOT Announces 2016 Allegheny County Highway and Bridge Improvement Projects	3/9/2016	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Pennsylvania	PennDOT Announces 2017 Allegheny County Highway and Bridge Improvement Projects	3/20/2017	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Pennsylvania	PennDOT Announces 2018 Allegheny County Highway and Bridge Improvement Projects	3/5/2018	Instructs drivers to late merge at work zone			Take turns merging	More fluid traffic, Reduce queue, reduce aggressive merging			
Vermont	VTrans to Try New Merging Pattern on I-89 at French Hill	7/26/2013	Announcement of the use of the zipper merge on			Take Turns	Reduce delays	Other states have used it	dynamic	

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
	Starting Monday Afternoon		certain construction location					successful ly		
Virginia	VDOT News - Fredericksburg	11/28/2018	News announcement about new signs being used to promote zipper merging	Single Lane Ahead			More efficient, better traffic flow, safer, Reduce congestion			
Virginia	Take Turns at the Merge on Route 627 in Spotsylvania County	11/28/2018	New signs posted to encourage zipper merging at congested point							
Washington	Traffic Operation 2017-2019 Low Cost Enhancement Program	3/2020	Two mentions of zipper merge implementations on construction projects							
Washington	Pilot Project: Zipper Merge	8/23/2019	Interesting project where Washington implements a zipper merge as a PERMANENT traffic solution on a congested area		Merge late	Take turns	Reduce congestion, reduce crashes, reduce backups, reduce delays			
Washington	Zipper Merge - applying the 'taking turns' approach to keep traffic moving	6/10/2019						Spends A LOT of time convincing that zipper merge is		

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
								not rude, and is actually better for everyone		
Washington	WSDOT Zipper Merge: Merge late, cooperate!	6/10/2019	Video accompanying above article		Use both lanes and merge late	It's okay to take turns				
Washington	Zipper Merge Project Announcement	N/A	Announcement of use of permanent zipper merge in area accompanied by a neat little graphic							
Washington	Zipper Merge Project Announcement	N/A	Written summary that goes along with the above graphic. The summary describes and explains the zipper merge, encouraging drivers to cooperate							
Wisconsin	Zipper Merge - What Is It and Why Is It Effective?	6/2/2016	Public facing communication explaining what a zipper merge is and why it is beneficial							

State	Item	Date	Summary	Infor-mation Only	Instruc-tions Only	Emotion-al Appeals	Appeals to Reason	Social Norm	Type of Signs	Humor
Wisconsin	Work Zone Safety	N/A	Work zone safety announcement that mentions zipper merging as a step in maintaining greater work zone safety for workers and drivers.	Lane Closed Ahead						