Effective Signing Strategies and Signal Displays for Work Zone Driveway Assistance Devices (DADs)

Final Report
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To address these issues, research was performed to determine best practices related to the DAD design and to develop guidelines related to the use of DADs in one-lane, bi-directional work zones. First, a nationwide online survey of drivers was conducted to determine the DAD signal configurations and auxiliary sign messages that elicited the highest rates of compliance or most effectively communicated the proper driver action. The survey was supplemented by a field study performed in northern Michigan that evaluated the effects of five different auxiliary signs on driver compliance when utilized with a DAD. The conclusions and recommendations resulting from these efforts are summarized as follows. The auxiliary signs most effectively conveyed the proper driver action if the message included the word “Turn” as opposed to “Yield” and if the word “Turn” was included. Additional improvements were observed for signs that included a prominent “WAIT” message at the top of the sign. These findings were consistent between the survey and field study. Turning to the characteristics of the DAD signal indication, compared to yellow flashing arrows, red flashing arrows showed far fewer “Turn at any time” survey responses, although yellow flashing arrows showed considerably less uncertainty as to the proper action for drivers. Considering the DAD signal head configuration, the horizontal and doghouse configurations more effectively conveyed the proper driver action compared to the red-over-yellow arrows configuration in the driver survey. Based on the research findings, DADs are recommended for continued experimental use along with appropriate auxiliary signage at work zones that include one-lane, two-way traffic where it is not practical or feasible to provide a continuous flagger or temporary traffic signal operation.

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EXECUTIVE SUMMARY

Work zones that include a single lane closure on a two-lane, two-way roadway present unique traffic control challenges. In these situations, traffic regulators (i.e., flaggers or temporary traffic signals) are often utilized to regulate traffic such that only a single direction utilizes the open travel lane at any time. Recently, an experimental traffic control treatment, referred to as the driveway assistance device (DAD), has been developed to help drivers safely enter a one-lane, bi-directional work zone from a driveway or minor side street by using alternating left and right flashing arrows along with a steady red indication. As the DAD is a relatively new and under-researched treatment, much is still unknown about the optimal designs of the signal display and auxiliary signage to provide the highest comprehension and compliance.

Background and Objectives

Prior research has found the DAD to give promising results in terms of the rate of legal and/or safe movements made by drivers exiting driveways, although a lack of motorist comprehension of the device has also been observed. Furthermore, a lack of consistent design, application, and formal evaluations between the states where DADs have been implemented have hindered its adoption into the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) and have delayed further development by manufacturers. As a result, the DAD continues to remain as an experimental traffic control treatment, and formal Federal Highway Administration (FHWA) approval is necessary prior to field implementation. Additional research is needed to determine the best practices related to the DAD display and other design features, and to develop guidelines related to the use of DADs in work zones. To address these issues, the following research objectives were formulated:

• Determine the DAD display design that best directs motorists to safely enter the one-lane, two-way operation and proceed in the proper direction of travel
• Develop guidelines regarding the design and utilization of DADs
• Develop presentation materials to support broad implementation of the research findings and corresponding guidelines to a variety of audiences

Research Methods

These objectives were accomplished through the following two primary tasks:

• A nationwide online survey of driver comprehension and preference to various DAD designs
• A field study that evaluated the effectiveness of various auxiliary signs in terms of driver compliance when used in conjunction with the DAD.

The research plan was developed with the intent that any positive findings may be used to support the adoption of the DAD into the MUTCD. The nationwide survey of 1,015 motorists was particularly useful for determining the signal-head arrangements and auxiliary sign
messages that provided the greatest comprehension, which were further evaluated in the subsequent field study. The field study focused on assessment of driver compliance to the DADs as a function of the auxiliary signage utilized in conjunction with the DAD at multiple access points. This field study was performed at 10 minor access points along a suburban section of work zone on US 31 in northern Michigan and included a rotation of five different auxiliary sign messages.

Building on the recommendations of the prior evaluations, the field study included several higher volume commercial driveways in order to assess the most effective use of DADs at access points where queuing may occur. Data were collected using elevated video cameras positioned at each driveway where a DAD was installed. These videos were then reviewed to assess the legality (with respect to the DAD signal status) and safety of the mainline entry movement for each vehicle exiting the driveway, in addition to other situational characteristics. A total of 2,258 exiting vehicle observations were obtained.

**Findings**

First, from a high-level standpoint, the DAD generally resulted in a high proportion of safe movements during the field study, with an overall safe movement rate of nearly 93 percent, which was consistent with the rates experienced in previous evaluations. Although the overall legal movement rate (62 percent) was lower than observed in prior studies, this could possibly be attributed to the DADs being employed at commercial driveways and minor side-streets with higher traffic volumes and longer wait times compared to the prior evaluations.

Beginning with the assessment of sign message effectiveness, the survey results suggested that signs more effectively conveyed the proper driver action if the message included the word “Turn” as opposed to “Yield.” The message effectiveness was further strengthened if it included the prominent “WAIT” text at the top of the sign, and this result was consistent between the survey and the field study. Perhaps the strongest signing related component for the DADs was the inclusion of a “No Turn on Red” (NTOR) sign, which was found to improve the message effectiveness in all cases. Additionally, the inclusion of the NTOR sign by itself beneath the DAD signal substantially increased the rate of proper response to the circular red indication. Specifically, with the NTOR sign in place, greater than 87 percent of survey respondents indicated the correct action (i.e., Stop and remain stopped until the signal changes), which was a greater than 8 percent improvement over the DAD without any signage. The NTOR sign was particularly effective toward reducing “Stop and turn right when clear of traffic” responses, which decreased by nearly one-half after the NTOR sign was added. This finding is particularly encouraging due to the typically permissive nature of right turns on red at most traffic signals in the US when an NTOR sign is not present.

Turning to the characteristics of the signal indication, yellow flashing arrows contributed to an improved response rate over red flashing arrows in terms of proper driver action when encountering the DAD signal. The red flashing arrows seemed to present considerable uncertainty amongst the survey respondents, as evidenced by the red arrows being greater than six times more likely to result in an “Unsure” response for the appropriate driver action.
compared to the yellow arrows. However, the red flashing arrows showed improvements over the yellow arrows toward reducing “Turn at any time” responses.

Finally, in terms of DAD signal head configuration, the survey respondents indicated that horizontal and doghouse configurations more effectively conveyed the proper driver action compared to the red-over-yellow arrows configuration. This result is not surprising due to the low level of implementation of such signal configurations nationwide.

Recommendations for Future DAD Implementation

Based on the collective results of the survey and field study, the following recommendations are provided regarding various design and operational aspects of DADs:

• DADs are recommended for continued experimental use at work zones that include one-lane, two-way traffic where it is not practical or feasible to provide a continuous flagger operation.

