Evaluation of Messaging Techniques to Increase Vehicle Spacing at Work Zones

Final Report
September 2023

SWZDI
Smart Work Zone Deployment Initiative

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16. Abstract

Rear-end collisions in work zones, induced primarily by speeding and tailgating, are a predominant concern for roadway safety. Although considerable research has shed light on the dangers and implications of speeding within these zones, there exists a conspicuous research gap on tailgating behaviors.

To address this gap, the present project was conducted in two main phases. In the first phase, a message design and comprehension test involved the development of graphics and messages tailored for both fixed signs and dynamic message signs (DMS). These messages were constructed to ensure not only that drivers understood them with ease but also that the messages emotionally resonated with drivers and conveyed positive sentiments. In the subsequent field test phase, the designed signs were installed in work zones to evaluate their effectiveness in real-world settings. Two key performance metrics, namely, the average vehicle headway and the probability of tailgating occurrences, were used for this evaluation.

Preliminary surveys among potential users indicated a strong inclination towards messages with a positive tone and without numerical specifics, underscoring the importance of the messages' lucidity and favorable reception. Field evaluations carried out at single-lane closure and shoulder closure construction sites demonstrated the efficacy of the signs evaluated in the surveys. There was an increase in average vehicle headway and a reduction in the probability of tailgating occurrences at both sites. Collectively, this research provides meaningful insights into tailgating behaviors in work zones, bridging the knowledge gap and laying a foundation for work zone safety strategies.

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EVALUATION OF MESSAGING TECHNIQUES TO INCREASE VEHICLE SPACING AT WORK ZONES

Final Report
September 2023

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EXECUTIVE SUMMARY

Following too closely (tailgating) is a persistent issue throughout the roadway system, and its consequences can be particularly severe in work zones. In fact, rear-end collisions are the most common type of crash in work zones. Maintaining sufficient car-following gaps allows drivers enough time to react to unexpected and complex situations in work zones and thus can reduce the potential for rear-end collisions.

This project developed anti-tailgating messages through a rigorous user comprehension test and deployed them in work zones to evaluate the effectiveness of the messages. Through a review of the state of the art and the state of the practice, measures and techniques that encourage drivers to maintain proper spacing were identified and summarized. Messaging techniques that encourage safe following distances in work zones were developed and presented to potential users in a preliminary survey, and the effectiveness of those messages were evaluated in real-world scenarios using vehicle speed and car-following (headway) data collected from sensors deployed in work zones.

In the survey phase, an array of anti-tailgating messages and sign graphics was developed and evaluated. Positive messages, such as PREVENT CRASHES and KEEP YOUR DISTANCE, demonstrated high intelligibility and evoked positive impressions among respondents. In contrast, negative-toned messages and specific numerical values for recommended following distances were often perceived as confusing. Therefore, signs that employ positive tones ranked highly in terms of comprehension and impression. These findings guided the selection of a fixed sign and a rotation of five daily anti-tailgating messages for implementation in work zones.

In the survey-based comprehension testing process, designs featuring graphics alone exhibited lower comprehension than text-based signs. This finding must be interpreted with great caution, as the sample population consisted almost entirely of native English speakers. Additionally, graphical traffic signs typically have a much larger legibility distance than text, an effect that was not captured in the pen-and-paper format of the surveys.

Field tests were conducted at two construction sites: a single-lane closure site on US 30 and a shoulder closure site on I-80. In the single-lane closure site, it was found that the use of overhead dynamic message signs, fixed signs, or a combination of both led to a significant increase in the average headway of drivers within the construction zone compared to upstream locations. Additionally, a marked decrease in severe tailgating events was observed with the installation of fixed signs. In the shoulder closure site, where lane changes were allowed between the two open lanes, the benefits of the anti-tailgating messaging methods were confirmed through the implementation of both portable dynamic message signs and fixed signs. The implementation markedly increased the average headway in both lanes and decreased the probability of tailgating occurrences in the right lane, suggesting a positive impact on traffic safety.

Ultimately, this research improves our understanding of tailgating behavior within work zones and provides a foundation for improved work zone safety strategies.

1. INTRODUCTION

Construction sites represent a veritable crux of traffic flow dynamics. They are complex and transitory and represent operational circumstances that deviate significantly from the standard driving conditions drivers are accustomed to. As sections of roadways that are temporarily transformed for construction or maintenance purposes, they incorporate advanced warning zones, activity areas, transition segments upstream and downstream, and termination zones. Each of these components has its own set of traffic regulations, safety protocols, and environmental considerations.

The interaction between these factors has far-reaching implications for traffic flow and safety. Among these, the most pronounced consequence is the increased risk of vehicular collisions. In particular, rear-end collisions emerge as the most dominant type of crash in these areas. According to 2014 statistics compiled by the Federal Highway Administration (FHWA), such accidents account for more than half of all reported work zone crashes. This statistical dominance underscores a critical behavioral pattern: tailgating or following too closely, one of the main causes of rear-end collisions in work zones.

Tailgating is not an anomaly exclusive to work zones; it is a ubiquitous issue in roadway systems around the world. However, its implications are considerably enhanced within the confines of a work zone. When vehicles follow too closely, they drastically reduce their available reaction time to accommodate unexpected changes in traffic flow, sudden braking by the vehicle in front, or unforeseen obstacles. This temporal crunch in reaction time is particularly potent in work zones, given their unpredictable nature and the potential for unexpected shifts in traffic patterns. The scientific literature constantly stresses the importance of maintaining optimal car-following gaps. Sufficient spacing between vehicles gives drivers the much-needed time to respond to sudden stimuli. This buffer is of paramount importance in complex driving environments, such as work zones.

Although the hazards of tailgating are universally recognized, the specific context of work zones and the potential benefits of tailgating countermeasures therein have received relatively limited attention in roadway safety studies. Several factors compound the risks associated with tailgating in work zones:

- **Environmental complexity**. The transformed geometries of work zones introduce drivers to unfamiliar terrain. With narrow lanes, repositioned alignments, and the visible presence of construction personnel and machinery, the cognitive demand on drivers increases.
- **Dynamic nature**. Work zones are transitory and changing. Frequent speed limits reversals, unpredictable lane closures, and changing vehicle routes can catch drivers off guard, especially if they are tailgating.
- **Speed variations**. One of the precursors to rear-end collisions, especially in work zones, is inconsistent speed. Although speed limits may be lowered in work zones, not all drivers adhere to these reductions, and differences in speed between vehicles can lead to situations conducive to tailgating. Moreover, sudden braking due to unexpected conditions can cause rear-end crashes, especially when vehicles are moving at high speeds.

- **Differential vehicle dynamics**. Different vehicles have different braking capabilities and sight restrictions. For example, the braking dynamics of a sedan differ considerably from those of a cargo truck. These divergences can increase the risk of tailgating, particularly when mixed vehicle types converge in the limited space of a work zone.

Addressing tailgating within work zones is not just a question of enhancing vehicular safety; it is imperative. The unique challenges posed by work zones, coupled with the inherent dangers of tailgating and speed variations, require proactive interventions. In essence, work zones, with their shifting terrains and regulations, amplify the dangers of tailgating and speed disparities. There is a pressing need for research that focuses on strategies and interventions that target these behaviors in such contexts. Therefore, this project seeks to fill this void by devising, implementing, and evaluating anti-tailgating messaging strategies aimed at mitigating tailgating tendencies and the consequent risks of rear-end collisions in work zones.

The following chapters of this report are organized as follows. In Chapter 2, the review of the literature delves into existing knowledge, highlighting previous endeavors in the realm of anti-tailgating countermeasures and the available technology for this purpose, thus setting a foundational understanding for the scope of this study. The methodology described in Chapter 3 elucidates the strategic underpinnings of this research, dissecting both the safety graphics comprehension testing paradigms and techniques used to evaluate the effectiveness of messaging techniques. In the results presented in Chapter 4, empirical data take center stage, offering an analytical portrayal of the outcomes from our on-ground sign deployments. This chapter provides tangible evidence of the real-world efficacy of the messaging strategy evaluated in this study. Lastly, the conclusions in Chapter 5 synthesize all of the previous insights, providing a holistic perspective on the relevance and implications of our findings within the broader context of work zone safety. The multipronged approach of this research ensures a balanced blend of theoretical knowledge, methodological robustness, empirical evidence, and interpretative insights and caters to both academic and practical audiences.

2. LITERATURE REVIEW

Tailgating remains a perennial challenge in the realm of traffic safety, and over the years numerous interventions have been investigated to mitigate this risk. This literature review seeks to systematically document and evaluate the extensive body of research pertinent to anti-tailgating treatments.

Pavement Markings

One of the foundational approaches explored is the use of pavement markings to deter tailgating. Helliar-Symons et al. (1995) evaluated chevron markings in a field test, applying them at a spacing of 40 m in a zone with a speed limit of 60 mph. The researchers' primary measure of effectiveness (MOE) was the number of crashes, which showed a significant reduction of 56% after the intervention. Another variant of pavement marking, the dot marking, was explored by Lertworawanich (2010). In his field study with dot markings spaced at 35 m, the MOE was distance headway. It was observed that these markings effectively increased the distance headway, though the exact magnitude was not specified.

Signage

Static and dynamic signage with clear messaging has also been a focal point in tailgating studies. Rämä and Kulmala (2000) implemented a field test examining the effectiveness of signage under two conditions: good road conditions and slippery road conditions. The MOE, the percentage of short headways, showed reductions ranging from 28% to 47% in good conditions and from 12% to 47% in slippery conditions. Michael et al. (2000) evaluated fixed message signs in a field test with varying speed limits (35 to 40 mph) and messages. The researchers found that while the message "Please Don't Tailgate" had no measurable impact on headway, the longer message "Help Prevent Crashes, Please Don't Tailgate" improved headways from 2.11 seconds to 2.29 seconds. In a driving simulator study, Wang and Song (2011) investigated both fixed signs and dynamic message signs (DMS) with varying messages and reported increments in headway time across different sign types and messages, with some configurations showing improvements from 1.06 seconds to up to 1.40 seconds. In a driving simulator study, Almallah et al. (2021) tested variable message signs, comparing fixed signs with graphic plus message signs. In conditions that simulated a warning of a work zone with a downstream lane closure, the primary MOE was the spacing. The results indicated that the spacing increased significantly after the introduction of the tailgating warning sign.

In-Vehicle Warnings

Recent technological advancements have facilitated the exploration of in-vehicle warnings for anti-tailgating. Hang et al. (2022) used a driving simulator to test the effects of leading vehicle brake warnings and "lane closed" warnings under varying conditions, such as clear and foggy weather. The MOEs included brake reaction time and minimum time headway. The findings suggested an increase in brake reaction time and headway, although not with significant differences. Merrikhpour et al. (2014) employed a unique feedback-reward system in a field test. The researchers' phased approach involved a baseline phase (without feedback), an intervention phase (with feedback and reward), and a post-intervention phase. The MOE was headway compliance in terms of percentage. Interestingly, the researchers observed a spike in compliance of 3.67% in the high-compliance group and a significant 18.27% in the low-compliance group during the intervention phase. Hurwitz and Wheatley (2001) evaluated headway warnings through a driving simulator test. Under normal conditions, the results showed an increase in headway after the introduction of warnings.

Collaborative Measures

Some studies have embraced a collaborative approach, combining multiple interventions. The Minnesota Tailgating Pilot Project (Minnesota DPS 2006) combined pavement markings with fixed message signs in a rural driving environment. The MOE was the average gap (in seconds), which was found to expand from 2.35 seconds to 2.52 seconds post-intervention. In a separate study, Wang and Song (2011) combined educational videos with message signs in a driving simulator test. The results were profound, demonstrating dramatic headway increases in scenarios with fixed signs and DMS. Lastly, Greibe (2010) implemented a field test that utilized both chevron markings and warning signs. The MOE, the percentage of short gaps (1 or 2 seconds), showed reductions of up to 11% for 1-second gaps and up to 4% for 2-second gaps. Although applications of these technologies have been limited in the United States, anti-tailgating edge line markings (Figure 1) are standard practice in France and some other Francophone countries (French Ministry of Ecology, Sustainable Development, and Energy 2016).

Figure 1. Anti-tailgating edge line markings and signage on Autoroute A40 in Magland, Haute-Savoie, France, 2017, with signs reading "1 Stripe Danger, 2 Stripes Safety"

Summary of Research on Anti-tailgating Treatments

In summary, various anti-tailgating interventions have been studied, including pavement markings, signage, in-vehicle warnings, and collaborative measures. The effectiveness of these interventions varies, but collectively these measures show the potential to curb tailgating and improve road safety. However, most research on anti-tailgating in work zones has predominantly used driving simulations; there is a pressing need for studies within real-world work zones to truly grasp the efficacy of these anti-tailgating techniques.

Message Design (Survey)

Previous road safety research indicates that the formulation of road safety messages strongly influences public acceptance of the messages. Furthermore, a positively framed message and a negatively framed message could influence driver choices differently.

For example, Whitelegg (2015) suggested a shift from negative road safety messages emphasizing the consequences of unsafe behavior to positive messages highlighting the benefits of safe behavior. This approach aligns with the findings of public health research such as a study by Notthoff and Carstensen (2014), which showed that people who are informed about the benefits of walking participated in the activity more than those who are informed about the negative consequences of not walking. Lewis et al. (2008) compared the effectiveness of humor- and fear-based messages targeting intoxicated driving and found that although negative appeals were more persuasive immediately after exposure, positive appeals had a more substantial long-term impact.

However, the differential impacts of positive and negative anti-tailgating messages have not been compared in previous research.

3. METHODOLOGY

This research was motivated by the urgent need to improve driver comprehension of anti-tailgating messages and induce constructive emotions regarding those messages, both of which would subsequently lead to safer driving practices. Therefore, the study was divided into two phases (Figure 2).

The initial phase of the research focused on the meticulous design and selection of graphics and messages for both fixed signs and DMS. Based on a detailed understanding of the driving environment in which the messages would be delivered, the chosen designs sought to promote greater understanding and positive emotions among drivers. The selected designs were made in accordance with American National Standards Institute (ANSI) standard Z535.3 (ANSI 2022). This standard serves as a blueprint for the design, evaluation, and application of safety symbols, with the overarching aim of identifying and preventing hazards and personal injury. The carefully selected signs were subsequently evaluated for comprehensibility and positive or negative sentiment through a three-stage survey of potential users.

The subsequent phase involved extensive field testing to investigate the impact of anti-tailgating messages on traffic flow within specific construction environments, namely single-lane closure and shoulder closure sites. Because the messages were installed in actual work zones, the researchers could assess their true effectiveness in a real-world setting. This phase underscored the vital connection between theory and practice, as the team navigated the intricacies of message content and legal compliance. The key metrics used to evaluate effectiveness included average headway and probability of tailgating occurrences. To implement the graphic signs, a request to experiment was submitted to the Federal Highway Administration (FHWA) *Manual on Uniform Traffic Control Devices* (MUTCD) team. However, the request required an additional legibility test, which was outside the scope of the project. This prompted a modification to the approach, leading to the removal of graphics from the fixed signs. The placement of both DMSs and fixed signs within the construction zones was executed with strategic precision, ensuring that they did not interfere with other safety and information signs. This placement was informed by valuable information from construction personnel and traffic safety experts, reflecting a collaborative and multidisciplinary approach.

Through these two comprehensive phases, this research represents a novel endeavor to explore the intersection of design, psychology, and road safety within the unique environment of construction zones. The methods used are characterized by rigorous adherence to standards, careful balance of aesthetics and functionality, and a keen awareness of practical constraints and legal requirements. The following sections will go into the methodology in more detail, elucidating the techniques, challenges, and innovations that defined this study.