• Auxiliary signage should be implemented in conjunction with any implementation of any DAD signal. Such signage should utilize messages that provide direction toward what action drivers should take both during the flashing arrow phase and the steady circular phase. For the flashing arrow phase, sign messaging should include “Turn” rather than “Yield.” For the steady circular red phase, a separate NTOR sign should be utilized in combination with any auxiliary sign, or as a standalone sign if no other auxiliary sign is provided. A prominent “WAIT” message may be included at the top of the auxiliary sign to further enhance the appropriate action during the steady circular red. It is important to note that these recommended signs may be used in conjunction with red or yellow flashing arrows. It is also important to note that the “WAIT Turn Only in Direction of Arrow” sign had the highest rate of safe movements of all signs tested in this study.

• Horizontal and doghouse signal configurations are recommended for future DAD implementations. Additional testing of red-over-yellow arrows is recommended prior to further implementation.

• Although yellow flashing arrows contributed to an improved response rate and decreased uncertainty compared to red flashing arrows in terms of proper driver action when encountering the DAD signal, the authors do not make a recommendation on flashing arrow color. Rather, the decision to use flashing red or flashing yellow directional arrows should remain at the discretion of the particular agency, based on the policies and practices within the jurisdiction. In many states, the flashing red arrow is either uncommon or unknown, thus leading to motorists confusion. Furthermore, at higher-volume locations, it may be more operationally more efficient to utilize flashing yellow arrows to eliminate the need for each vehicle to make a complete stop while exiting.

• It is evident that controlling the available gap time and dwell time at each DAD would add value toward influencing legal, safe movements. Thus, the DAD should be timed in a way
such that gap time is optimized to allow platoon clearance but deter drivers from joining the end of a platoon illegally on the steady circular red. It is also recommended that further investigation be made into the DAD signal timing with respect to the device location relative to portable traffic control signal.

- Providing left and right storage lanes could improve DAD operations at higher-volume access points. As experienced in this field study, impatient queued motorists often created ad hoc turn lanes if their desired turn was blocked by the queue leader. This leads to numerous illegal and/or unsafe maneuvers. At wider access points, and especially those with higher traffic volumes, separate left and right turn lanes could reduce the possibility of long queues by improving flow and also reduce unsafe movements.

- There is a need to investigate DADs at 4-leg locations, both intersections and driveways. The current DAD design has two issues at 4-leg locations. There is no provision with the current DAD design to permit a legal crossing maneuver. There is also conflict between right turns and opposing lefts during a permitted turning phase. Thus, it is necessary to modify the DAD or provide additional auxiliary signage to operate correctly at 4-leg locations, and further testing is recommended.
1. INTRODUCTION

Worker injuries and fatalities are a major concern during construction and maintenance work performed on our nationwide transportation network. The U.S. Bureau of Labor Statistics (BLS) reported that from 2003 to 2010, a total of 442 fatal crashes occurred that involved workers being struck by vehicles or equipment, and 92 of those fatalities (21 percent) involved flaggers (Pegula 2013). To address the safety and operational concerns at work zones, various traffic control strategies have been developed to facilitate traffic flow while simultaneously lowering the risk for work zone injuries and fatalities.

Work zones that include a single lane closure on a two-lane, two-way roadway present unique traffic control challenges. In these situations, traffic regulators (i.e., flaggers or temporary traffic signals) must be utilized to regulate traffic such that only a single direction utilizes the open travel lane at any time. Typically, a traffic regulator is stationed at either end of the work zone and at major intersections in-between. The traffic regulation strategy is confounded by the presence of intermittent driveways and minor intersections within these sections. Issues arise when motorists attempt to exit such access points onto the work zone segment where a single lane is used to service bi-directional traffic. In these situations, drivers wishing to exit the driveways or minor intersections and turn onto the open travel lane of the primary roadway are often not provided with adequate information regarding the current direction of traffic flow along the segment.

Thus, provisions are necessary to control and alternate two-way traffic flow on a temporary one-way facility while providing access to traffic onto the mainline from low-volume access points along the work zone through legal and safe movements. In addition to flaggers, multiple alternative traffic control treatments including pilot vehicles, automatic flagger assistance devices (AFAD), temporary traffic control signals (TTCS), and the smaller portable traffic control signals (PTCS), have been employed nationwide to regulate mainline traffic during temporary one-way operations (Ullman and Levine 1987, Daniels et al. 2000). Many of these strategies may also be used at intermittent minor access points to regulate the movements of exiting vehicles. However, in many cases, particularly when the exiting traffic volumes are low, the use of flaggers or other traffic control devices at driveways and minor intersections might not be cost effective (Ullman and Levine 1987, Daniels et al. 2000), leaving these access points without additional traffic regulation. This creates situations where drivers are forced to assess the current direction of the mainline traffic along with the time remaining until the opposing direction is released.

1.1. Background

Recently, driveway assistance devices (DADs) have been developed to help guide drivers desiring to enter a one-lane, bi-directional work zone from a driveway or minor side street and proceed in the proper direction of travel. This device has been originally developed and refined by the Texas Department of Transportation (TxDOT). Typically, each DAD is equipped with alternating left and right flashing arrows to notify motorists of the current traffic flow direction along the work zone segment. These flashing arrows may be presented in various configurations...
(e.g., horizontal, doghouse, red-over-yellow) and may be either yellow or red, depending on the jurisdictional preference. In most cases, a solid red indication (circular or arrows) is displayed when it is unsafe to enter the work zone. In addition to various signal display alternatives, there also remains little consensus as to the level of auxiliary signage that should be used. While a “No Turn on Red” (NTOR) sign is typically recommended, many agencies also install an additional sign to provide guidance related to how motorists should proceed on the arrow. Some of the example messages that have been implemented include:

- Yield in Direction of Arrow
- Turn Only in Direction of Arrow
- STOP Then Yield in Direction of Flashing Arrow
- Yield in Direction of Flashing Red Arrow After Stop
- Proceed on Flashing Red Arrow After Stop

DADs are wirelessly connected with the temporary traffic signals placed at each end of the lane closure and are coordinated with the signal timing plan for directional traffic on the major roadway. The DAD arrows are programmed to cease flashing as traffic moves through the work zone, helping to reduce the likelihood of drivers entering the work zone near the end of the cycle (Finley 2016). An example DAD is displayed in Figure 1.

![Example Driveway Assistance Device (DAD)](image)

**Figure 1. Example driveway assistance device (DAD)**

The early findings by TxDOT indicate the DAD to be a potentially low-cost and a promising alternative to flagger or other traffic regulator at low-volume access points, providing potential cost savings, productivity benefits, and increases in worker safety (Ullman and Levine 1987, Daniels et al. 2000). However, as DADs are a relatively new and under-researched treatment, much is unknown about motorist comprehension and compliance, optimal designs of the signal heads and auxiliary signage, and appropriate conditions for use (Finley 2016, Finley et al. 2020, MDOT 2019). Figure 2 displays the current level of utilization of the DAD nationwide.
As of late 2021, eight states have received permission from the Federal Highway Administration (FHWA) to experiment with the DAD, while an additional 13 states have permitted the use of DADs on specific projects, and five other states have expressed interest in the DAD.