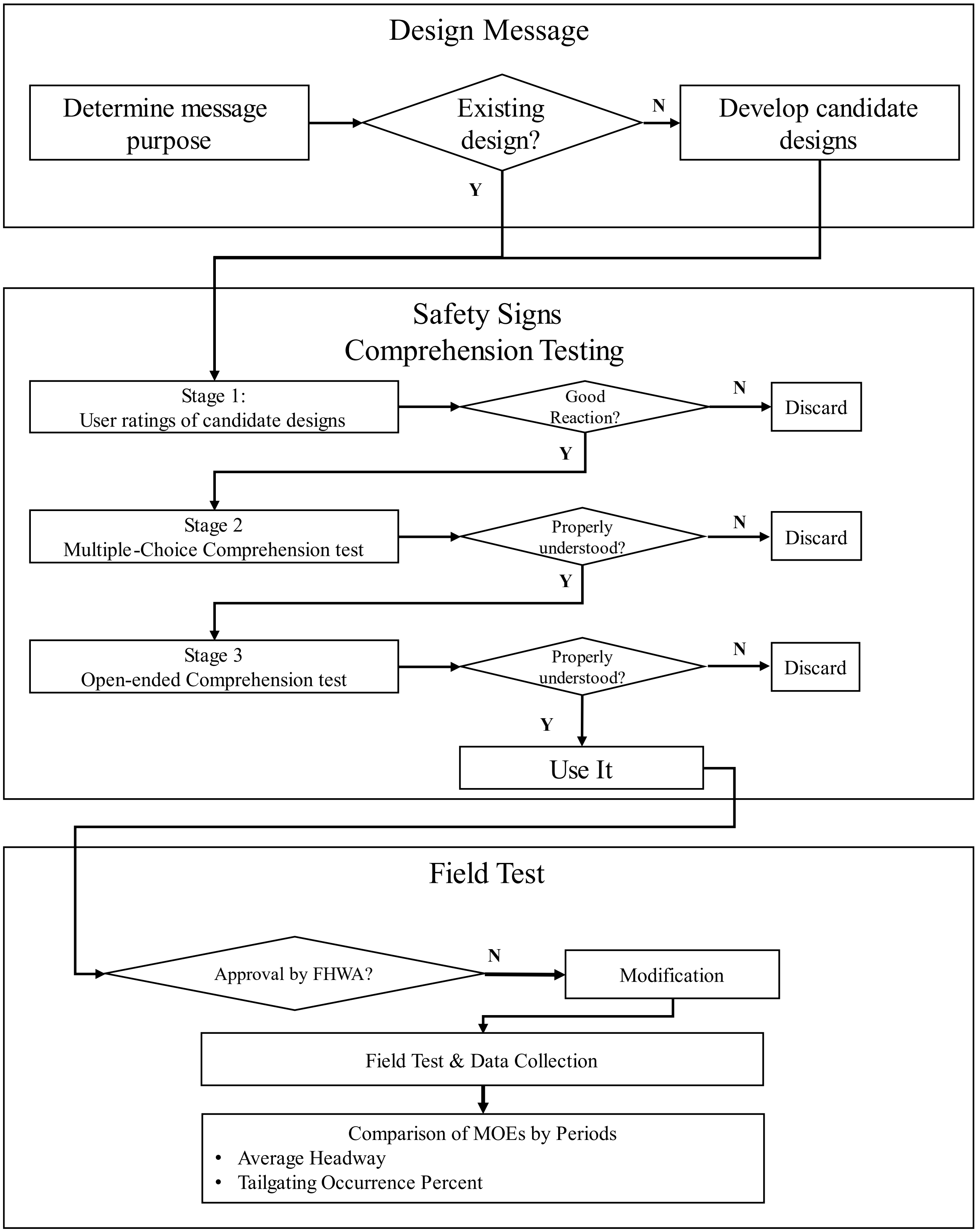


Figure 2. Research framework

Phase 1: Message Design and Comprehension Testing

When crafting the content for anti-tailgating message signs, the research closely followed the guidelines laid out by ANSI standard Z535.3 (ANSI 2022). This specific standard delineates a structured process for the design, evaluation, and deployment of safety symbols, with the primary objective of identifying and warning against potential hazards and possible harm to individuals (Shaw et al. 2017). To kickstart the design process, the study convened a diverse panel of experts that included traffic safety professionals, traffic engineers, and renowned academic researchers. Their collective responsibility was to brainstorm and devise messages specifically targeting the reduction of tailgating tendencies in work zones. This task began with an exhaustive review of preexisting design blueprints, which then paved the way for the creation of fresh design contenders. Each of these new contenders emerged from the wealth of expertise and recommendations presented by the panel.

To ensure the robustness and reliability of the generated designs, surveys of the traveling public were conducted in a strict three-phase comprehension assessment procedure, as illustrated in Figure 3.

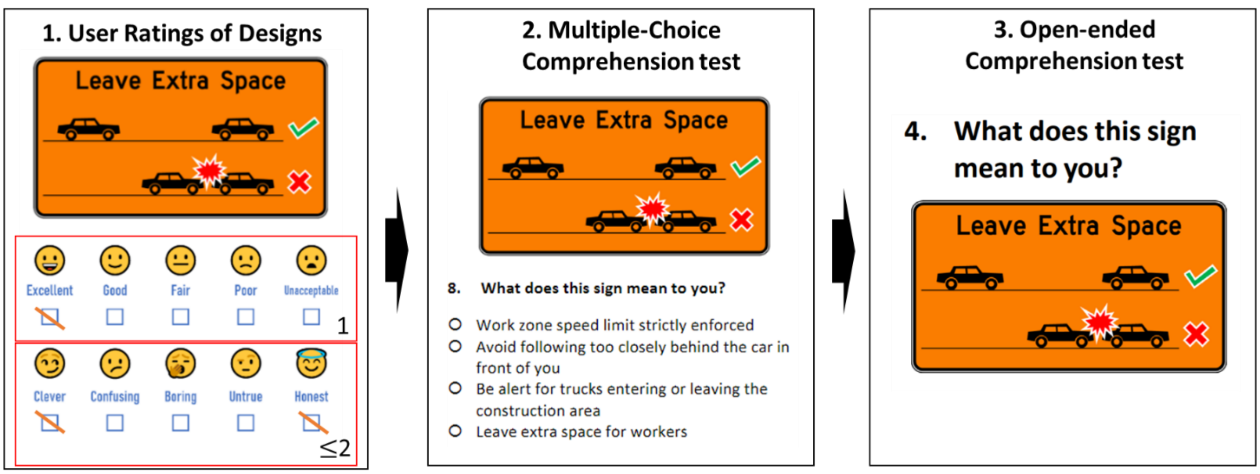


Figure 3. ANSI Z535.3 survey process

Stage 1. User Rating of Candidate Designs

The initial stage consisted of a user-oriented assessment. Participants were provided with a meticulously designed pen-and-paper survey. They were tasked with rating the clarity and comprehensibility of the suggested messages and graphics using a well-defined five-point Likert scale, which spanned from “Excellent” to “Unacceptable.” Additionally, respondents were encouraged to associate a maximum of two distinct sentiments or reactions with the message set, with options including clever, confusing, boring, untrue, and honest. This approach was geared towards gauging the participants’ immediate cognitive and emotional reactions to the proposed design prototypes. The responses were divided into two reaction types: positive and negative. The “clever” and “honest” reactions were considered positive reactions, and the rest were considered negative reactions. Here, the survey administrators explained in detail the purpose of conducting this survey and the design and intention of each sign and graphic to the participants. The first-stage survey form is provided in Appendix A.

Stage 2. Multiple Choice Comprehension Test

After the initial user rating evaluation in the first stage, those design concepts that garnered high comprehension scores and evoked largely positive feedback progressed to the subsequent evaluation stage. Here, participants, through a structured pen-and-paper survey, were asked to choose one of four possible reactions. However, in contrast to the first stage, the survey administrators did not provide a detailed explanation to the participants regarding the purpose of conducting the survey and the design and intent of each message and graphic to avoid suggesting any clues to deciphering the meaning of each design. The second-stage survey form is presented in Appendix B.

Stage 3. Open-Ended Question Comprehension Test

The third stage focused on gaining a deeper understanding of the participants' interpretations of the shortlisted designs, with participants again given no suggestion to help them determine the intent and meaning of the designs. Through open-ended questions on a pen-and-paper survey, insights were collected on the clarity, perceived intent, and effectiveness of each design. This stage culminated in the identification of design candidates that would be suitable for both fixed signs and DMS, primarily based on consistently high comprehension metrics. These finalist designs then underwent field tests for practical validation. The third-stage survey form is provided in Appendix C-1.

To maintain the rigor of the survey and ensure genuine responses, all three stages of the comprehension assessment intermingled standard and experimental signs. The intent was to discourage participants from offering redundant or biased responses due to prior exposure. As an illustration, the standard MUTCD W4-2 LANE ENDS sign was seamlessly integrated alongside a novel graphic that had demonstrated promise in previous research efforts. Additionally, a total of five questions were added to the last page of each pen-and-paper survey to investigate the driving experience and linguistic background of the respondents:

- Do you have a driver's license or permit?
- What is your primary language?
- Which best describes your gender?
- Age
- How many hours do you drive each week?

The logistics of the survey administration were meticulously planned as follows:

- The initial survey was carried out at two strategically chosen Department of Motor Vehicles (DMV) offices, one in Ames, Iowa, where the survey was conducted on April 15, 2022, and one in Ankeny, Iowa, where the survey was conducted on April 22, 2022.

- The subsequent multiple-choice comprehension survey was conducted at the Ankeny DMV on April 29, 2022.
- The open-ended comprehension survey was conducted at the Ankeny DMV on June 22, 2022.

Phase 2: Field Evaluation of Messaging Techniques

Field experiments were meticulously planned and executed to investigate the impact of the designed anti-tailgating messages on traffic flow dynamics. The primary focal points of these tests were drivers' reactions to anti-tailgating signs and messages, particularly in two specific scenarios: (1) at a construction site characterized by a single-lane closure and (2) at a construction site with only a shoulder closure. Such environments are typically replete with challenges, and it was crucial to assess the effectiveness of messaging within these real-world settings. A noteworthy challenge that the researchers faced was a misalignment between the study's proposed timeline and the stringent requirements set forth by the FHWA for experimental procedures. This required a recalibration of the original plan. As a consequence, graphic elements, initially intended to be part of the fixed signs, were omitted. Instead, the research team crafted a text-centric design that meticulously aligned with the standards prescribed in the 2009 edition of the MUTCD.

The original intent of the project was to display anti-tailgating messages on static signs and portable changeable message signs (PCMS) in the selected work zones. Since previous work indicated that tailgating was more likely to occur in free-flowing traffic with demand approaching the capacity of the roadway, the plan was to trigger the PCMS messages dynamically based on combinations of traffic flow rate and speed. Unfortunately, due to software issues, dynamic triggering of the PCMS messages could not be implemented during the construction season. Instead, the messages were displayed during peak hours on DMS or PCMS located in work zones. A complementary message was also provided on two static signs.

Such a pivot in design philosophy did not compromise the core objective of the study. When implementing signs, be they DMS or fixed signs, a strategic approach was embraced. The signs' positioning within the construction zones was executed with the utmost precision, ensuring that they seamlessly complemented and did not interfere with other essential safety directives or information markers. This careful placement was deeply informed by invaluable insights from those on the ground, construction workers who were familiar with the intricacies of the site, and traffic safety mavens who brought expertise on how drivers would likely react.

The choice of the sites for these critical field tests was also not a trivial matter. The decision to opt for the state of Iowa was driven by a host of practical considerations. The team carried out a systematic assessment of the ongoing construction sites in the state, evaluating them against a variety of criteria. These included the expected duration of construction work, the typical volume of traffic the work zones experienced, and recorded instances of tailgating. For clarity, tailgating was rigorously defined as situations where the headway was one second or less and where vehicles traveled at speeds exceeding 45 mph.

This comprehensive site selection process culminated in a technical committee meeting to assess candidate sites and determine where the field studies would be ultimately conducted. This assembly was characterized by its diverse representation, including traffic safety experts, experienced researchers passionate about the topic, and department of transportation (DOT) representatives from several states. Through deliberations and data-driven discussions, the committee reached a consensus, choosing the most suitable sites that would offer robust and reliable findings.

Data collection was performed using the SpeedLane Pro from Houston Radar. SpeedLane Pro is a state-of-the-art, energy-efficient, multilane traffic measurement radar based on dual-beam "speed trap" technology that ensures precise measurements without requiring on-site calibration. The device is approved by the Federal Communications Commission (FCC) and Conformite Europeenne (CE) for a full 250 MHz operation and can be non-intrusively mounted on the side of the road, functioning flawlessly in all weather and lighting conditions. The device can simultaneously measure vehicles across 16 user-defined lanes, providing detailed data for each vehicle in every lane in real time, which is stored in its memory. These data include vehicle counts, length-based class, average and 85th percentile speeds, occupancy, headway, and gap measurements. The SpeedLane Pro also features a 1.3 MP HD video camera to facilitate remote traffic monitoring.

The radar can be interfaced with through a companion Windows application, which offers an intuitive GUI for configuration, real-time plots of targets, and HD video viewing. For connectivity, the device integrates Class I 2.1+EDR Bluetooth, RS232/RS485 serial ports, and Ethernet, and it has 512 megabytes of internal storage with an additional SD card slot. Developers can utilize the comprehensive Houston Radar protocol, along with C and C# SDKs. For data retrieval, there is a robust SQL-based query interface to access historical data. In addition, several optional features are available, such as cloud-based server integration for data aggregation, a UPS with a rechargeable battery that lasts more than 24 hours, an MPPT solar charger, an internal 96 Wh LiFePO4 battery, a penta-band GSM cellular modem, PoE, and additional Ethernet capabilities (Houston Radar n.d.). The speed measurement error for this equipment has been found to range from 1% to 3%, with a traffic volume error of less than 3% (Vickich 2019).

Single-Lane Closure Construction Site

Located on US 30 near Cedar Rapids, Iowa, the primary site for this study was selected based on its ongoing reconstruction activities surrounding the Cedar River bridge. Renovation work on the eastbound bridge began on March 14, 2022, and concluded with the reopening of the eastbound lanes on October 20, 2022. Throughout 2022, this particular site reported an annual average daily traffic (AADT) of 11,750 vehicles. Construction activities predominantly influenced eastbound traffic, given the closure of the right lane. This forced vehicles to streamline their movement into a single operational lane.

To mitigate the risk of tailgating under these conditions, a combination of fixed signs and an overhead DMS was deployed. Two fixed signs specifically designed for this purpose were anchored on the right side of the driving direction. The first, stationed upstream, aimed to increase awareness of the dangers of tailgating. A downstream sign, supplemented by an overhead DMS, was strategically placed to directly modulate and influence driver behavior. The overhead DMS remained active only during peak traffic hours, from 14:00 to 17:00 on weekdays (Figure 4).

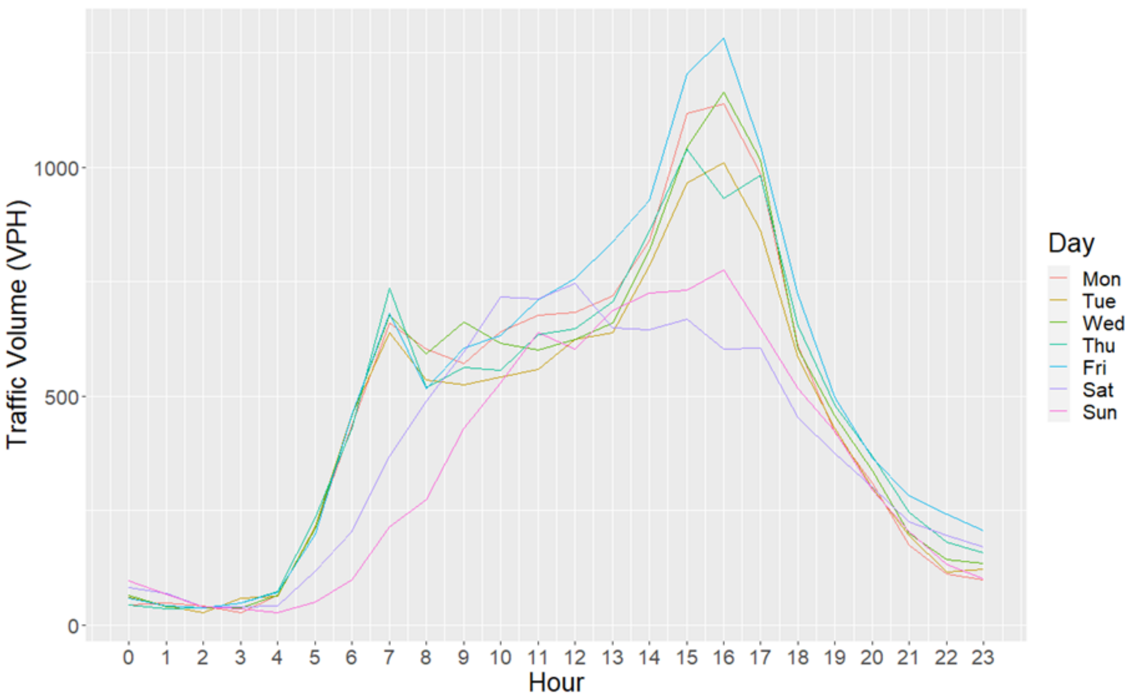


Figure 4. Traffic volumes by time of day and day of week at the single-lane closure construction site

In an effort to capture comprehensive traffic data and evaluate the efficacy of the anti-tailgating messages, sensors were judiciously placed at strategic locations. The initial set of sensors was placed immediately after the fixed sign upstream to record the unaltered traffic behavior. Another set was installed after the downstream sign to capture traffic nuances after the influence of the anti-tailgating messages. To complement this, two Houston Radar sensors were integrated into the system on August 18, 2022. Their role was crucial in obtaining precise data on individual vehicle speeds and the headways between them. The construction site is shown in Figure 5.

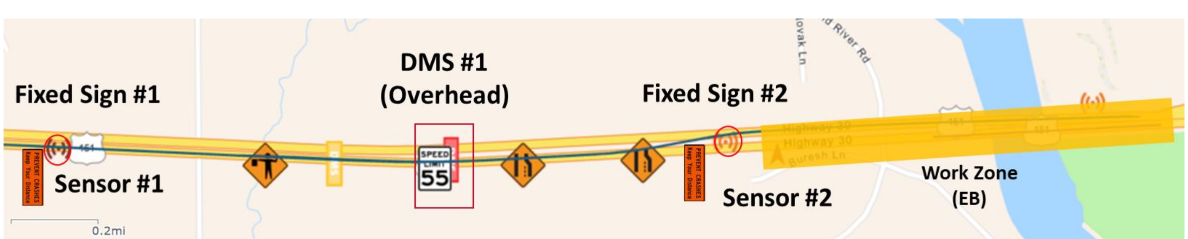


Figure 5. Single-lane closure construction site on US 30

To support the analysis, the study was classified into specific experimental periods:

1. **Baseline**. August 21 through September 10, 2022 (3 weeks)
2. **Only Overhead DMS**. September 11 through September 24, 2022 (2 weeks)
3. **Overhead DMS and Fixed Signs**. September 25 through October 8, 2022 (2 weeks)
4. **Only Fixed Signs**. October 9 through October 19, 2022 (10 days)

The message wording was originally designed to fit the technical limitations of the Iowa DOT's PCMS (3 lines of 8 characters). The same text was displayed on the overhead DMS, but the line breaks were altered to fit the larger aspect ratio of the DMS (2 lines of 17 characters). In normal circumstances, the overhead DMS displays messages from a statewide message program operated by the Iowa DOT called "Roadside Chat," which displays messages on permanently mounted dynamic message signs every Friday from 12:01 a.m. to 11:59 p.m. The program displays the year-to-date fatality counts of the roads, as well as conversation starter messages related to highway safety. No program-related messages are displayed from Monday to Thursday. For the present study, the anti-tailgating message was displayed on weekdays between 14:00 and 17:00, while the statewide Roadside Chat message was displayed outside these hours on Fridays. The display time for each message phase was 3 seconds, and the messages varied by day of week so that drivers would not become easily desensitized to the constant use of a single message. The following messages were displayed each day:

- Monday

- Tuesday

- Wednesday

- Thursday

- Friday

The initial design of the fixed sign was intended to combine both graphics and text. However, to secure approval from the FHWA, further driver testing would have been required, leading to the removal of the tailgating-specific graphic from the design. The precise size of the fixed sign used in this study can be seen in Figure 6.

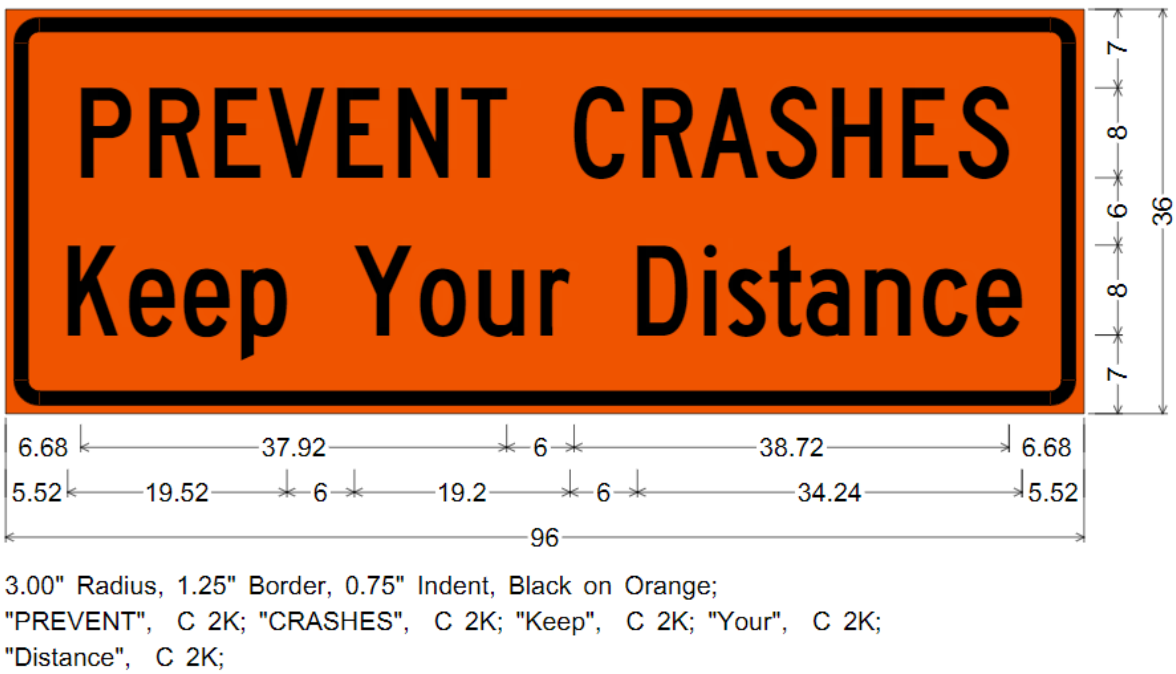


Figure 6. Fixed sign with text only

Shoulder Closure Construction Site

The study expanded its focus to another construction site, this one characterized by a shoulder closure, located on I-80 between the IA 38 West Branch exit and the Walcott exit. Construction activities began on April 3, 2023, with an end date projected for December 20, 2023. Activities focused mainly on the median, resulting in blockage of the left shoulder in the east and west directions. The region is undergoing nighttime construction, which often requires intermittent lane closures. A width limit of 11 feet was enforced, with construction operations scheduled from 8:00 p.m. to 6:00 a.m. CDT from Monday to Thursday and from 9:00 p.m. to 6:00 a.m. CDT on Sundays. This shoulder closure site received attention due to its significant traffic volume, registering an AADT of 18,650 vehicles in 2022. Additional factors in site selection included a portland cement concrete (PCC) pavement grade and new infrastructure, covering a stretch from 0.2 miles east of County Road X52 (Pine Avenue) to 0.7 miles west of US 6 at Sugar Creek (eastbound/westbound). This zone was also equipped with queue detection mechanisms and cameras.

In this work zone, an overhead message board was not available, so a PDMS was deployed. This PDMS was in operation during peak traffic hours in the afternoon from 14:00 to 18:00 on weekdays (Figure 7).

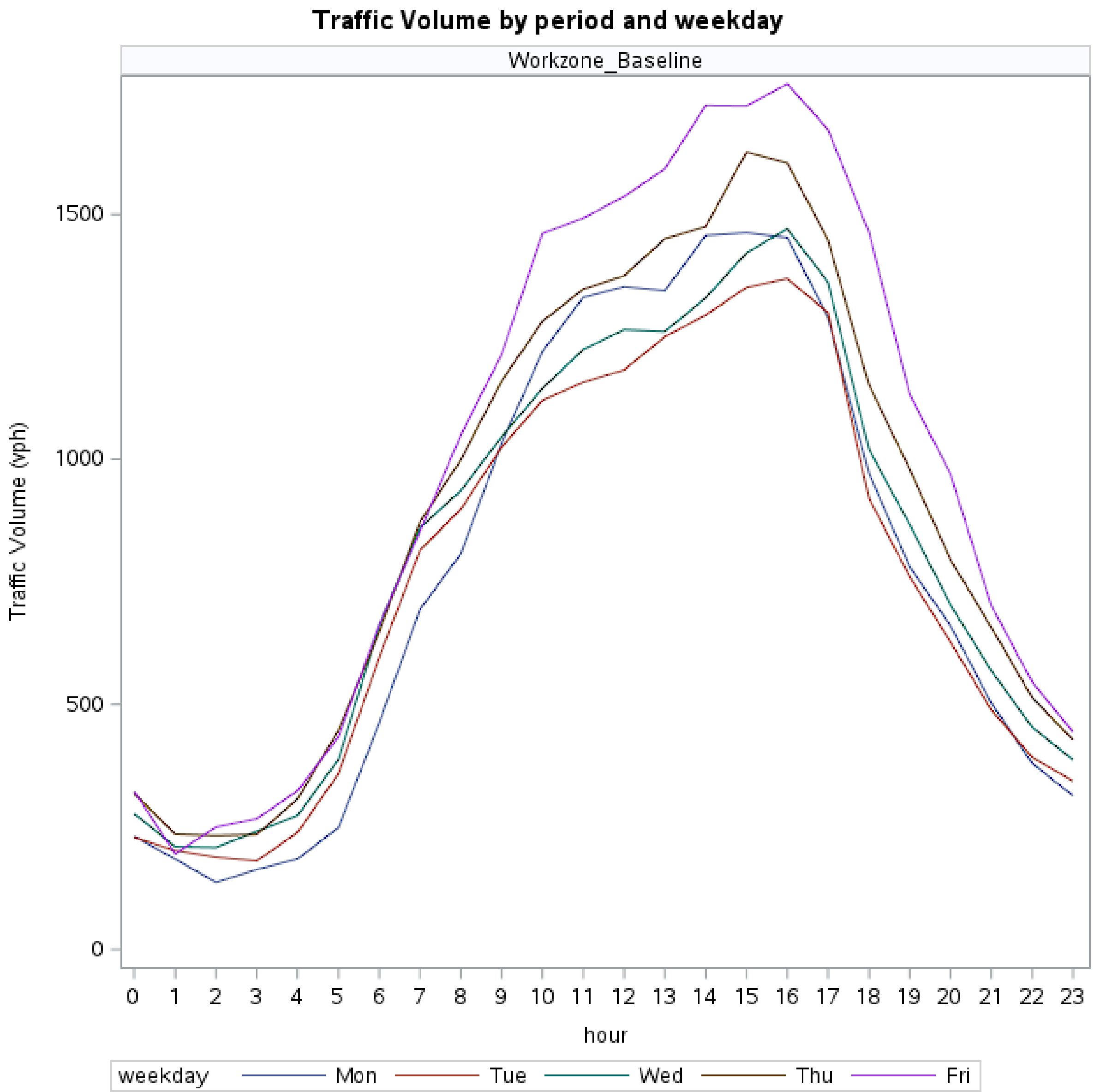


Figure 7. Traffic volumes by time of day and day of week at the shoulder closure construction site

Both the PDMS and the accompanying fixed signs were placed methodically. The first of the sensors was located upstream of the primary sign, while a second sensor was placed at the tail end of the construction zone to gauge post-intervention traffic dynamics. The spatial limitations of the site required sign installations only on the right side, leading to lane-specific assessments. The work zone is presented in Figure 8. For enhanced data collection, three Houston Radar sensors were deployed on March 29, 2023. A fixed sign was proposed to prevent crashes and promote safe follow-up distances at a disused I-beam signpost (GPS coordinates 41.6444866, -91.0965128), situated approximately 1,200 feet before the initial PDMS. Another similar sign was suggested to replace an existing DEER CROSSING sign (GPS coordinates 41.6442986, -91.0796626) to reduce work zone signage clutter.

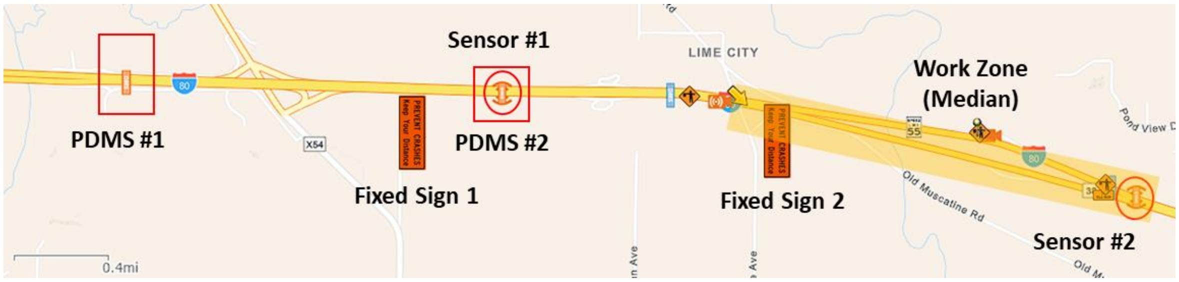


Figure 8. Shoulder closure construction site on I-80

The research phase at this location was divided into the following periods:

1. **Baseline**. May 16 through June 18, 2023 (5 weeks)
2. **Only PDMS**. June 19 through July 11, 2023 (4 weeks)
3. **PDMS and Fixed Signs**. July 12 through August 18, 2023 (5.5 weeks)

The fixed sign used at the shoulder closure construction site was the same as that used at the single-lane closure construction site. However, since a PDMS was used at this site instead of an overhead message sign, the message wording was customized to fit the technical constraints of the Iowa DOT's PCMS, which allows for 3 lines of 8 characters. In addition, a different message was displayed to drivers each day, as follows:

- Monday

- Tuesday

- Wednesday

- Thursday

- Friday

Performance Evaluation

Routine assessments were conducted using data collected during DMS operating hours for each construction site. These data were grouped into hourly segments, which allowed calculations for hourly traffic counts, mean headway, and the probability of tailgating occurrences. The mean headway was calculated from the average of all headways under 5 seconds where speeds exceeded 45 mph. The probability of tailgating occurrences was determined by the proportion of severe tailgating instances (with a headway of 1 second or less and speeds greater than 45 mph) relative to the hourly traffic count. An f-test was used to determine whether the variances were consistent; a p-value of 0.05 or less suggested significant statistical evidence for inconsistent variances, prompting the adoption of Welch's t-test method. For greater p-values, a t-test with assumed pooled variance was used. Furthermore, an analysis of variance (ANOVA) test was performed to confirm that identical values were observed at the same location across different time intervals. The findings were then comparatively evaluated based on time period and location.