### 1.2. Problem Statement and Research Objectives

While the DAD has shown promising results in terms of the rate of legal and/or safe movements made by drivers exiting driveways, the DAD has also demonstrated a lack of motorist comprehension of the device (Finley 2016, MDOT 2019). Furthermore, a lack of consistent design, application, and formal evaluations between the states where DADs have been implemented have hindered its adoption into the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) and have delayed further development by manufacturers (FHWA 2012). As a result, the DAD continues to remain as an experimental traffic control treatment, and formal FHWA approval is necessary prior to field implementation. Additional research is needed to determine the best practices related to the DAD display and other design features and develop guidelines related to the use of DAD in work zones. To address these issues, the following research objectives were formulated:

- Determine the DAD display design that best directs motorists to safely enter the one-lane, two-way operation and proceed in the proper direction of travel
- Develop guidelines regarding the design and utilization of DADs
• Develop presentation materials to support broad implementation of the research findings and corresponding guidelines to a variety of audiences

This research sought to build upon the two prominent prior DADs evaluations performed in Texas and Michigan (Finley 2016, Finley et al. 2020, MDOT 2019) by considering the following:

• A field study of driver compliance that includes higher volume access points, additional DADs test conditions, and larger vehicle sample sizes
• A nationwide survey of motorist comprehension of the DADs configuration and operation

The research plan was developed with the intent that any positive findings may be used to support the adoption of the DADs into the MUTCD. To that end, this research included a nationwide online driver survey and a field evaluation of DADs deployment in Michigan, performed under MDOT’s DADs experimentation plan. The nationwide survey was particularly useful for determining the signal-head arrangements and auxiliary sign messages that provided the greatest comprehension, which were further evaluated in the subsequent field study. The field study focused on assessment of driver compliance to the DADs as a function of the auxiliary signage utilized in conjunction with the DAD at multiple access points. Building on the recommendations of the prior Texas and Michigan evaluations, the field study included several higher volume commercial driveways in order to assess the most effective use of DADs at access points where queuing may occur. This report details the methods, findings, conclusions, and recommendations of the research, and is organized as follows:

• Chapter 1 – Introduction
• Chapter 2 – Review of Literature and Practice
• Chapter 3 – Nationwide Driver Survey
• Chapter 4 – Field Study
• Chapter 5 – Conclusions and Recommendations for Future Use
2. REVIEW OF LITERATURE AND PRACTICE

A comprehensive review of the existing guidelines, current practices, and previous research carried out for temporary traffic control devices in work zones was performed. Several prior studies have evaluated the effectiveness of using PTCS or AFAD to regulate mainline traffic flows within one-lane, two-way work zones. The body of literature on these devices, however, is lacking in the context of low-volume access points. Furthermore, the literature specifically detailing the use of DADs is particularly sparse.

2.1. Temporary Traffic Control for One-Lane, Two-Way Work Zone Sections

Section 6C.10 of the MUTCD states, “provisions should be made for alternate one-way movement . . . via methods such as flagger control, a flag transfer, pilot car, traffic control signals, or stop or yield control” (FHWA 2012). The manual also suggests that when both ends of a work zone are not visible, flagging procedures or PTCS, with or without a pilot car, should be used. Both the MUTCD and Michigan MUTCD offer guidance on using PTCS and AFAD in a work zone (FHWA 2012, MDOT 2013). However, there is no specific information related to a driveway assistance device. Consequently, the DAD is considered as an experimental device by the FHWA and must follow the formal experimentation process.

Within the MUTCD, Section 6E contains guidelines for using AFAD at the end of a one-lane, two-way work zone, stating that “when using an AFAD, there must either be a traffic regulator in the work zone that controls both devices, or one controlling each.” This is contrary to the goal which is to eliminate the need for human control of the traffic stream, which is especially important given the number of DADs that could be in use in a certain work zone. Also, “Because AFAD are not traffic control signals, they shall not be used as a substitute for or a replacement for a continuously operating temporary traffic control signal.” as described in Section 6F.84. The manuals also recommend that an AFAD should have incorporated gates or bars to block the stopped direction of traffic in addition to a “Stop Here On Red (R10-6(a))” sign, as stated in Section 6E.06 (FHWA 2012, MDOT 2013). Furthermore, the need of a flashing yellow arrow and the inclusion of a change interval between it and solid red phases for AFAD are required to be addressed.

The Texas MUTCD states that movements from each end shall be coordinated and that access should be controlled throughout the one-lane section (TxDOT 2014). This manual acknowledges that driveways create a problem that should be monitored, and that closures of all entering intersections within the work zone should be considered. It also suggests that traffic control at driveways and intersecting roadways may be achieved by flaggers, but they are typically used for short duration operations (work that occupies a location up to 1 hour) and short-term stationary operations (daytime work that occupies a location for more than 1 hour within a single daylight period). Flagger control may also be used at night as long as the flagger station is illuminated.

As an alternate to flagger control, Texas MUTCD suggests that STOP or YIELD signs may be used to control traffic on low-volume roads at one-lane, two-way work zones when motorists are able to see the other end of the one-lane section and have sufficient visibility of approaching
vehicles (TxDOT 2014). Alternatively, this manual indicates that TTCS are preferable to flaggers for long-term projects and other activities that would require flagging at night (TxDOT 2014). Moreover, TxDOT standards (2012) state that for long-term, one-lane, two-way control (work that occupies a location more than three days), TTCS should be used for longer work zone section with high traffic volume, instead of stop and yield control.

Similar to Texas MUTCD, the Ohio MUTCD (2005) suggests that, for alternate control for one-way movement through the single lane section, flagger control, stop or yield control, TTCS or pilot vehicles may be used. TTCS may either be constructed of standard signal components or may be a portable traffic control signal (PTCS), which is self-contained and trailer-mounted. These PTCS can be programmed to operate in a pre-timed or actuated mode (ODOT 2005, 2002, 2019). According to the Ohio MUTCD (2005) and the Ohio Traffic Engineering Manual (TEM) (2002), all flaggers should be able to communicate with each other orally, electronically, or with manual signs, to ensure coordination among movements. Also, according to Ohio Supplemental Specification 830 (ODOT 2014), AFAD can be used at each end of the constricted section or at one end of the constricted section with a flagger at the opposite end. Two flaggers must be used with either method, unless a single flagger has an unobstructed view of both AFADs and an unobstructed view of approaching traffic in both directions. There are two types of AFAD: those with a stop/slow paddle and those with a red/yellow lens (ODOT 2005, 2002, 2012). As suggested by the Ohio Department of Transportation (ODOT), both types of AFAD must include a gate arm that descends to the down position across the approaching traffic lane when traffic is stopped and ascends to an upright position when traffic may proceed. A flag should also be added to the end of the gate arm to improve conspicuity of the arm (ODOT 2012). ODOT personnel noted that these devices were easy to setup and use, and worked best for short lane closures.