4. RESULTS

In this chapter, we discuss our findings regarding the comprehension of anti-tailgating signs and messages. Our focus was on evaluating how well these signs and messages are understood by the public and the efficacy of their messaging. Specifically, we explore the results from the survey of potential users as well as the implementation of these techniques in two different construction sites: a site with a single-lane closure and a site with a shoulder closure.

Safety Sign and Message Comprehension (Survey)

A total of 247 respondents, 44 from the Ames DMV and 203 from the Ankeny DMV, participated in the three surveys. Table 1 provides a comprehensive snapshot of the data collected from the surveys, including information on various aspects such as demographics, driving status, primary language, and driving frequency.

Table 1. General information from survey participants

Survey		First Survey		Second Survey		Third Survey		Total for All Surveys	
Question	**Answer**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Do You Have a Driver's License/Permit	Yes	132	92%	47	90%	51	100%	230	93%
	Came to apply	9	6%	4	8%	0	0%	13	5%
	No	3	2%	1	2%	0	0%	4	2%
	Total	144	100%	52	100%	51	100%	247	100%
Primary Language	English	132	92%	47	90%	49	96%	228	93%
	Spanish	3	2%	3	6%	0	0%	6	2%
	Hmong	1	1%	0	0%	0	0%	1	0%
	Other	7	5%	2	4%	2	4%	11	4%
	Total	143	100%	52	100%	51	100%	246	100%
Gender	Woman	58	41%	20	38%	24	47%	102	41%
	Man	82	57%	31	60%	27	53%	140	57%
	Nonbinary	0	0%	0	0%	0	0%	0	0%
	Prefer not to answer	3	2%	1	2%	0	0%	4	2%
	Total	143	100%	52	100%	51	100%	246	100%
Age	<13	0	0%	0	0%	0	0%	0	0%
	14–16	1	1%	2	4%	3	6%	6	2%
	17–18	7	5%	2	4%	6	12%	15	6%
	19–24	28	20%	4	8%	4	8%	36	15%
	25–34	33	23%	14	27%	17	33%	64	26%
	35–44	22	15%	15	29%	4	8%	41	17%
	45–54	14	10%	7	13%	11	22%	32	13%
	55–64	21	15%	2	4%	2	4%	25	10%
	65–74	9	6%	5	10%	2	4%	16	7%
	75–84	6	4%	1	2%	1	2%	8	3%
	85+	1	1%	0	0%	1	2%	2	1%
	Total	142	100%	52	100%	51	100%	245	100%
Hours Driven/Week	<2	14	11%	10	20%	6	12%	30	13%
	3 to 5	42	33%	13	25%	14	27%	69	30%
	6 to 10	28	22%	13	25%	15	29%	56	24%
	11 to 15	16	12%	4	8%	8	16%	28	12%
	16 to 20	11	9%	5	10%	1	2%	17	7%
	21 to 25	9	7%	2	4%	0	0%	11	5%
	26 to 30	1	1%	2	4%	2	4%	5	2%
	31 to 35	1	1%	0	0%	2	4%	3	1%
	40+	7	5%	2	4%	3	6%	12	5%
	Total	129	100%	51	100%	51	100%	231	100%

Regarding driver's license or permit status, the first survey revealed that a significant majority, 92%, reported having a driver's license or permit. A smaller group, 6%, mentioned that they were in the process of applying, while a mere 2% reported not having one. In the second survey, 90% had a driver's license or permit, 8% indicated that they came to apply, and 2% did not have one. However, the third survey stood out with a unanimous 100% of the participants having a license or permit. Collectively in all surveys, 93% had a driver's license or permit. When it comes to primary language preferences, English was the primary choice for most of the participants in the three surveys, with 92% in the first, 90% in the second, and 96% in the third. This is reflected in the survey total, where 93% of all respondents indicated English as their primary language. Spanish, although the second most frequent response, had a fairly low representation, ranging from 2% to 6% in the individual surveys. The gender distribution in the surveys showed that men were the majority, accounting for 57% in the first survey, 60% in the second, and 53% in the third. Women were close behind, with 41% in the first survey, 38% in the second, and 47% in the third.

Regarding age distribution, the 25–34 and 35–44 brackets were the most represented in all three surveys. In particular, the 25–34 age group had a strong presence in the third survey, representing 33% of its respondents. The youngest age group, which included respondents between 14 and 24 years old, made up between 6% and 28% of all respondents in the surveys. Older age groups, especially respondents 55 and older, had a lower representation, with a unique spike in the 45–54 age group in the third survey, where this group represented 22% of the responses. The total percentage for each age group is presented in Figure 9.

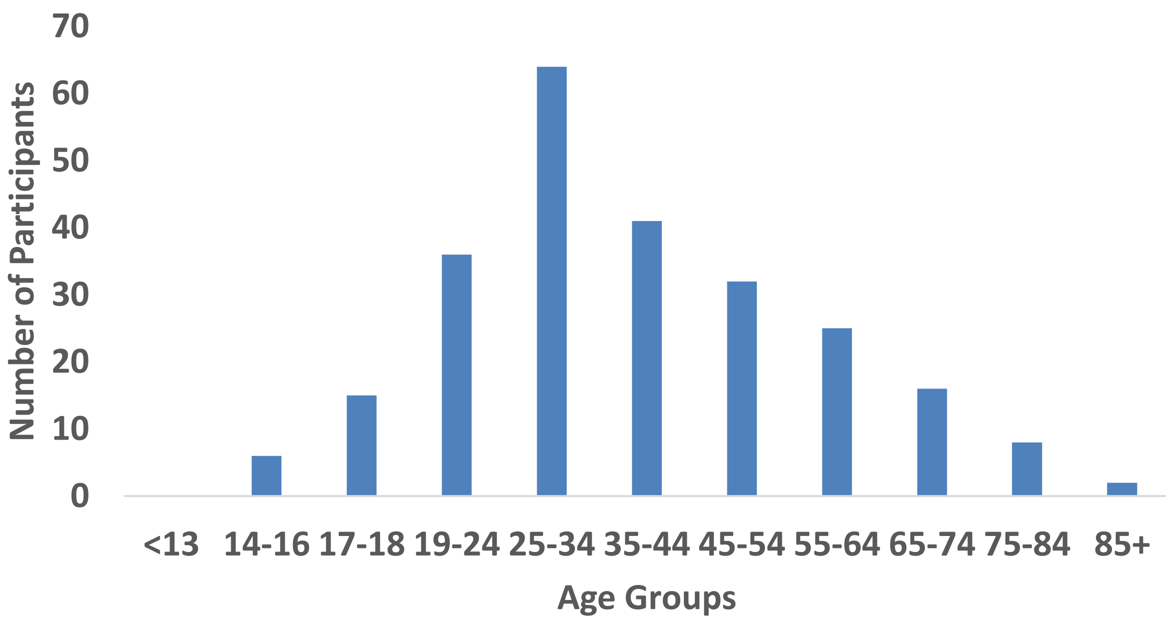


Figure 9. Age groups of participants

Regarding the hours driven per week, most of the respondents, regardless of the survey, reported driving between 3 and 10 hours a week. The most frequently reported segment was 3 to 5 hours, with this segment having an overall representation of 30%. An average of 13% of respondents in all surveys reported driving less than 2 hours per week, and the least frequent driving duration reported was between 26 and 35 hours per week. The total percentage for each segment of hours driven per week is presented in Figure 10.

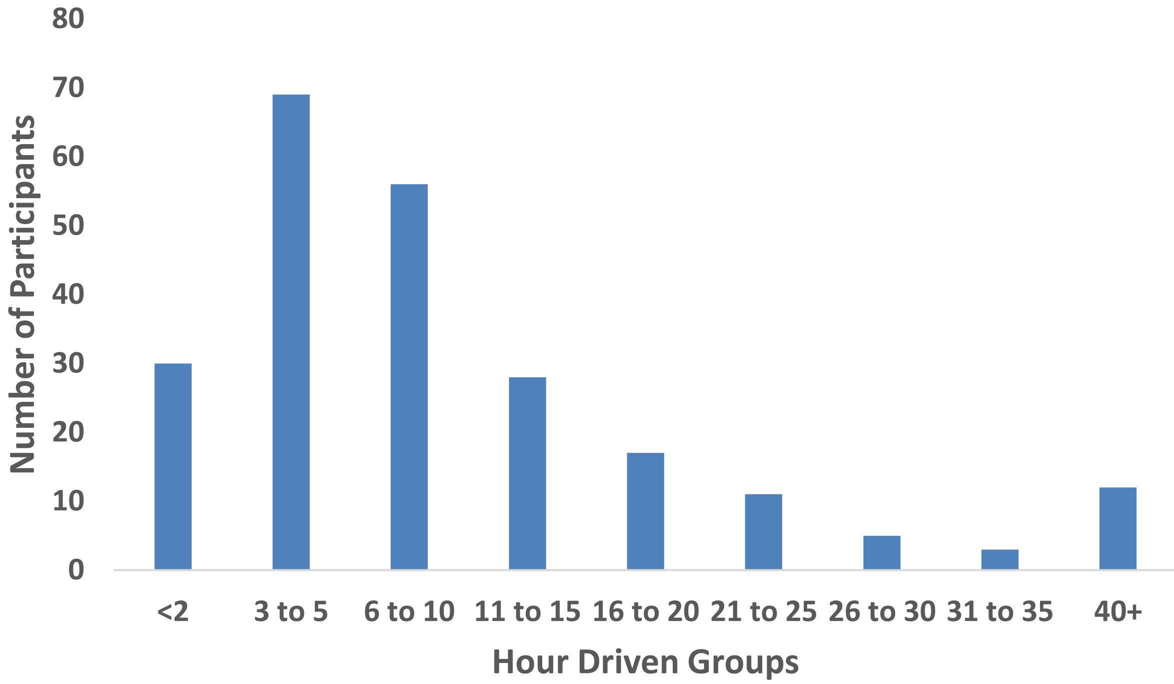


Figure 10. Hours driven per week by participants

To summarize, the surveys largely portray a demographic that is predominantly English speaking, is majority male, is mostly within the age range of 25 to 44, drives between 3 and 10 hours a week, and holds a driver's license or permit. The uniformity in the responses, especially in areas such as driver's license status, primary language, and gender, suggests that all three samples represent a similar demographic group.

Stage 1: User Rating for the Candidate Designs

To assess the comprehensibility of the newly designed anti-tailgating messages and user preferences for specific messages, 8 distinct sign designs and 12 anti-tailgating messages were crafted based on expert recommendations. When the user rating survey was conducted, detailed explanations of the intended meaning of each sign were given. Feedback was collected on the clarity of the signs and the responses they generated.

In fixed-sign designs, a combination of four sets was chosen. These included signs with optimistic messages, such as PREVENT CRASHES, KEEP YOUR DISTANCE, and LEAVE EXTRA SPACE, as well as signs with a more cautious tone, such as NO TAILGATING. Additionally, there were designs that combined positive messages with specific distancing suggestions, such as STAY 200 FEET APART and STAY 10 CAR LENGTHS APART. A comparison was drawn between purely graphical signs and those that combined graphics with text. Feedback on a five-point Likert scale was categorized into positive ("Excellent" and "Good") and negative ("Poor" and "Unacceptable").

Preliminary results showed that signs with cautionary phrases, despite being clear in meaning, often came across as dull or perplexing. Designs that specify distances in numerical terms seemed to decrease clarity and induce confusion. Purely graphical designs had the least clarity and were typically seen as perplexing by users. On the other hand, positive-toned designs were easier to understand and perceived as honest rather than boring, illustrating the potential benefits of using optimistic tones in traffic sign design. The pairing of PREVENT CRASHES with KEEP YOUR DISTANCE scored high in clarity and left a positive initial impact, leading to its selection as a potential fixed sign (as shown in Figure 11).

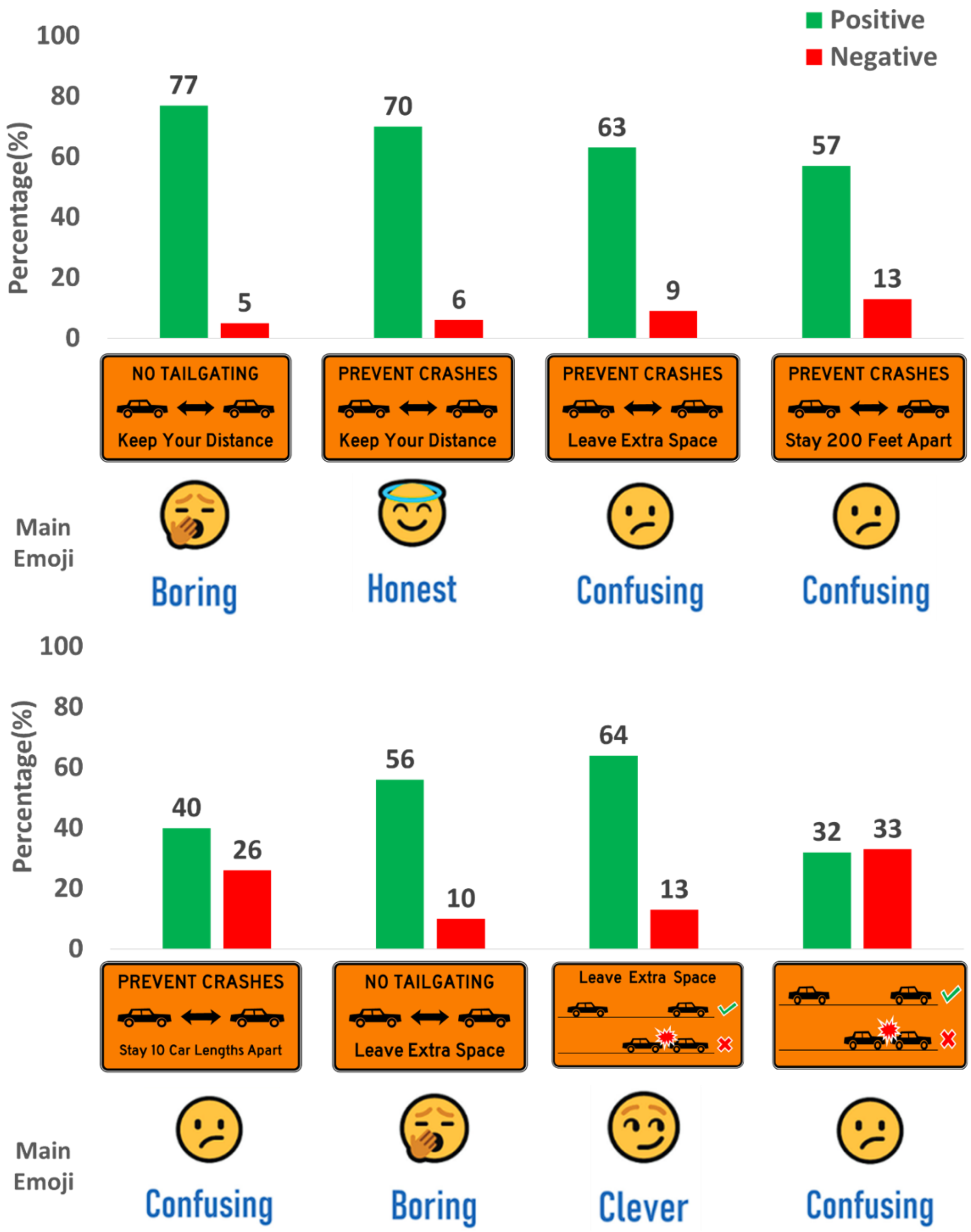


Figure 11. User rating for fixed signs

For the 12 anti-tailgating messages, a mix of positive, negative, and humor-infused phrases was used. Similarly to the fixed-sign results, positive phrasing generally achieved better clarity. Messages that provided specific numerical guidance were less clear to users. Humorous messages similarly seemed to lose some effectiveness in conveying their intended meaning.