AFAD has also been utilized in Minnesota for several years. A survey was conducted in Minnesota to understand drivers’ opinions of the AFAD. The data indicated that the majority of the drivers felt the AFAD were effective in controlling the traffic in the work zones (MnDOT 2011, Finley et al. 2015).

An earlier field study conducted by Ullman and Levine (1987) compared motorist delays between flagger and PTCS treatments. Results found that motorists interacting with a PTCS incurred only a 0.1-hour increase in delay, as compared to flagger treatment. A cost analysis found conservative estimates of the savings achieved by using PTCS ranged from $9 to $14 an hour (in 1987 dollars).

Daniels et al. (2000) conducted a feasibility study on replacing mainline flaggers with PTCS in Texas work zones (Daniels et al. 2000). The low number of red-light violations found by this group confirmed the feasibility of using mainline PTCS. The authors claimed the removal of a flagger would provide operational benefits. This report influenced future work by also suggesting improvements upon feasibility of PTCS, comprehension, and compliance related to the devices, and the ideal work zone characteristics for PTCS use. The cost-benefit analysis performed as a part of this study found that assuming elimination of one full-time flagger, the equipment would pay for itself after 2.02 years and would show an average yearly savings of
When a flagger is reassigned to contribute to other work activities, the average annual savings would be nearly $20,000 with a payoff period of 2.80 years.

A 2009 research study assessing the state-of-the-practice on AFAD by Texas A&M Transportation Institute (TTI) identified that the extent of experience using AFAD by different state agencies varied considerably. Most of these agencies were only using one type of AFAD (either stop/slow or red/yellow lens). Several factors were identified as deterrents to AFAD use and they include: cost of AFAD, problems with the remote controls and charging the units, and ease of using TTCS instead, among others. A subsequent study was carried out in 2011, and through driver surveys and field studies, it determined the driver understanding of AFAD and the operational and safety effectiveness of AFAD relative to the use of flaggers at lane closures on two-lane, two-way roadways (Finley et al. 2012).

A study from Trout, Finley, and Ullman used motorist surveys to investigate comprehension of two AFAD designs (Trout et al. 2013). A significant difference in the design of these AFAD from prior evaluations is that they both had a gate that would alternate depending on traffic flow. For both device designs, participants were shown a sequence of videos depicting a progression of the device in use. All participants understood that, for a red-yellow device, a steady red signal meant to stop. However, in all but one of seven scenarios, results showed that at least 94 percent felt a flashing yellow signal meant to proceed with caution. This result was consistent whether participants were shown a stop, proceed, and transition, or if the transition phase was omitted. For the slow-stop device, participant actions were recorded in response to varying auxiliary signs. The most effective sign included “WAIT ON STOP SIGN SYMBOL” and “GO ON SLOW SIGN SYMBOL” messages. With this sign, 92 percent of participants indicated they would remain stopped until a SLOW sign was shown. However, this was not significantly different from the 85 percent threshold set for comprehension. Synthesis of results from both AFAD designs suggest that similar designs may be effective for DAD application; specifically, a red/flashing-red signal, in addition to simple, effective, and symbolic auxiliary signs.

A study by Schrock et al. (2016a) evaluated the effectiveness of three work zone mainline traffic control treatments: PTCS only, flagger only, and PTCS with flagger all while using a pilot vehicle. They measured the effectiveness by collecting data on red light running, vehicle delays, queue lengths, and green interval times, and found that a PTCS had a 3.1 percent violation rate, higher than 1.1 percent for flagger only and 1.3 percent for PTCS with flagger. This study also incorporated an investigation into operational efficiencies of the treatments and found that delays decreased by 5 percent with the presence of a flagger. Moreover, they argued that adding signage, either static or dynamic, to provide guidance on wait times could dissuade drivers from the temptation to make an illegal movement.

A related study by Schrock et al. (2016b) developed models for best use of a PTCS using appropriate traffic characteristics for PTCS with pilot car. These results of this study found that a PTCS system would fail above an AADT of 7,083 vehicles per day, given a maximum delay threshold of 15 minutes, and maximum pilot car speed of 40 mph. These results corresponded to a maximum green time of 446 seconds.
Later research by Finley and Theiss (2017) assessed compliance with mainline PTCS with pilot vehicle treatments, both with and without flaggers. Researchers argued that the necessity of flagger presence negated the safety and construction operational benefits that should come with a PTCS with pilot vehicle. The field study for this project was conducted at eight sites in Texas with varying lane closure lengths, speed limits, and visibility of work activity or PTCS. The activity of vehicles arriving at the PTCS were reviewed and collected to determine behavior at the sites. Results showed that 2.7 percent and 2.3 percent of motorists were non-compliant, with and without flagger presence, respectively. Due to the closeness of the rates, no significant difference was observed between the treatments. Given the high compliance rates, the authors of this study suggested a revision of the MUTCD to allow for the use of PTCS at one-lane, two-way work zones without a flagger.

2.2. Driveway Assistance Devices

In 2016, Finley reviewed a 2013 study conducted by TxDOT (Finley et al. 2014) on using innovative traffic control devices at low-volume access points within a lane closure (Finley 2016). The researchers used a modified hybrid (doghouse) device and a blank-out sign device to conduct a survey of motorist comprehension of the new devices followed by a field study at a rural intersection work zone in Texas. Controlled and non-controlled participants were observed to determine operational efficacy and motorist comprehension of the devices. Results for the non-controlled study found that 13 percent and 8 percent of motorists, respectively, misunderstood the meaning of the doghouse and blank-out signs. Nevertheless, the findings from both controlled and non-controlled studies indicates that the blank-out device performed better than the modified hybrid device. However, Finley acknowledged that the blank-out sign is more expensive and less readily available and suggested that further investigation is necessary to improve motorist understanding of both devices.

A Michigan Department of Transportation (MDOT) report summarized five pilot tests of temporary portable DADs, which are shown in Figure 3.
These pilot tests employed DADs at residential driveways at work zone segments on state highways across the state from 2015 through 2018 (MDOT 2019). Overall, 82.8 percent of observed motorists proceeded correctly and safely when encountering the DAD, while 15.7 percent proceeded incorrectly, but safely, resulting in a safe movement rate of 98.5 percent. Given these results, MDOT concluded the DAD was safe and effective at residential driveways, and recommended the device to be considered for inclusion in the next MUTCD. Some concerns were noted on the importance of appropriate work zone visibility, geometrics, and volume. Similarly, a recommendation was made to provide left and right turn storage lanes at certain sites to alleviate excessive queues. The report also recommended additional testing of the DADs at locations experiencing higher volumes.