An interesting observation was the role of word placement in shaping user perceptions. When a warning phrase led the message, the message often appeared dull or confusing. However, rearranging the message to begin with a positive or question-based phrase followed by a cautionary phrase changed the perception such that the message was seen as clever or honest. This points to the potential advantages of thoughtfully structuring message content for maximum impact and clarity. User feedback on the DMS messages is illustrated in Figure 12.

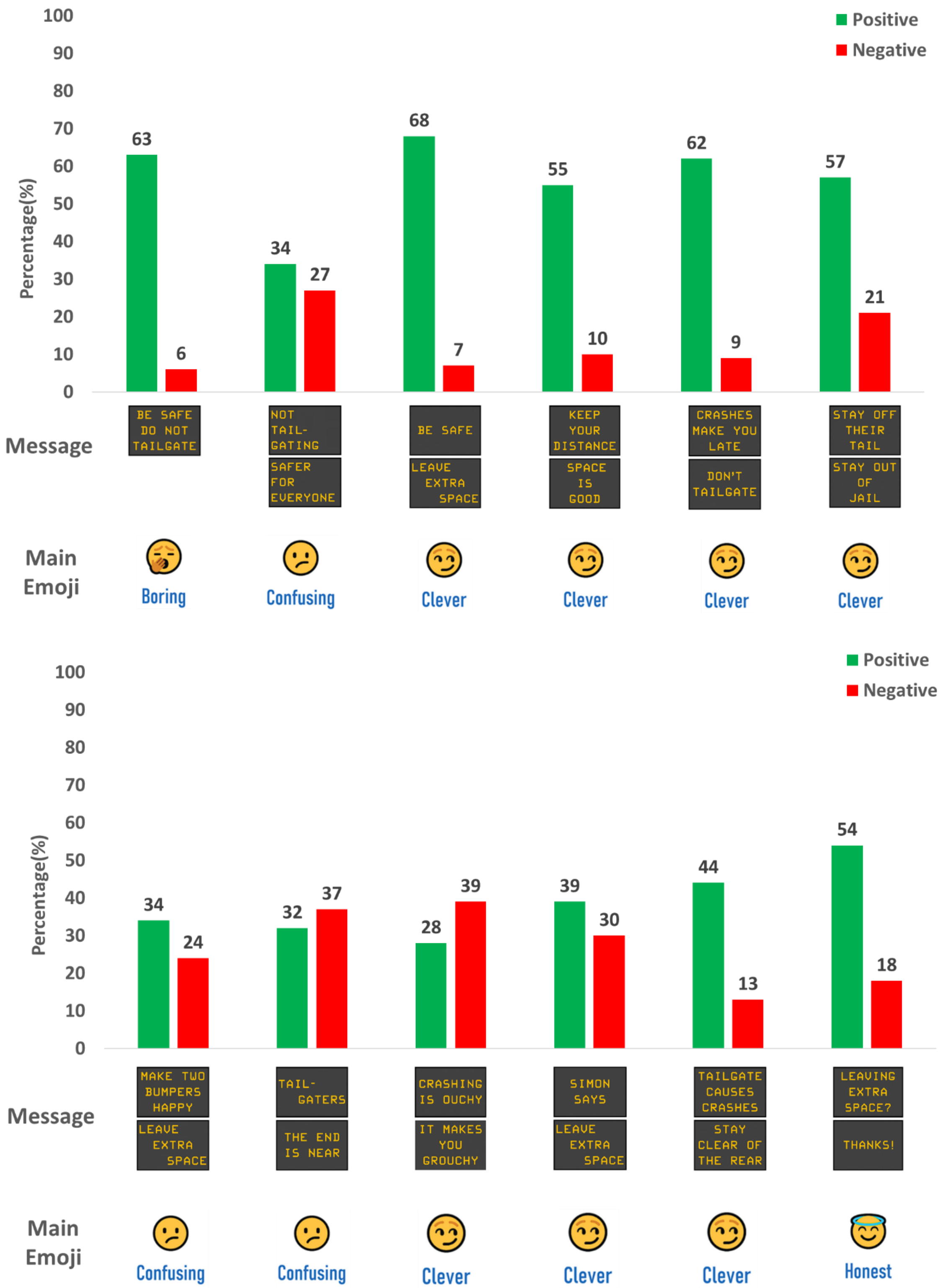
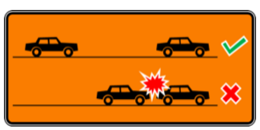


Figure 12. User ratings for DMS messages

All results for these messages are summarized in Table 2.

Table 2. Results of the user rating survey

Candidate Sign	Intelligibility					Impression				
	Excellent	Good	Fair	Poor	Unacceptable	Clever	Confusing	Boring	Untrue	Honest
No Tailgating / Keep Your Distance 	23%	54%	21%	2%	0%	6%	1%	8%	0%	8%
Prevent Crashes / Keep Your Distance 	17%	52%	25%	5%	1%	5%	4%	5%	1%	9%
Prevent Crashes / Leave Extra Space 	13%	50%	28%	8%	0%	4%	7%	3%	0%	7%
Prevent Crashes / Stay 200 Feet Apart 	23%	33%	27%	16%	1%	5%	9%	4%	1%	9%

Candidate Sign	Intelligibility					Impression				
	Excellent	Good	Fair	Poor	Unacceptable	Clever	Confusing	Boring	Untrue	Honest
Prevent Crashes / Stay 10 Car Lengths Apart 	10%	29%	30%	22%	4%	3%	17%	2%	6%	3%
No Tailgating / Leave Extra Space 	17%	38%	32%	9%	1%	3%	5%	8%	0%	6%
Leave Extra Space (Graphic) 	32%	32%	19%	12%	1%	13%	8%	3%	1%	5%
Wordless Graphic 	10%	22%	26%	28%	7%	9%	23%	2%	4%	2%

Candidate Sign	Intelligibility					Impression				
	Excellent	Good	Fair	Poor	Unacceptable	Clever	Confusing	Boring	Untrue	Honest
Be Safe Do Not Tailgate BE SAFE DO NOT TAILGATE	28%	32%	34%	6%	0%	7%	1%	7%	0%	7%
No Tailgating / Safer For Everyone NOT TAIL- GATING SAFER FOR EVERYONE	9%	25%	37%	24%	4%	3%	12%	7%	0%	4%
Be Safe / Leave Extra Space BE SAFE LEAVE EXTRA SPACE	21%	47%	24%	6%	1%	9%	4%	4%	1%	5%

Candidate Sign	Intelligibility					Impression				
	Excellent	**Good**	**Fair**	**Poor**	**Unacceptable**	**Clever**	**Confusing**	**Boring**	**Untrue**	**Honest**
Keep Your Datance / Space is Good KEEP YOUR DISTANCE SPACE IS GOOD	13%	42%	35%	9%	1%	6%	5%	5%	0%	4%
Crashes Make You Late / Don’t Tailgate CRASHES MAKE YOU LATE DON’T TAILGATE	25%	37%	28%	8%	1%	22%	3%	3%	1%	8%
Stay Off Their Tail / Stay Out of Jail STAY OFF THEIR TAIL STAY OUT OF JAIL	20%	37%	19%	19%	1%	27%	1%	1%	1%	6%

Candidate Sign	Intelligibility					Impression				
	Excellent	Good	Fair	Poor	Unacceptable	Clever	Confusing	Boring	Untrue	Honest
Make Two Bumpers Happy / Leave Extra Space MAKE TWO BUMPERS HAPPY LEAVE EXTRA SPACE	12%	22%	40%	23%	1%	16%	11%	1%	0%	0%
Tailgaters / The End is Near TAIL- GATERS THE END IS NEAR	9%	23%	27%	29%	7%	12%	17%	1%	2%	2%
Crashing is Ouchy / It Makes You Grouchy CRASHING IS OUCHY IT MAKES YOU GROUCHY	9%	19%	28%	33%	6%	14%	9%	2%	1%	4%

Candidate Sign	Intelligibility					Impression				
	Excellent	Good	Fair	Poor	Unacceptable	Clever	Confusing	Boring	Untrue	Honest
Simon Says / Leave Extra Space 	9%	30%	26%	26%	4%	19%	7%	6%	1%	2%
Tailgate Causes Crashes / Stay Clear of the Rear 	11%	34%	39%	11%	2%	13%	4%	5%	1%	5%
Leave Extra Space? / Thanks! 	13%	41%	30%	16%	1%	4%	5%	5%	1%	6%

Note: The sum percentages of Excellent to Unacceptable may not add up to 100% due to duplicate responses or nonresponse of the respondents.

Stages 2 and 3: Multiple Choice and Open-Ended Comprehension Test

When the multiple choice and open-ended questions were administered, respondents were not provided with explanations about the intended meaning of each sign. Instead, they were prompted to deduce the meanings based on their own interpretations. In particular, the clarity of the fixed signs and messages aimed at discouraging tailgating was found to be comparable to, if not better than, the clarity of conventional traffic signs currently in use. However, the message BE SAFE / LEAVE EXTRA SPACE proved to be particularly challenging for participants to interpret correctly. Without explicit contextual clues, many misinterpreted it as a call to maintain additional lateral space around obstacles adjacent to their lane. The results of the analysis of the multiple choice and open-ended surveys can be seen in Figure 13 and Figure 14, respectively. The complete results of the open-ended survey are presented in Appendix C-2.

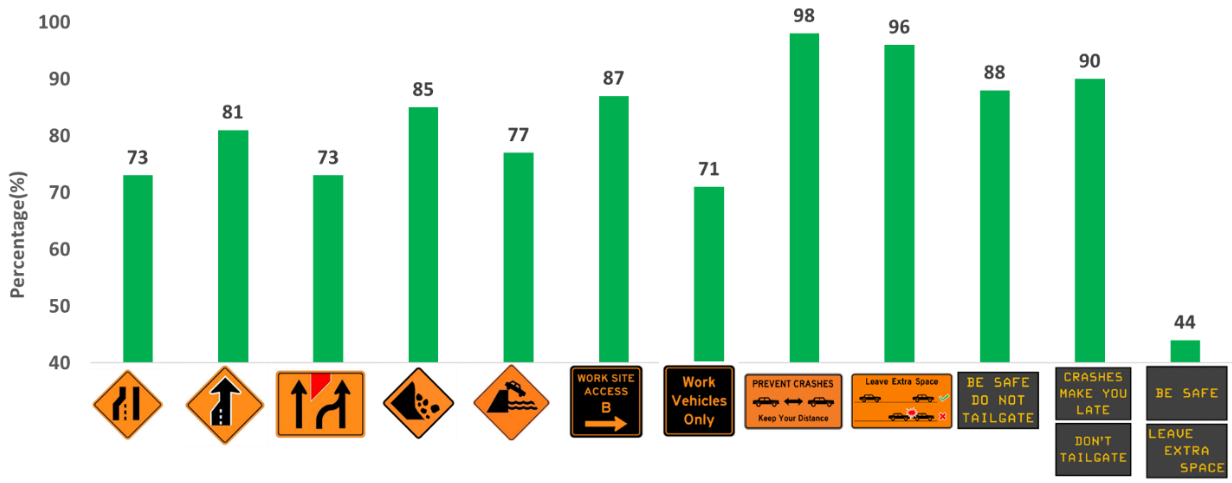


Figure 13. Multiple-choice questions (correct answers)

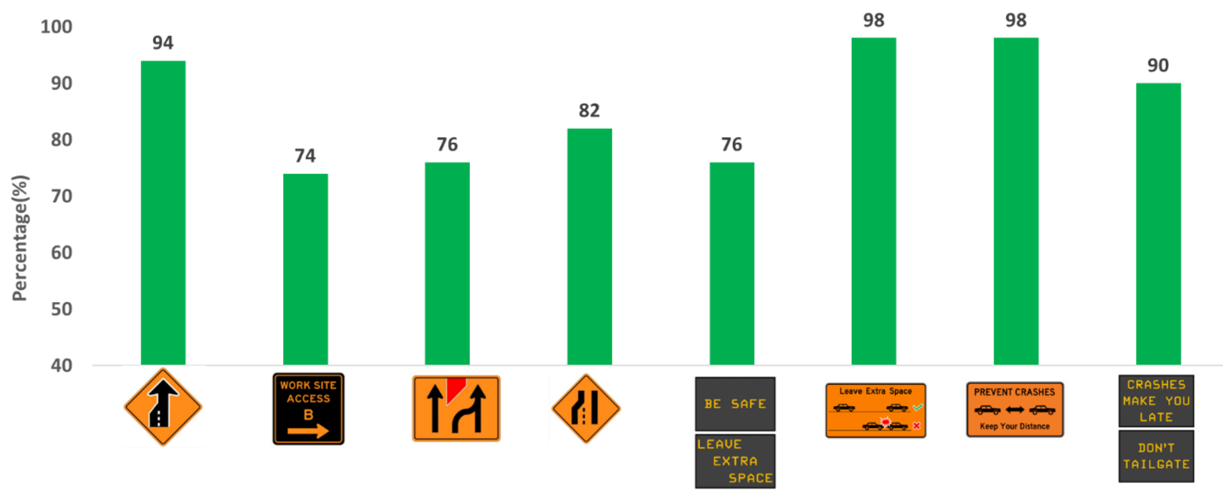


Figure 14. Open-ended questions (correct answers)

In summary, signs and messages aimed at discouraging tailgating, especially those written in optimistic language, were not only positively received by participants but were also found to be as clear as standard traffic signs. As a result, a specific fixed sign was chosen to be placed in the work zones, with a set of five anti-tailgating messages to be displayed rotationally. The initial plan for the fixed sign was to combine both graphic imagery and text. However, additional driver tests would have been necessary to secure approval from the FHWA for graphic imagery, leading to the removal of the tailgating-associated graphic. In terms of the DMS messages, given the potential for drivers to become accustomed to and overlook repetitive messaging, a variety of anti-tailgating phrases were chosen to be showcased throughout the week.

Deployment of Messaging Techniques (Field Tests)

In our research, we adopted specific anti-tailgating messaging strategies and applied them to two different work zone conditions: a single-lane closure located on US 30 and a shoulder closure located on I-80. The implementation of these strategies spanned unique durations, which allowed us to monitor their effectiveness across varying timeframes. To gain a complete understanding of driver behaviors in relation to tailgating tendencies, sensors were placed both ahead of the construction zones (upstream) and directly inside the active work zones. The main goal of placing these sensors was to observe and evaluate whether the presence of our anti-tailgating messages would indeed influence drivers' behaviors and prompt them to maintain safer distances between vehicles.

To compare the metrics or MOEs recorded at each of these locations, we used the t-test. This statistical test was chosen to discern any significant variations in the data drawn from the single-lane closure and the shoulder closure. Each graph that presents these data also displays the calculated p-values, which denote the statistical significance of the observed differences. In addition to the above comparison, we also attempted to discern potential fluctuations or disparities that might occur over different time spans at a single location. To inspect these differences, an ANOVA test was utilized. All results and insights derived from this test have been systematically compiled and are presented in the tables accompanying our findings.

US 30 Single-Lane Closure

In the period from June 1, 2022, to October 19, 2022, this construction site experienced a total of seven crashes. Five of these crashes occurred from June 1 to September 10, prior to the implementation of the anti-tailgating messages, with all five occurring in June alone. These incidents involved two cases of noncollisions (single vehicle) and three cases of rear-end collisions. The major causes of the rear-end collisions included tailgating, and the major causes of the noncollisions included driver distraction and vehicles running off the road. These crashes all took place on weekdays during peak hours. Subsequent to the introduction of the anti-tailgating messages from September 11 to October 19, two crashes were recorded, both involving noncollision cases where the vehicles ran off the road (one attributed to drug/alcohol influence) and the drivers disregarded signs/road markings. It is noteworthy that these incidents occurred during nonpeak hours (one at 1 a.m. and one at 9 p.m.).

At each monitored location, our observations during specified timeframes, and particularly during the afternoon's peak traffic hours, revealed that the flow of traffic was substantial. On average, an estimated 1,150 to 1,200 vehicles per hour were seen traversing the available lane. Detailed statistical evaluations, specifically using the t-test and ANOVA methods, provide robust evidence that traffic volumes remained largely uniform regardless of time or location. This consistency in traffic flow is illustrated in Table 3. When digging deeper to assess the efficacy of each anti-tailgating strategy in place, there were notable findings. A statistical improvement in the average headway between vehicles was observed when the vehicles were within designated construction zones, especially compared to upstream traffic. This increase in average headway was evident for all anti-tailgating messaging strategies: the overhead DMS on its own, a combination of the overhead DMS with fixed signs, or the fixed signs alone.

Table 3. Descriptive statistics of measurements in single-lane closure construction site

Location	Period	N	Traffic Volume (vphpl)				Average Headway (s)				TOP[1] (%)			
			Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Upstream	Baseline	56	1,180	173	895	1,460	2.07	0.12	1.83	2.35	13.51	3.62	6.11	20.88
	DMS[2]	40	1,189	186	867	1,493	2.03	0.12	1.82	2.33	15.21	3.21	9.47	20.15
	DMS+FS[3]	40	1,186	188	841	1,463	2.08	0.13	1.84	2.35	13.21	4.24	4.79	20.81
	FS	28	1,163	173	865	1,477	2.08	0.12	1.89	2.29	13.61	3.98	6.66	20.03
	ANOVA Test		F-value: 0.14 / P-value: 0.9367				F-value: 1.47 / P-value: 0.2254				F-value: 2.34 / P-value: 0.0757			
Work zone	Baseline	56	1,176	172	885	1,433	1.89	0.09	1.73	2.10	14.12	2.65	8.88	19.05
	DMS	40	1,187	190	852	1,476	2.10	0.09	1.96	2.29	15.27	2.70	8.81	19.13
	DMS+FS	40	1,182	189	839	1,465	2.27	0.11	2.12	2.51	10.08	2.17	5.51	14.13
	FS	28	1,158	181	843	1,427	2.34	0.11	2.17	2.68	10.42	2.29	3.92	14.14
	ANOVA Test		F-value: 0.15 / P-value: 0.9272				F-value: 171.81 / P-value: <.0001				F-value: 42.74 / P-value: <.0001			

[1] TOP: tailgating occurrence percentage
[2] DMS: dynamic message sign
[3] FS: fixed sign

An important observation pertains to the more severe cases of tailgating. These are defined as vehicles traveling at speeds over 45 mph while maintaining a dangerously short headway of just 1 second or less. Significantly, these precarious driving behaviors declined notably with the installation of fixed signage. However, not all strategies seemed to make a difference. A specific area of interest was the deployment of the overhead DMS alone. Its implementation did not cause a statistically significant change in the likelihood of tailgating. A plausible reason for this apparent ineffectiveness could be visibility issues. The overhead sign, which was only operational during the afternoon peak hours, was strategically placed on the eastbound lanes and was located at the apex of a vertical curve. Under clear weather conditions, this setup made the sign susceptible to the powerful and blinding glare of the descending sun, potentially hindering its visibility for drivers. Box-and-whisker plots providing further context and clarity on the effects of the anti-tailgating messaging strategies can be seen in Figure 15 and Figure 16.

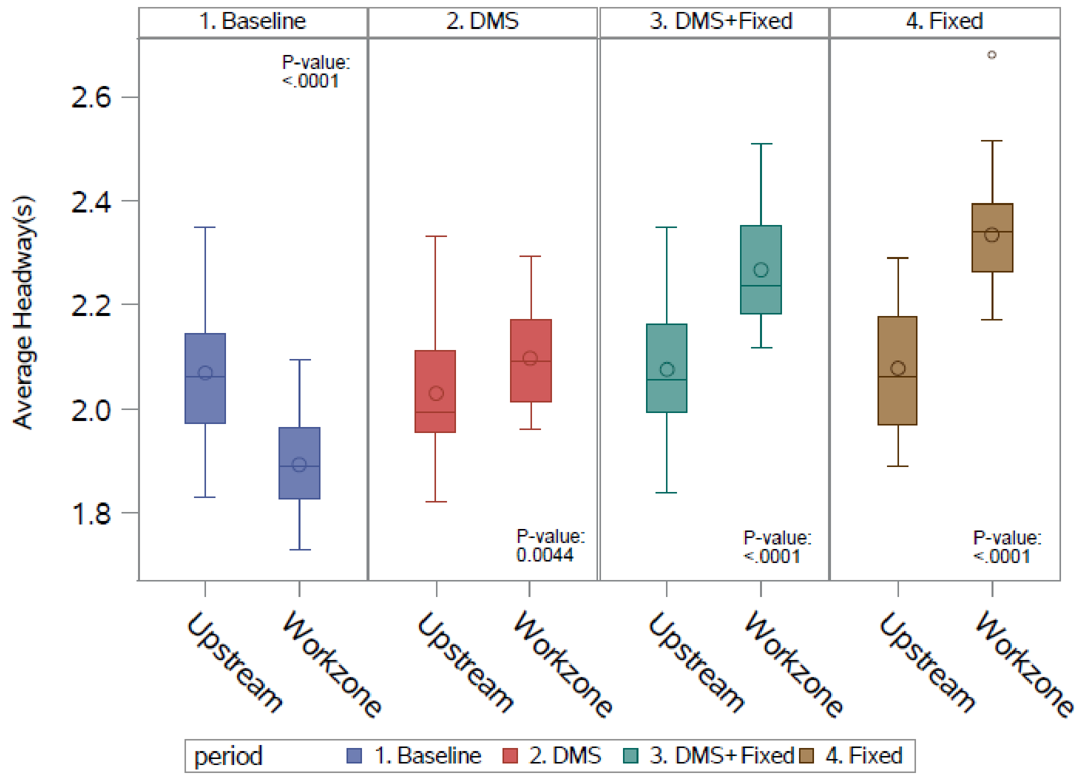


Figure 15. Average headway in single-lane closure construction site

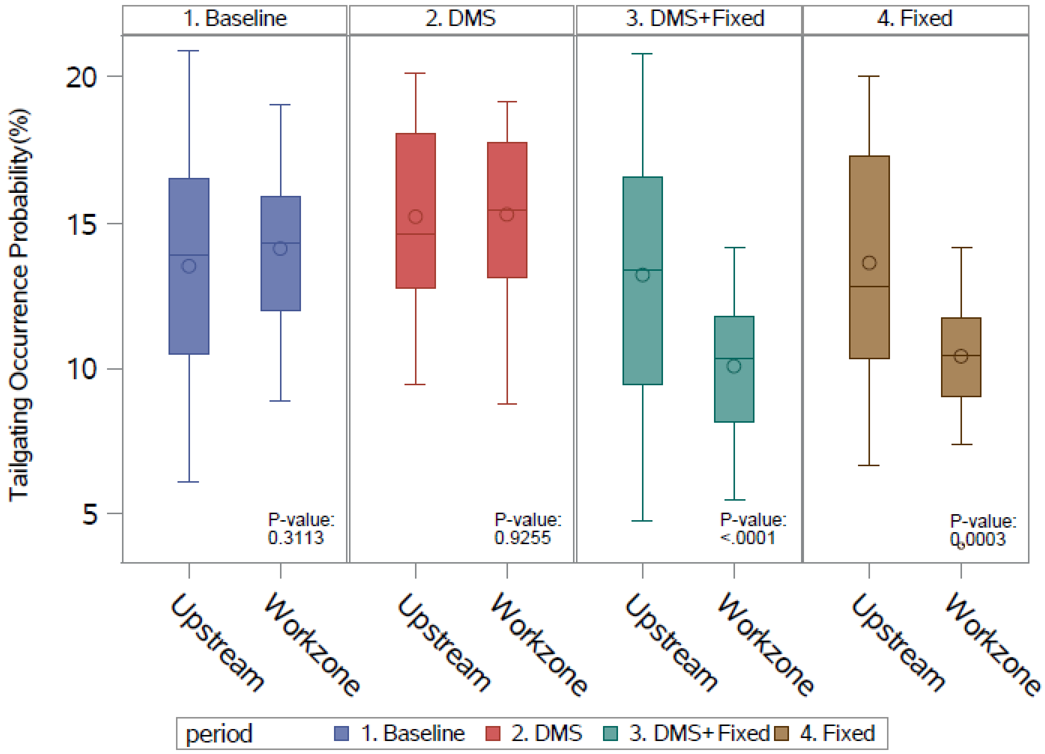


Figure 16. Probability of tailgating occurrences in single-lane closure construction site

I-80 Shoulder Closure

Between March 1, 2023, and August 19, 2023, a total of five crash events occurred in this construction zone. Before the anti-tailgating messages were installed, two crashes occurred at the beginning of the construction zone. One incident involved a run-off-road event during nonpeak hours (12:00), and the other took place during peak hours (15:20) and was attributed to following too closely. In the period after the introduction of the anti-tailgating messages on June 19, three crashes occurred within the construction site. Two of these were not caused by tailgating behavior. One occurred during peak hours and involved a vehicle running off the road, and the other occurred during nonpeak hours and involved the driver operating the vehicle in a careless manner. Both events happened when the PDMS and the fixed signs were active. The crash locations were within the construction zone downstream from the last fixed anti-tailgating sign. The third crash that occurred after June 19 was caused by tailgating and occurred downstream from the location of the last anti-tailgating sign when only the PDMS was active. This incident also occurred within the construction zone.

The evaluation of driving behavior during the shoulder closure on I-80, where lane changes were allowed, is more complicated than the evaluation of driving behavior during the single-lane closure on US 30. In the initial phase of the observation, many vehicles moved to the right lane when approaching the construction area, likely due to the presence of a subsequent exit ramp and a blocked median shoulder. However, the introduction of the PDMS led to fewer vehicles switching to the right lane, especially when the PDMS was combined with a fixed sign. This suggests that these signs influenced drivers' decisions to move to the right lane, which is closer to the anti-tailgating message signs. In addition, 15% more traffic was detected in the left lane during the PDMS and fixed sign combination period than during other periods (Figure 17).

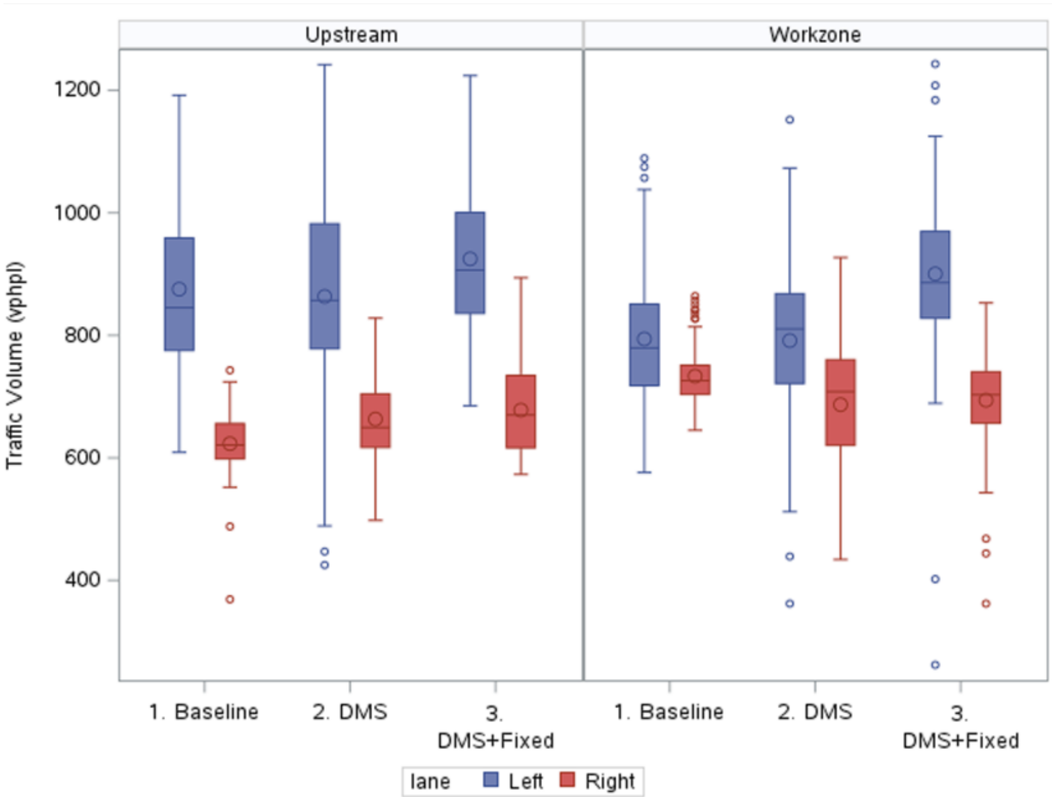


Figure 17. Traffic volumes in shoulder closure construction site

In the period before the anti-tailgating messages were installed, the analysis of average headway and probability of tailgating occurrences showed a notable reduction in average headway and an increase in the probability of tailgating occurrences in the right lane between the upstream and work zone areas. However, when the PDMS alone was present, these variations between upstream and work zone behaviors were not statistically significant. When fixed signs were added, there was an increase of about 0.1 seconds in average headway and a slight drop in the probability of tailgating occurrences between the upstream and work zone areas. Taking into account the initial observations, where the average headway decreased by 0.2 seconds and the probability of tailgating occurrences increased by 3.5% in the right lane between the upstream and work zone areas, the combined effects of the PDMS and fixed signs were found to effectively combat tailgating (Figure 18 and Figure 19).