In addition to the completed research, there are other currently ongoing projects investigating DADs. One such study is being conducted in Nebraska (Tufuor 2022, in progress). The goals of the study are similar to the Michigan pilot study, with the addition of studying stop-controlled locations. DADs also continue to be evaluated in an ongoing project for TxDOT conducted by the Texas A&M Transportation Institute (Finley et al. 2020). Further, there is additional ongoing FHWA experimentation by respective statewide transportation agencies in Indiana, Massachusetts, Mississippi, New York, and Vermont (FHWA n.d.).
3. DRIVER SURVEY

One of the principal components of this research was to perform a nationwide survey of drivers to determine the DAD signal configurations and auxiliary sign messages that elicited the highest rates of proper driver action or most effectively communicated the proper action. The specific objectives of the survey were to assess driver comprehension of the following DAD attributes:

- **Auxiliary Sign Message**
  - “Turn Only in Direction of Arrow”
  - “Yield in Direction of Arrow”
  - “WAIT Turn Only in Direction of Arrow”
  - “WAIT Then Yield in Direction of Arrow”
  - “WAIT for Arrow before Turning”
- **Signal Head Configuration**
  - Horizontal
  - Doghouse
  - Red over Yellow Arrows
- **Arrow Colors**
  - Yellow
  - Red (with and without “STOP Then Yield in Direction of Flashing Arrow” sign)
- **No Turn on Red sign**
  - Stand-Alone
  - Used with Other Signs

The survey was designed online in Qualtrics and was initially previewed and vetted by the project technical panel and piloted to a sample Qualtrics panel prior to the nationwide launch. Thereafter, the survey was distributed to a nationwide panel of drivers who were recruited by Qualtrics and met two self-reported conditions: (1) over the age of 18 and (2) possessed a valid driver’s license.

3.1. Questionnaire

The survey began with a series of demographic questions, related to the following:

- Age
- Race
- Household income
- Education
- Miles driven in a typical year (approximate)
- State of residence

Due to the general lack of familiarity with DADs nationwide, before proceeding with the DAD related survey questions, the survey takers were then asked to first view the Figure 4 image and description and indicate that they have viewed the signal animation before proceeding. Note that
the image was actually an animated gif in the online survey, with flashing left and right arrows alternating with the circular red indication.

**Figure 4. Introductory DAD image and description**

After viewing the introductory animated DAD image and corresponding description, survey takers were then displayed a series of questions pertaining to either (1) an action that should be taken for a given DAD signal indication, or (2) the sign message that most effectively describes the proper action that should be taken. The survey questions included images or animated gifs pertaining to various aspects of the DADs.

### 3.2. Demographic Descriptive Statistics

In total, 1,050 responses were received. A series of quality control checks led to the removal of 35 of these responses, leaving 1,015 responses for further analysis. Responses were received
from 49 states, with the sample sizes for each state shown Figure 5. The states with the largest representation in the survey sample included California (104 responses), New York (99 responses), Florida (96 responses), and Texas (94 responses). Collectively, these states accounted for 38.7 percent of the responses.

**Figure 5. Number of survey responses by state**

The survey descriptive statistics for the demographic variables included in the analysis are presented in Table 1.
Table 1. Demographic summary statistics from online driver survey (n = 1,015)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver’s age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18–34</td>
<td>327</td>
<td>32.2%</td>
</tr>
<tr>
<td>35–54</td>
<td>339</td>
<td>33.4%</td>
</tr>
<tr>
<td>55–74</td>
<td>330</td>
<td>32.5%</td>
</tr>
<tr>
<td>74+</td>
<td>19</td>
<td>1.9%</td>
</tr>
<tr>
<td>Driver’s gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>512</td>
<td>50.4%</td>
</tr>
<tr>
<td>Male</td>
<td>503</td>
<td>49.6%</td>
</tr>
<tr>
<td>Driver’s race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>661</td>
<td>65.1%</td>
</tr>
<tr>
<td>Black</td>
<td>118</td>
<td>11.6%</td>
</tr>
<tr>
<td>Other</td>
<td>236</td>
<td>23.3%</td>
</tr>
<tr>
<td>Annual household income</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;$50,000</td>
<td>387</td>
<td>38.1%</td>
</tr>
<tr>
<td>≥$50,000 and ≤$100,000</td>
<td>331</td>
<td>32.6%</td>
</tr>
<tr>
<td>&gt;$100,000</td>
<td>297</td>
<td>29.3%</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to high school</td>
<td>195</td>
<td>19.2%</td>
</tr>
<tr>
<td>Some college or 2 years degree</td>
<td>341</td>
<td>33.6%</td>
</tr>
<tr>
<td>4 years bachelor degree</td>
<td>262</td>
<td>25.8%</td>
</tr>
<tr>
<td>Graduate or professional degree</td>
<td>217</td>
<td>21.4%</td>
</tr>
<tr>
<td>Number of miles driven in 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4,000</td>
<td>183</td>
<td>18.0%</td>
</tr>
<tr>
<td>≥4,000 and &lt;8,000</td>
<td>239</td>
<td>23.5%</td>
</tr>
<tr>
<td>≥8,000 and &lt;12,000</td>
<td>240</td>
<td>23.6%</td>
</tr>
<tr>
<td>≥12,000 and &lt;16,000</td>
<td>183</td>
<td>18.0%</td>
</tr>
<tr>
<td>≥16,000 and &lt;20,000</td>
<td>78</td>
<td>7.7%</td>
</tr>
<tr>
<td>≥20,000</td>
<td>92</td>
<td>9.1%</td>
</tr>
</tbody>
</table>

This includes the frequency for which each category was observed, as well as the percentage of the total survey sample. As can be seen from Table 1, the age distribution was split evenly between young (18–34 years), middle-aged (35–54 years), and older drivers (54+ years). The survey was also relatively evenly split between the gender and annual household income categories. In terms of the educational attainment, the largest proportion of drivers had some college education or a two-year degree, followed by four-year/bachelor’s degree, and then graduate or professional degree. Approximately 47 percent of the respondents drove between 4,000 and 12,000 miles in 2019.
3.3. Survey Results

3.3.1. Driver Action on Circular Red without/with NTOR

The first series of questions were related to the steady circular red indication and are displayed in Figure 6.

![Survey question for driver action on circular red without/with NTOR](image)

**Figure 6. Survey question for driver action on circular red without/with NTOR**

The question was initially posed to the respondents without the NTOR sign in place (left image) and was asked again immediately thereafter with the NTOR positioned below the DAD signal (right image). As such, the question was intended to measure driver response to the DAD’s steady circular red and changes in response with the addition of an NTOR sign. Note that in order to effectively gauge responses, this series of questions was displayed prior to indicating
proper driver action to respondents. As displayed in Figure 6, five possible responses were provided in multiple choice format (single choice only) and were displayed in the same order to each of the respondents. The response breakdown is displayed in Table 2.

Table 2. Response for driver action on steady circular red without/with NTOR

<table>
<thead>
<tr>
<th>Driver Action</th>
<th>DAD without NTOR sign</th>
<th>DAD with NTOR sign</th>
<th>% change in response with NTOR sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop and remain stopped until signal changes (CORRECT RESPONSE)</td>
<td>818 80.6%</td>
<td>887 87.4%</td>
<td>8.4%</td>
</tr>
<tr>
<td>Stop and turn right when clear of traffic</td>
<td>90 8.9%</td>
<td>46 4.5%</td>
<td>-48.9%</td>
</tr>
<tr>
<td>Stop and turn left when clear of traffic</td>
<td>38 3.7%</td>
<td>24 2.4%</td>
<td>-36.8%</td>
</tr>
<tr>
<td>Stop and turn right or left when clear of traffic</td>
<td>53 5.2%</td>
<td>36 3.5%</td>
<td>-32.1%</td>
</tr>
<tr>
<td>Unsere</td>
<td>16 1.6%</td>
<td>22 2.2%</td>
<td>37.5%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1015 100%</td>
<td>1015 100%</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 clearly shows that the NTOR sign improved the rate of correct driver action. Without the NTOR sign, 80.6 percent of respondents selected the correct action. However, with the NTOR sign included beneath the DAD signal, 87.4 percent of respondents indicated the correct action, an improvement of 8.4 percent. It was also of interest to analyze changes to each of the specific incorrect or unsure responses, which are reflected in Figure 7.
The inclusion of the NTOR sign beneath the DAD signal substantially decreased the response frequency for each of the three incorrect actions. Collectively, the NTOR sign decreased the frequency of incorrect response by 41.4 percent, from 181 to 106 responses. The NTOR sign was particularly effective toward reducing “Stop and turn right when clear of traffic” responses, which decreased by nearly one-half after the NTOR sign was added. This finding is particularly encouraging due to the typically permissive nature of right turns on red at most traffic signals in the US when an NTOR sign is not present. Similar, albeit less dramatic, results were observed for the other two incorrect actions. Interestingly, the number of “Unsure” responses increased by 38 percent with the inclusion of the NTOR sign, which might indicate a lack of understanding associated with the NTOR sign for a small selection of motorists.

3.3.2. Driver Action on Flashing Arrow (Red vs. Yellow)

The survey was also utilized to assess differences in response as a function of the flashing arrow color (yellow vs. red), and whether a specialized sign may help improve response to the flashing red arrow. The question, which is displayed in Figure 8, was initially posed to the respondents with a flashing yellow left arrow animated gif displayed (left image).
The question was posed again later in the survey utilizing a flashing red left arrow (center image), and again immediately thereafter with a flashing red left arrow and a “STOP Then Yield in Direction of Flashing Arrow” sign posted below the DAD signal (right image) which is utilized with DAD installations in Nebraska. As such, the question was intended to measure driver response as a function of arrow color and auxiliary sign. Note that the appropriate arrow color (i.e., red or yellow) was noted in the blank underlined area of the question shown in Figure 8.

As displayed in Figure 8, four possible responses were provided in multiple choice format (single choice only) and were displayed in the same order to each of the respondents. The response breakdown is displayed in Table 3 and Figure 9.
Before proceeding with any discussion comparing the response to yellow vs. red arrows, it must first be noted that the correct response varies based on arrow color. For the flashing red arrow, the correct response was “Stop and turn left when clear of traffic.” For the flashing yellow arrow, either “Stop and turn left when clear of traffic” or “Turn left when clear of traffic” was considered as the correct response, as both are appropriate legal movements in this situation. Any direct comparison of the results between the yellow and red arrows should keep this aforementioned point in mind.

From Table 3, it can be observed that 81.4 percent responded with “Stop and turn left when clear of traffic” or “Turn left when clear of traffic” when viewing the question with the flashing yellow arrow. With the flashing red arrow in place, but without any auxiliary signage, 70.5
percent provided a response of “Stop and turn left when clear of traffic.” This rate improved to 77.4 percent when the auxiliary sign was included beneath the DAD signal.

Perhaps the most interesting finding from this survey question was the number of “Unsure” responses associated with the flashing red arrow. The flashing red arrow was greater than six times more likely to elicit an “Unsure” response compared to the flashing yellow arrow. The inclusion of the auxiliary “STOP Then Yield in Direction of Flashing Arrow” sign with the flashing red arrow reduced the number of “Unsure” responses, although this response still occurred at a four times greater rate than with the flashing yellow arrow. This finding suggests that drivers possess a greater level of uncertainty with the flashing red arrow compared to the flashing yellow arrow, regardless of whether an auxiliary sign was utilized.

Finally, one area where the flashing red arrow showed improvements over the flashing yellow arrow was in the number of responses to “Turn left at any time,” which was reduced by more than one-half when the flashing red arrow was utilized compared to the flashing yellow. The inclusion of auxiliary signage provided a further reduction in this incorrect response.

3.3.3. Sign Message Effectiveness (without NTOR sign)

One of the principal objectives of this survey was to determine signing alternative(s) that would help improve motorist comprehension of the DADs. To assess sign message comprehension, the survey included a question, as shown in Figure 10, which asked respondents to rate the effectiveness of five different sign messages on a scale of 0 to 5.
Due to the lack of familiarity with the DADs, a description of the proper driver action was included as a part of the question. Further, because of the ordered nature of the sign messages, the signs were presented in the same order to each respondent. Note that the DAD image was presented in the online survey as an animated gif, with flashing left and right yellow arrows.
alternating with the steady circular red. The results associated with this question are presented in Table 4.

Table 4. Results for DAD sign message effectiveness

<table>
<thead>
<tr>
<th>Sign</th>
<th>Mean</th>
<th>St Dev</th>
<th>25th%</th>
<th>50th%</th>
<th>75th%</th>
<th>% at or below 2.0</th>
<th>% at or above 4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TURN ONLY IN DIRECTION OF ARROW</strong></td>
<td>3.66</td>
<td>1.40</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>17.5%</td>
<td>45.4%</td>
</tr>
<tr>
<td><strong>YIELD IN DIRECTION OF ARROW</strong></td>
<td>3.31</td>
<td>1.46</td>
<td>2.5</td>
<td>3.5</td>
<td>4.5</td>
<td>24.1%</td>
<td>34.0%</td>
</tr>
<tr>
<td><strong>WAIT TURN ONLY IN DIRECTION OF ARROW</strong></td>
<td>3.60</td>
<td>1.34</td>
<td>2.5</td>
<td>4</td>
<td>5</td>
<td>16.8%</td>
<td>40.0%</td>
</tr>
<tr>
<td><strong>WAIT THEN YIELD IN DIRECTION OF FLASHING ARROW</strong></td>
<td>3.47</td>
<td>1.40</td>
<td>2.5</td>
<td>3.5</td>
<td>5</td>
<td>19.2%</td>
<td>36.4%</td>
</tr>
<tr>
<td><strong>WAIT FOR ARROW BEFORE TURNING</strong></td>
<td>3.64</td>
<td>1.40</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>17.4%</td>
<td>42.6%</td>
</tr>
</tbody>
</table>

Note: Data represent the aggregated ratings to the question “How effectively does each of the signs communicate the proper action?” Ratings were given on a scale of 0 (poor) to 5 (excellent).