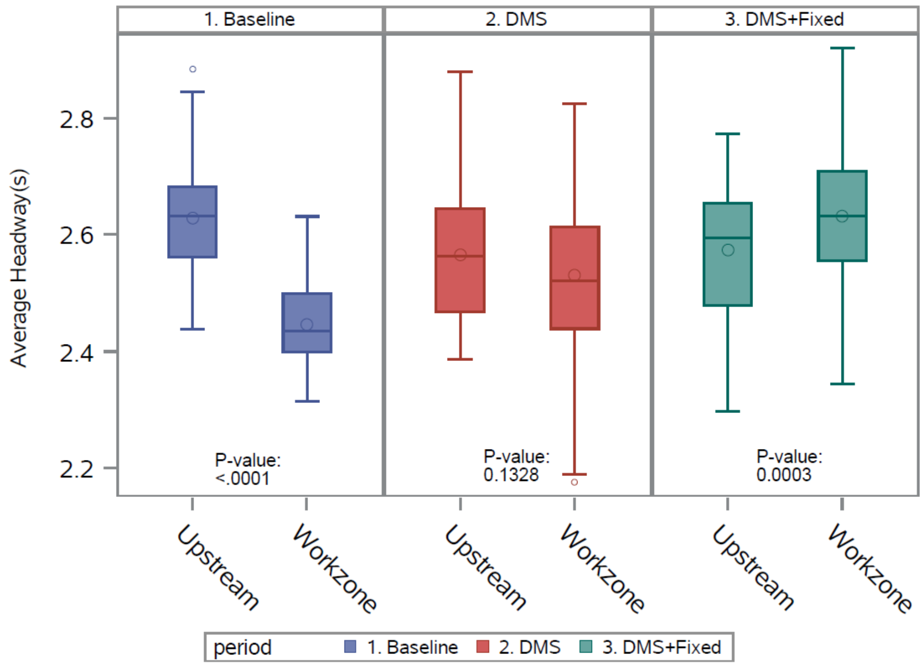


Figure 18. Average headway in shoulder closure construction site (right lane)

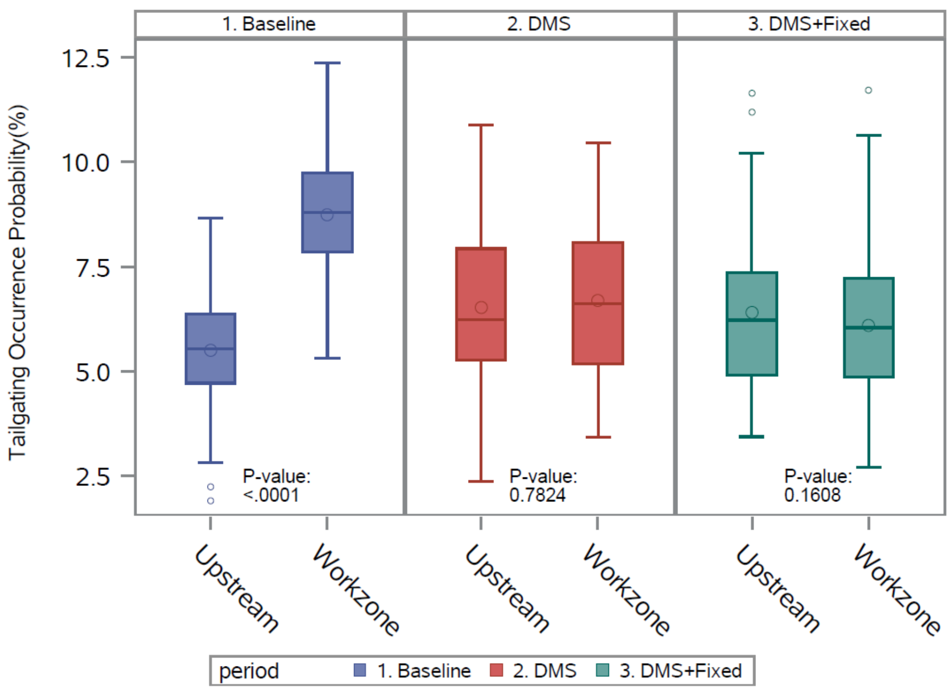


Figure 19. Probability of tailgating occurrences in shoulder closure construction site (right lane)

The analysis of the data from the overtaking (left) lane showed that there was a significant increase in traffic when both the PDMS and the fixed signs were present. However, the average headway increased slightly and the probability of tailgating occurrences dropped by about 4.0% when drivers entered the construction zone. Similar patterns were observed during the period before the anti-tailgating messages were installed, but traffic decreased between the upstream and work zone areas because vehicles typically moved from the overtaking lane to the right lane between these areas. The statistics for the baseline period show an increase in average headway and a drop in the probability of tailgating occurrences in the overtaking lane, probably due to the reduced traffic volume and the closed median shoulder. However, when the PDMS and fixed signs were present, there was an increase in headway and a reduction in the probability of tailgating occurrences between the upstream and work zone areas even without a decrease in traffic volume, highlighting the efficacy of the messaging strategy (Figure 20 and Figure 21).

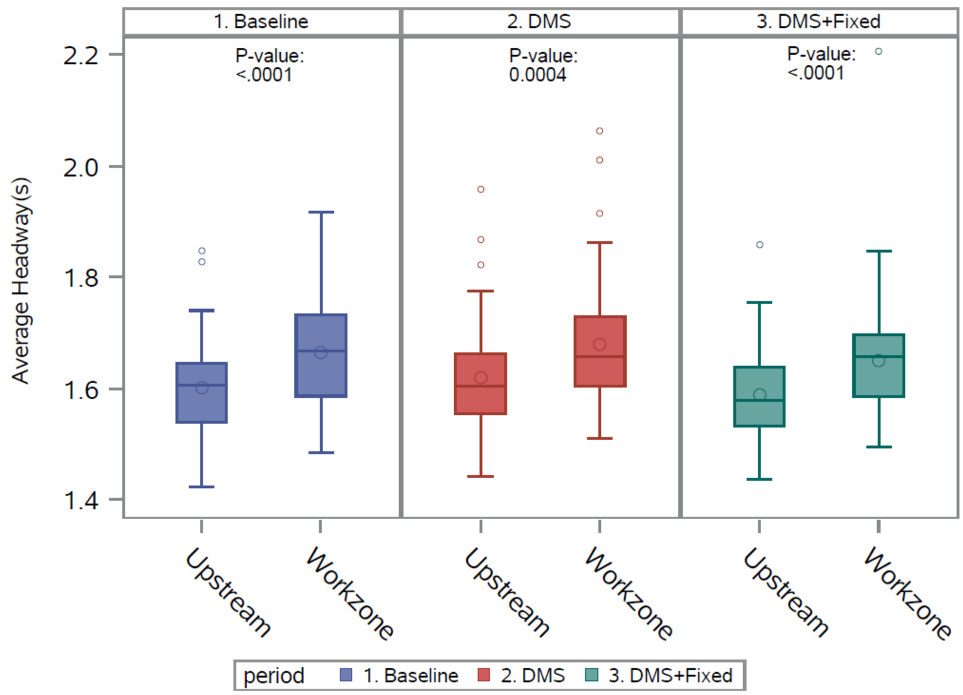


Figure 20. Average headway in shoulder closure construction site (left lane)

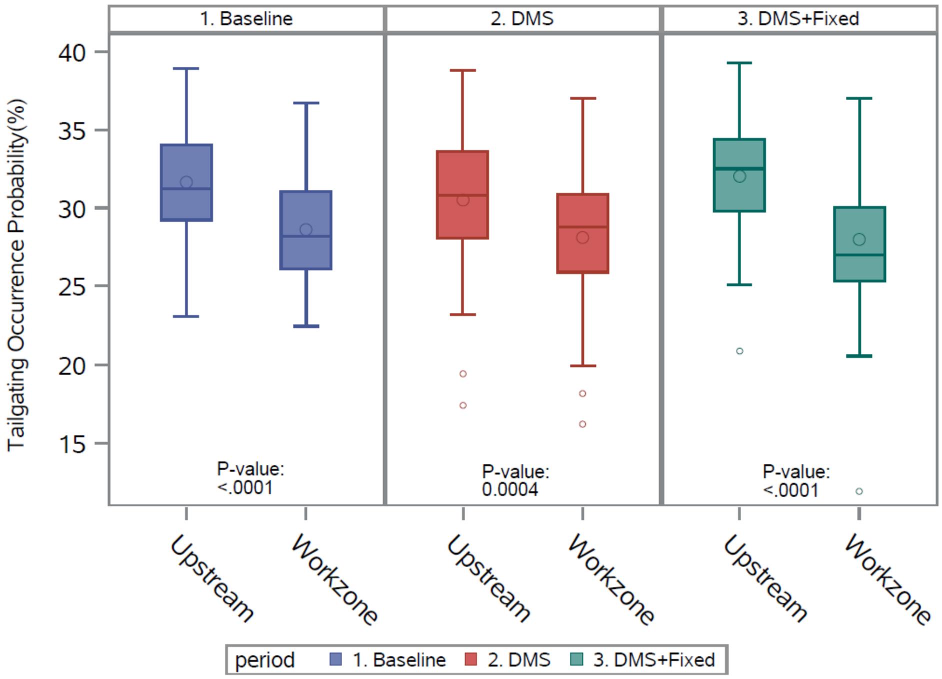


Figure 21. Probability of tailgating occurrences in shoulder closure construction site (left lane)

Detailed metrics for the shoulder closure construction site can be found in Table 4.

Table 4. Descriptive statistics of measurements in shoulder closure construction site

Location		Period	N	Traffic Volume (vphpl)				Average Headway (s)				TOP[1] (%)			
				Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Left Lane (Overtaking)	Upstream	Baseline	96	875	134	609	1,192	1.59	0.09	1.36	1.85	32.10	3.90	23.07	42.43
		PDMS[2]	86	888	158	524	1,242	1.61	0.11	1.40	1.96	30.99	4.55	17.37	39.00
		PDMS+FS[3]	92	925	119	685	1,224	1.58	0.08	1.44	1.86	32.21	3.47	20.86	39.27
		ANOVA Test		F-value: 5.00 / P-value: 0.0075				F-value: 2.21 / P-value: 0.1115				F-value: 3.07/ P-value: 0.0482			
	Work Zone	Baseline	96	794	106	576	1,089	1.67	0.09	1.48	1.92	28.62	3.24	22.45	36.71
		PDMS	86	803	132	512	1,152	1.68	0.11	1.51	2.06	28.23	4.15	16.20	37.00
		PDMS+FS	90	913	110	689	1,243	1.65	0.10	1.49	2.21	28.19	4.26	11.89	38.25
		ANOVA Test		F-value: 27.56 / P-value: <0.0001				F-value: 1.55 / P-value: 0.2154				F-value: 0.71 / P-value: 0.4909			
Right Lane	Upstream	Baseline	96	627	42	552	743	2.62	0.09	2.44	2.85	5.77	1.13	1.90	8.47
		PDMS	86	666	67	545	828	2.56	0.11	2.39	2.89	6.77	1.80	2.36	10.88
		PDMS+FS	92	678	69	573	894	2.57	0.11	2.30	2.77	6.57	1.88	3.43	11.63
		ANOVA Test		F-value: 17.85 / P-value: <0.0001				F-value: 7.16 / P-value: 0.0006				F-value: 9.12 / P-value: 0.0002			
	Work Zone	Baseline	96	733	50	645	864	2.43	0.07	2.32	2.63	9.24	1.22	6.61	12.36
		PDMS	86	694	88	529	927	2.50	0.16	2.12	2.82	7.82	2.69	3.42	13.50
		PDMS+FS	89	703	63	543	853	2.63	0.12	2.38	2.90	6.19	1.75	2.82	11.72
		ANOVA Test		F-value: 8.19 / P-value: 0.0004				F-value: 79.86 / P-value: <0.0001				F-value: 89.03/ P-value: <0.0001			

[1] TOP: tailgating occurrence percentage
[2] PDMS: portable dynamic message sign
[3] FS: fixed sign

5. CONCLUSIONS

The urgent need to counteract rear-end collisions in work zones, which are predominantly instigated by behaviors like speeding and tailgating, was the primary catalyst for this research. While a myriad of studies have investigated speeding, there is a conspicuous absence of in-depth studies specifically addressing the issue of tailgating in work zones. This discernible research void, combined with the paramount necessity of improving road safety, underscored the motivation for embarking on this study.

During the preliminary survey phase, the team developed a diverse array of messages and graphical signs specifically designed to deter tailgating. Messages that conveyed a positive tone, such as PREVENT CRASHES and KEEP YOUR DISTANCE, were not only intelligible but also elicited overwhelmingly positive reactions from survey respondents. In contrast, messages that conveyed a negative tone or those that incorporated specific numerical metrics for the recommended following distances were frequently deemed perplexing. As a result, messages and signs that expressed positivity stood out for their lucidity and favorable reception. These empirical observations steered the eventual selection of a static sign format and a rotating roster of five daily messages intended to deter tailgating in work zones.

During comprehension tests based on feedback gathered during the preliminary survey, designs primarily reliant on graphics without accompanying text were often found to yield lower comprehension scores compared to their text-based counterparts. However, this result should be taken with caution. The predominance of native English speakers in our sample set could have skewed the results. Furthermore, when it comes to real-world applicability, graphical traffic signs tend to be discernible from greater distances than text-based signs, a pivotal aspect not considered in the written format of the survey.

Field tests of the selected signs and messages were conducted at two construction sites: a single-lane closure site and a shoulder closure site. In the single-lane closure site on US 30, the data showed that the deployment of a DMS, fixed signs, or a combination of these invariably amplified the average headway of drivers navigating through the construction zone, especially when compared to locations upstream. Furthermore, the incorporation of fixed signs was directly correlated with a noticeable downward trend in severe tailgating incidents. The shoulder closure site on I-80, which allowed lane changes between the two open lanes, similarly demonstrated the efficacy of the anti-tailgating initiative through the concurrent use of PDMS and fixed signs. This intervention conspicuously increased the mean headway in both lanes and simultaneously decreased the probability of tailgating, indicative of an enhancement in traffic safety.

However, the research was not devoid of challenges. An initial aspiration to integrate a tailgating-centric graphic into the fixed-sign design had to be shelved due to time and resource constraints. Obtaining permission to experiment with such designs in the field requires additional testing of the sign.

It was also discerned that the legibility of a DMS is invariably dependent on its installation location and time of day. A particular concern emerged during our field tests at the single-lane closure construction site, where the overhead DMS encountered legibility issues due to sunlight glare during peak hours. Due to the uphill terrain of the site, the angle between the DMS' face and the driver's line of sight exceeded 90 degrees. This unique topography resulted in the DMS becoming susceptible to "washout," a phenomenon where visual contrast deteriorates, primarily due to the glare of the late afternoon sun. Unfortunately, this washout coincided with the specific time of day when the anti-tailgating messages were actively displayed, making them less legible to drivers. This site-specific impediment suggests that the anti-tailgating messages displayed through the DMS may not have achieved their optimal impact. Additionally, the readability of PDMS, particularly when placed on a road's right shoulder, could potentially be compromised in scenarios where dense traffic is concentrated in the rightmost lane. Future endeavors should consider the location of overhead signs to minimize sunlight interference and, if spatial dynamics permit, the symmetric positioning of PDMS on either side of the road to amplify the messages' impact.

Because of these challenges, it is advised to consider future data collection improvements. Focus should be placed on optimizing the location, angle, and legibility of DMS as well as determining the ideal roadside placement for PDMS. Furthermore, future research is suggested to compare the effectiveness of overhead DMS versus PDMS installations, explore the impacts of different messages displayed on DMS, conduct legibility tests, and evaluate the efficiency of graphic signs versus text-only signs. These steps can collectively advance the anti-tailgating messaging strategies in work zones and promote road safety.

Furthermore, the fact that anti-tailgating signage is perceivable to all drivers, not just tailgaters, broaches questions regarding the potential creation of speed differentials among those adhering to the signage and the outliers. This possibility underscores an urgent need for innovative research to create mechanisms specifically targeting tailgaters, potentially via vehicle alerts or precision-driven messaging methodologies. By honing and improving existing tactics, the overarching goal of curbing tailgating in work zones can be accomplished with enhanced efficacy.

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APPENDIX A. USER RATINGS SURVEY FORMS

INSTITUTE FOR TRANSPORTATION

Work Zone Tailgating Prevention Survey

Hello! We are looking for ways to discourage drivers from following too closely (tailgating) in work zones. On the next few pages you will see some traffic signs meant to remind drivers to keep a safe following distance. *Please tell us your reaction to each sign by selecting up to 3 emoji (icons):*

Excellent ☐	Good ☐	Fair ☐	Poor ☐	Unacceptable ☐
Clever ☐	Confusing ☐	Boring ☐	Untrue ☐	Honest ☐

About this project:

This survey is being done by the Institute for Transportation at Iowa State University. The research is sponsored by the Smart Work Zone Deployment Initiative, a coalition of transportation agencies from several states. If you have questions about this project, contact Dr. Jing Dong-O'Brien 515-294-3957 or Mr. John Shaw 515-294-4366. Your participation in the survey is voluntary and anonymous. Sorry, there are no prizes or other compensation.

Anti-Tailgating Survey Version 3.0 1

These are some ideas we had for regular signs to encourage safe following distances in work zones. Which signs best explain that message?

Please indicate your reaction to each sign by marking up to three emoji (icons).

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

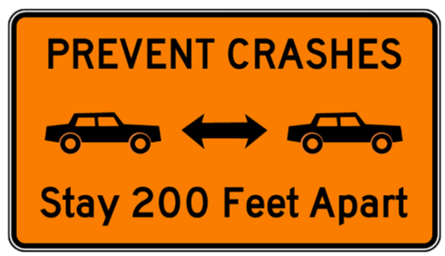
Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

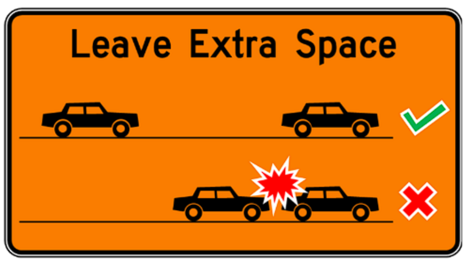


Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

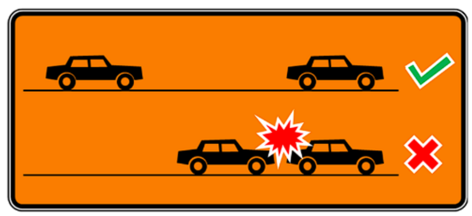
Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐



Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐



Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Messages on portable electronic signs are usually used in pairs, one screen after the other. Please indicate your reaction to each message set.

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐
Clever	**Confusing**	**Boring**	**Untrue**	**Honest**
☐	☐	☐	☐	☐

MAKE TWO BUMPERS HAPPY

LEAVE EXTRA SPACE

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

TAIL- GATERS

THE END IS NEAR

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

CRASHING IS OUCHY

IT MAKES YOU GROUCHY

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

SIMON SAYS

LEAVE EXTRA SPACE

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

TAILGATE CAUSES CRASHES

STAY CLEAR OF THE REAR

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

LEAVING EXTRA SPACE?

THANKS!

Excellent	Good	Fair	Poor	Unacceptable
☐	☐	☐	☐	☐

Clever	Confusing	Boring	Untrue	Honest
☐	☐	☐	☐	☐

About You...

Do you have a driver license or permit?
- ○ Yes
- ○ Came to the DMV today to apply for one
- ○ No

What is your primary language?
- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify) ____________________

Which best describes your gender?
- ○ Woman
- ○ Man
- ○ Non-Binary
- ○ Prefer not to answer

Age
- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

Approximately how many hours do you drive each week?
- ○ Less than 2
- ○ 3 to 5
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 40 or more

Comments

Thank you for your participation!

APPENDIX B. SIGNAGE UNDERSTANDABILITY SURVEY – MULTIPLE CHOICE

INSTITUTE FOR TRANSPORTATION

Signage Understandability Survey

We are evaluating the understandability of several traffic signs. Some you may have seen before, and others are new. For each sign, please PICK ONE OPTION that best describes what that sign means to you.

This survey is being done by the Institute for Transportation at Iowa State University. The research is sponsored by the Smart Work Zone Deployment Initiative, a coalition of transportation agencies from several states. If you have questions, contact Dr. Jing Dong-O'Brien 515-294-3957 or Mr. John Shaw 515-294-4366. Your participation in the survey is voluntary and anonymous. Sorry, there are no prizes or compensation.

1. What does this sign mean to you?

- O Lanes narrow ahead
- O Overhead construction – watch for falling debris
- O Left lane ending – traffic in left lane should merge into right lane
- O Lanes shifting ahead - expect an S-curve in the left lane

2. What does this sign mean to you?

- O Right turn ahead
- O Work trucks that need access to construction area "B" should turn right here
- O Be alert for slow trucks entering the roadway
- O Work zone entrance for tour group "B" is on the right

3. What does this sign mean to you?

- O Be alert for trucks entering or leaving the construction area
- O Leave extra space behind the vehicle in front of you
- O Move over if you see workers or work vehicles
- O Drive through the work zone quickly

4. What does this sign mean to you?

- O Road near river or lake has no guard rail – use caution
- O Pavement ends
- O Car ferry terminal ahead
- O Boat launch ahead

Please continue on Page 2…

5. What does this sign mean to you?

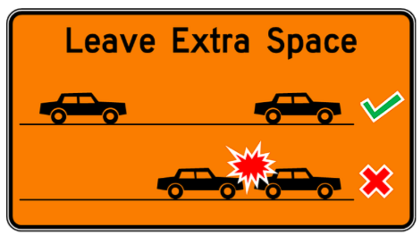
- O Blasting zone
- O Overhead construction – be alert for falling debris
- O Broken pavement – be alert for loose stones
- O Unstable hillside – be alert for falling rocks

6. What does this sign mean to you?

- O Lanes narrow ahead
- O Left lane ending – traffic in left lane should merge into right lane
- O Lanes shifting ahead - expect an S-curve in the left lane
- O Construction of a multi-story building in progress – be alert for falling debris

7. What does this sign mean to you?

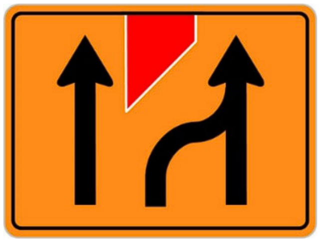
- O Drive through the work zone quickly
- O Leave extra space between your vehicle and the one in front of you
- O Leave extra space for workers
- O Parties prohibited at rest areas in the work zone



8. What does this sign mean to you?

- O Work zone speed limit strictly enforced
- O Avoid following too closely behind the car in front of you
- O Be alert for trucks entering or leaving the construction area
- O Leave extra space for workers

Please continue on Page 3…



9. What does this sign mean to you?

- ○ Traffic in center lane should stop
- ○ Reduction in the number of lanes – left lane ends
- ○ Road work in center lane – vehicles in the center lane should merge into the right lane
- ○ Obstruction in the roadway – keep left

10. What does this sign mean to you?

- ○ Drive through the work zone quickly
- ○ Parties prohibited at rest areas in the work zone
- ○ Leave extra space for workers
- ○ Avoid following too closely behind the vehicle in front of you

11. What does this sign mean to you?

- ○ Avoid following too closely behind the car in front of you
- ○ Leave extra space for workers
- ○ Avoid driving too close to temporary barriers
- ○ All of the above

12. What does this sign mean to you?

- ○ Roadside area where you can stop to make phone calls or send text messages
- ○ Parking area for construction workers
- ○ Access to construction site – for construction trucks only
- ○ Designated lane for construction vehicles

Almost done – just a few demographic questions…

About You…

Do you have a driver license or permit?

- O Yes
- O Came to the DMV today to apply for one
- O No

What is your primary language?

- O English
- O Spanish
- O Hmong
- O Other (please specify)

____

Which best describes your gender?

- O Woman
- O Man
- O Non-Binary
- O Prefer not to answer

Age

O 13 or Younger	O 25-34	O 65-74
O 14-16	O 35-44	O 75-84
O 17-18	O 45-54	O 85 or Older
O 19-24	O 55-64	

Approximately how many hours do you drive each week?

O Less than 2	O 11 to 15	O 26 to 30
O 3 to 5	O 16 to 20	O 31 to 35
O 6 to 10	O 21 to 25	O 40 or more

Comments

Thank you for your participation!

APPENDIX C-1. SIGNAGE UNDERSTANDABILITY SURVEY – OPEN-ENDED

INSTITUTE FOR TRANSPORTATION

Signage Understandability Survey

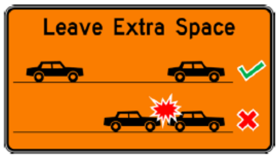
We are evaluating the understandability of several traffic signs. Some you may have seen before, and others are new. For each sign, please explain *in your own words* what that sign means to you.

This survey is being done by the Institute for Transportation at Iowa State University. The research is sponsored by the Smart Work Zone Deployment Initiative, a coalition of transportation agencies from several states. If you have questions, contact Dr. Jing Dong-O'Brien 515-294-3957 or Mr. John Shaw 515-294-4366. Your participation in the survey is voluntary and anonymous. Sorry, there are no prizes or compensation.

1. What does this sign mean to you? 	
2. What does this sign mean to you? 	
3. What does this sign mean to you? 	

Please continue on Page 2...

4. **What does this sign mean to you?**



5. **What does this sign mean to you?**

6. **What does this sign mean to you?**

7. **What does this sign mean to you?**

Please continue on Page 3...

8. What does this sign mean to you?	
	

About You...

Do you have a driver license or permit?
- ○ Yes
- ○ Came to the DMV today to apply for one
- ○ No

Age

○ 13 or Younger	○ 25-34	○ 65-74
○ 14-16	○ 35-44	○ 75-84
○ 17-18	○ 45-54	○ 85 or Older
○ 19-24	○ 55-64	

What is your primary language?
- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

____

Approximately how many hours do you drive each week?

○ Less than 2	○ 11 to 15	○ 26 to 30
○ 3 to 5	○ 16 to 20	○ 31 to 35
○ 6 to 10	○ 21 to 25	○ 40 or more

Which best describes your gender?
- ○ Woman
- ○ Man
- ○ Non-Binary
- ○ Prefer not to answer

Comments

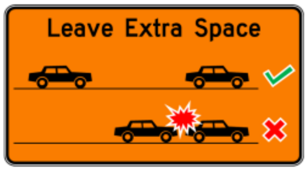
Thank you for your participation!

APPENDIX C-2. SIGNAGE UNDERSTANDABILITY SURVEY – OPEN-ENDED RESULTS

Answer (39)
Maintain fair distance between cars, at least more than you usually would
leave space
slow down, leave space between yourself and others
Be careful and leave extra room between cars
Don’t follow too closely
Drive safely
don’t follow so close, be alert.
Leave more space between you and the car in front of you
Make sure to leave a few cars length space between you and the car in front of you
Leave more than usual space to car ahead
Leave more space between cars in front of you
Don’t crowd too close to the car ahead
Proceed with caution and give extra room
Leave plenty of room between you and other cars
Leave space between you and the car ahead of you
leave extra space when following a car
Leave room between vehicles
I this this is proposing have a safe following distance between your own car and the one in front of you
Traffic may be slowing due to road conditions. Driver showed slow down and leave extra space between the car in front of me and behind me
leave space between cars so no crashes occur
Leave space between you and the car ahead of you
Keep a safe distance between the vehicle in front of you and yourself
Be safe, Leave more room
Don’t tailgate
Leave space between vehicles
Keep safe distance in between vehicles
use caution, drive slow, leave space between cars
Spacing for Breaking
Don’t tailgate
Keep your distance?
Drive carefully - don’t tailgate
stay focused, obey speed limit, don’t tailgate
Don’t follow to close to other cars
Do not follow this vehicle closely
Having enough space
Put a good amount of distance between you and driver in front, Don’t tailgate
Do not tailgate
Don’t follow too closely
Drive safe with space between each vehicle

Vague (8)
Notice : general messages to a driver
drive cautiously
Weather related. Mainly snow or ice on road.
Safety signs
Drive with caution
Drive Carefully
Use extra caution; Changing driving situation
you might get hit

Wrong (4)
Leave space between parking
Construction will be coming up
Either lanes(s) become narrow or the lanes curve repeatedly
Be careful while driving. Parking in crowded places



Answer (49)
Maintain large distance between cars
keep room between cars
Too not close
leave room between yourself and other vehicles
leave space, otherwise to close you’re going to crash into other vehicle in front of you since there was no space left between the cars
Don’t tail drivers
Extra room between cars
Don’t follow too closely
Don’t tailgate cars
Extra room prevent crash
don’t tailgate
Leave more space between you and the next car
Make sure to leave a few cars length space between you and the car in front of you
Be aware of tour spacing. The legal speed decreases quickly
Leave more than usual space
Accident ahead in right lane
Leave more space between your car and the car in front of you
Don’t tailgate
Ensure there is a good amount of space between my car and the one in front of me
don’t ride so close
Leave enough space between you and the front car to be safe
leave space when behind a vehicle
Don’t follow too closely
Encouraging a safe following distance between cars.
Example on the top is “what good looks like”, Example on bottom is what “Not to do”
leave space between you and the car ahead of you to avoid any crashes
Leave space between you and the car in front of you to avoid accidents
Leave extra room between you and the car to prevent crash
More following distance
Leave space
Keep safe distance
Drive with caution, Keep your distance
Maintain adequate spacing to avoid crashes
Proper spacing for breaking
Don’t tailgate
Drive safely
Keep your distance
Don’t tailgate/drive too close to the car in front of you
Don’t tailgate, If someone slam on there breaks, you could crash into them
Don’t follow to close to others cars
Follow cars at a safe distance
To avoid collision, Leave space
NO tailgating
tells you to leave enough room so an accident does not happen
Do not tailgate another car, Drive plenty of space between cars
lane space between parking cars
Don’t follow to close to other cars
Don’t follow too closely
Leave more space to prevent accidents

Vague (2)
Two second lane
You might get rear ended

Wrong (-)

Answer (49)
Keep fair distance between cars
keeping proper space helps prevent accidents
keep your distance not too
keep a safe distance
keep car space between each other.
Notice for drivers to not tail
Extra room between cars
Keep distance, don’t follow too closely
Leave space between you and the car in front of you
keep distance with the front car to prevent crash
Keep your distance
Leave space between you and the next car
Leave a few cars length space between you and the car in front of you
Same as 4 (Leave extra space) too
Maintain appropriate distance
keeping distance from cars
Don’t tailgate
Allow for extra space between cars
don’t ride to close
Leave enough space
leave space when following vehicles
Keep an acceptable distance between your car and the next one
Same answer as 4, Keep safe distance between cars
Keep a large distance between vehicles
keep the distance between cars and stay safe on the road
keep space between you and the car ahead of you
Keep your safe distance to prevent crashes
Keep distance
Don’t tailgate
Leave space
Keep safe distance
keep distance
Keep adequate distance for safety
Spacing between drivers
Don’t tailgate
Drive with care, safe distance
Keep your distance
don’t tailgate
Don’t tailgate
Keep safe distance away from other cars
Follow cars at a safe distance
Keep distance
Keep appropriate amount of space between you and car in front
Keep space to avoid accidents
Keep a good distance between cars while driving
Don’t follow close
Never follow close keep your distance
Don’t follow too closely
Keep safe distance from other vehicles

Vague (1)
Drive with caution

Wrong (1)
Potential conjected area ahead

Answer (42)
Stay for distance from car ahead of you
slow down, drive safe, keep distance
Not to tailgate, No close
leave space between you and others. Don't be an asshole
Don't follow too closely
Be safe on the road
Drive safely, leave extra space
Keep your distance. The crash from tailgating would take longer to take care of then just slowing down and keeping distance.
keep distance between you and the next car
Slow down, Be aware of your speed/distance
Reminds to leave proper space
Don't get too close to the car in front of you
Don't follow too closely to cars ahead
It's not worth it to speed and follow closer to people to try and get ahead
Leave enough space between the car in front of you
leave space when following
Don't follow too closely
tailgating means you are following a car close to their tailgates, so also encouraging a safe following distance between cars.
Keep distance between cars. The result if you don't could be crash
tailgating can cause crashes which prevent you to get to your destination
Don't follow the car ahead of you too closely
Don't drive too close to the car in front of you
More following distance
Same as the two last pages
Leave space
Keep safe distance
Leave space between the car in front of you
Driver's safe speeding may actually cost more time in the long run, Maintain good distance
Keep distance
Don't tailgate?
Drive safely
Keep your distance
Don't tailgate(drive too close) or you may get in a crash
Give yourself ample time when driving, Don't get to close to other vehicles
Don't follow closely to other cars. If you do, you may get into a crash which will make you late
Do not follow a car in front of you too closely
Do not tailgate
Don't be too close to car in front
Keep a good distance between cars while driving. If you don't, you could get into a car accident
Leave space between cars
Don't follow too closely
Don't drive close to others to prevent a crash that could make you late somewhere

Vague (5)
drive cautiously
General notice
Reminder to pay attention
Don't be in a hurry take your time
Safety signs

Wrong (4)
don't be in a hurry
Tailgating doesn't make anyone go faster.
potential congestion ahead
Sudden stop

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InTrans centers and programs perform transportation research and provide technology transfer services for government agencies and private companies;

InTrans contributes to Iowa State University and the College of Engineering's educational programs for transportation students and provides K–12 outreach; and

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