Although the signs showed relatively consistent levels of effectiveness, several interesting findings were observed. First, there seemed to be a preference toward signs that included the word “Turn” as opposed to “Yield.” The two signs that included the term “Yield” were rated as less effective than those signs that did not include the term. Similarly, the three signs that included “Turn” were rated as most effective. Furthermore, generally speaking drivers tended to prefer signs that included the prominent “WAIT” message at the top.
3.3.4. Sign Message Effectiveness (with NTOR Sign)

As a continuation of the prior question, it was also of interest to determine whether the inclusion of an NTOR sign increased the effectiveness of the sign message. To assess whether the NTOR increased the effectiveness rating, the respondents were again asked to rate the effectiveness of the sign messages on a scale of 0 to 5. However, instead of including all five of the prior signs, only two signs were included in this question, each presented with and without the NTOR sign positioned above. The two signs included in this question were “Turn Only in Direction of Arrow” and “WAIT Turn Only in Direction of Arrow.” Since all other aspects of the question were identical to the prior question related to the effectiveness of the five signs, the question is omitted here for brevity. The results associated with this question are presented in Table 5.

Table 5. Results for DAD sign message effectiveness with NTOR sign

<table>
<thead>
<tr>
<th>Sign</th>
<th>Mean</th>
<th>St Dev</th>
<th>25th%</th>
<th>50th%</th>
<th>75th%</th>
<th>% at or below 2.0</th>
<th>% at or above 4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TURN ONLY IN DIRECTION OF ARROW</strong></td>
<td>3.49</td>
<td>1.42</td>
<td>2.5</td>
<td>4</td>
<td>5</td>
<td>21.2%</td>
<td>38.3%</td>
</tr>
<tr>
<td><strong>WAIT TURN ONLY IN DIRECTION OF ARROW</strong></td>
<td>3.52</td>
<td>1.34</td>
<td>2.5</td>
<td>4</td>
<td>5</td>
<td>18.6%</td>
<td>35.3%</td>
</tr>
<tr>
<td><strong>NO TURN ON RED</strong></td>
<td>3.81</td>
<td>1.44</td>
<td>3</td>
<td>4.5</td>
<td>5</td>
<td>16.3%</td>
<td>52.5%</td>
</tr>
<tr>
<td><strong>TURN ONLY IN DIRECTION OF ARROW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO TURN ON RED</strong></td>
<td>3.88</td>
<td>1.33</td>
<td>3</td>
<td>4.5</td>
<td>5</td>
<td>12.9%</td>
<td>51.4%</td>
</tr>
</tbody>
</table>

Note: Data represent the aggregated ratings to the question, “How effectively does each of the signs communicate the proper action?” Ratings were given on a scale of 0 (poor) to 5 (excellent).
The results shown in Table 5 clearly indicate a preference toward the inclusion of the NTOR sign. There also seems to be a slight preference toward the use of a prominent WAIT message. The inclusion of the WAIT message also provided a more consistent response, as indicated by the lower standard deviations compared to the message variants without the WAIT.

3.3.5. Signal Configuration Effectiveness

The survey was also used to determine the effectiveness of three common configurations of the DAD signal heads. To make this assessment, respondents were asked to rate the effectiveness of the three DAD signal head configurations shown in Figure 11 on a scale of 0 to 5.

![Figure 11. Survey question for rating DAD signal configuration effectiveness](image)

As previously stated, the proper driver action is as follows:

Drivers may turn in the direction of the flashing arrow when the crossroad is clear of traffic. Drivers must remain stopped at all other times.

On a scale of 0 (poor) to 5 (excellent), how effectively does each of the following signal configurations communicate the proper action?

Again, a description of the proper driver action was included as a part of the question due to the lack of familiarity with the DAD. For this particular question, because there was no natural order to the signal head configurations, the three configurations were displayed in a randomized order to the survey respondents. Further, the DAD image was presented in the online survey as an animated gif, with flashing left and right yellow arrows alternating with the steady circular (or arrow) red for each of the three configurations. The results associated with this question are presented in Table 6.
The results shown in Table 6 clearly indicate a preference toward the horizontal and doghouse configurations over the red-over-yellow arrows configuration. This result is not surprising due to the level of implementation of such signal configurations nationwide. While horizontal and doghouse signals are common traffic signal configurations at intersections and other contexts, the red-over-yellow arrows signal head arrangement is not commonly utilized. It follows that the survey respondents were likely more familiar with horizontal and doghouse signals, which likely positively influences the rating of these signal head configurations when utilized on the DADs.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Mean</th>
<th>St Dev</th>
<th>25th%</th>
<th>50th%</th>
<th>75th%</th>
<th>% at or below 2.0</th>
<th>% at or above 4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.86</td>
<td>1.20</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
<td>10.9%</td>
<td>45.5%</td>
</tr>
<tr>
<td>3.90</td>
<td>1.13</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
<td>8.7%</td>
<td>46.4%</td>
</tr>
<tr>
<td>3.53</td>
<td>1.46</td>
<td>2.5</td>
<td>4</td>
<td>5</td>
<td></td>
<td>20.5%</td>
<td>41.0%</td>
</tr>
</tbody>
</table>
4. FIELD STUDY

The work zone section utilized for this field study was on US 31 in Benzonia, Michigan, which is displayed in Figure 12.

Figure 12. US 31 construction zone near Benzonia, Michigan used for field evaluation

During normal conditions, this section existed as a two-lane highway with a two-way-left-turn-lane. The project extended from M-115 on the north side to 800 ft south of the bridge over the Betsie River, a length of approximately 1.5 miles. The work consisted of full-depth pavement removal and hot mix asphalt (HMA) replacement, curb and gutter removal and replacement, and drainage improvements.

The research team worked with MDOT to develop a DADs evaluation plan within this work zone during the summer of 2020. The construction work was performed in three phases, starting in the north and continuing south. One lane was left open to handle bi-directional traffic while construction was performed within the remaining portion of the roadway. The staging of the project allowed for the DAD to be placed in numerous locations along the project. In each phase, portable traffic signals were positioned at both ends of the work zone to regulate mainline traffic flow. A series of four DADs were placed at minor road intersections and commercial driveways between the portable traffic signals along the work zone segment.

4.1. DAD Configuration and Operation

The devices were placed either at the end of the driveway on the near side, or directly across the major roadway from access point. The decision to position the DADs on the near or far side was
based on the construction phase and location of the work area. The signal heads on the DAD were oriented horizontally. For all trials, the middle signal was 12 in. solid red. The left and right signals were either 8 in. or 12 in. flashing red arrows. The use of red flashing arrows in this study was based on MDOT’s use of the red arrows for the DADs in the prior pilot study, which had been selected for the more emphatic safety message provided by red indications. DAD signal heads were generally raised to a height of 7 ft for motorist visibility, which was adjusted based on the line-of-site afforded at an access point.

The DADs operated synchronously with the PTCS stationed on the mainline at both ends of the work zone. The flashing directional arrow phase was sequenced with the mainline PTCS green phase, which afforded drivers waiting at the DAD with ample opportunity for access to the mainline before and/or after the arrival of the platoon. The flashing directional arrow was initiated at the beginning of the mainline PTCS green phase for that direction and was terminated at the end of the green phase, at which point the center steady red signal became illuminated. The steady red signal served as a clearance phase and remained illuminated until initiation of the mainline green phase for the opposite direction of traffic, at which point the opposite directional DAD arrow began to flash. This alternating directional arrow/steady red phases repeated continuously. The duration of the flashing arrow and stop phases varied for each of the three construction phases and were based on the distance between the two PTCS.

Alongside the DAD was a standalone sign mount where the auxiliary test signs were mounted. The NTOR sign was present for all sign test conditions indicating for drivers to remain stopped at the access point. All signs were visible to each motorist attempting to exit an access point. However, the PTCS at the end points of the one-lane section were not always visible from all driveways where the DADs were located. A typical DAD setup used in this study can be seen in Figure 13.
4.2. Video Recording Setup

Driver compliance data were collected using a series of video cameras positioned such that the access point, mainline, and DAD indications were clearly visible in the video. Data were collected only during clear, dry daylight conditions. The video footage was captured using consumer-grade, high-definition video cameras located at each subject access point. The cameras were mounted to aluminum poles that were affixed to a pole or signpost and were telescoped from between 7 and 20 ft in height to ensure a clear view of the DAD and access point. The small size of the setup allowed for flexible placement and discrete recording, unknown to motorists at the access point or along the mainline. Setup of the camera and pole apparatus was performed in 5 minutes or less and did not require assistance from MDOT. Each camera recorded for two three-hour sessions per site during a data collection day. An example of the video footage collected can be seen in Figure 14.
4.3. Test Signs

One of the primary objectives of this study was to determine the DAD auxiliary sign(s) that provided the highest rates of compliance. A series of five auxiliary signs were utilized in the field study, each of which were paired with an NTOR sign. The five signs, which are displayed in Figure 15, were selected for various reasons in consultation with the project panel.

![Figure 15. Auxiliary signs used in the field study](image-url)
The Federal Highway Administration (FHWA) expressed interest in testing the “Turn Only in Direction of Arrow” message, while the Michigan DOT expressed interest in testing the “WAIT” message, which was subsequently included at the top of two signs. The “Stop and Wait…” sign is a variation of a sign used with DADs in Nebraska. The “Proceed” sign was included as it is currently utilized by the Michigan DOT with DAD installations. It is worth noting that the “Turn Only…” and both “WAIT…” signs had the highest comprehension results in the motorist survey. As identified in a previous study (Finley et al. 2020) and shown in survey results, the inclusion of an R10-11 (NTOR) sign greatly increased motorist compliance. Thus, the NTOR was included on each of the tested signs.

4.4. Data Collection

In total, data were collected at 10 minor access points along the US 31 work zone segment. Data were collected for at least one full day at each location. Due to the traffic volumes and phasing of the road work, it was generally not feasible to collect data for each sign at each DAD location. Thus, data were collected for a single sign condition at 8 of the 10 sites. However, at the remaining two sites (McDonald’s and Sav-A-Lot), conditions allowed for data to be collected with each of the five signs in place. A sign rotation schedule was implemented over the course of a five-day period in August 2020 to allow for data to be collected for at least one morning and one afternoon session. Figure 16 displays the access points where the DADs were utilized during each of the three construction phases, in addition to the test signs.

Figure 16. DADs study sites and test signs
4.5. Data Reduction

Data were extracted through a manual video review process by trained graduate research assistants. Data were entered into a spreadsheet for each exiting vehicle. Researchers used QuickTime Version 7.7.9 to record frame-specific time stamp data.

The queue position and time-stamp of each exiting vehicle was recorded upon arrival into video field-of-view. The DAD signal display and time-stamp was noted when a vehicle both reached the front of the queue, and when it entered the mainline. The turning direction and legality (based on the DAD signal status) of the turning movement was recorded, with examples of both legal and illegal movements displayed in Table 7.

Table 7. Examples of legal/illegal and safe/unsafe movements

<table>
<thead>
<tr>
<th>Movements</th>
<th>Safe</th>
<th>Unsafe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal</td>
<td>- Right turn on right arrow</td>
<td>- Driving around queue leader to enter mainline</td>
</tr>
<tr>
<td></td>
<td>- Left turn on left arrow</td>
<td>- Forcing mainline to slow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Driving into closed lane</td>
</tr>
<tr>
<td>Illegal</td>
<td>- Joining end of platoon on a solid signal</td>
<td>- Wrong way entrance on an arrow</td>
</tr>
<tr>
<td></td>
<td>- Accepting a gap w/in platoon</td>
<td>- Driving into oncoming traffic</td>
</tr>
<tr>
<td></td>
<td>- Crossing movements</td>
<td></td>
</tr>
</tbody>
</table>

The observer also recorded whether the movement was safe or unsafe based on the conditions provided in Table 7. Additionally, the observer also recorded whether the vehicle came to a full stop once becoming queue leader and whether the vehicle proceeded unimpeded or joined a mainline platoon.

The time stamps were utilized to calculate queue time, dwell time, and gap time. The queue time was defined as the duration a vehicle spent in a queue prior to becoming the queue leader. Dwell time is the time each vehicle spent at the front of the queue prior to exiting the access point. Gap time was the duration of the mainline gap that the exiting vehicle accepted.

4.6. Descriptive Statistics

The field study resulted in 2,258 vehicles observed across all sites and signs. A summary of the data collected for each site and sign condition is shown in Table 8.
Table 8. Total observations and legal movement rate for vehicles exiting a DAD driveway, by location and sign

<table>
<thead>
<tr>
<th>Site</th>
<th>Proceed</th>
<th>Turn Only</th>
<th>Stop and Wait</th>
<th>WAIT For Arrow</th>
<th>WAIT Turn Only</th>
<th>No Sign</th>
<th>Total (Legal %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDonald’s</td>
<td>298</td>
<td>103</td>
<td>351</td>
<td>385</td>
<td>209</td>
<td>x</td>
<td>1246 (66%)</td>
</tr>
<tr>
<td>Sav-a-Lot</td>
<td>92</td>
<td>63</td>
<td>63</td>
<td>53</td>
<td>59</td>
<td>x</td>
<td>330 (55%)</td>
</tr>
<tr>
<td>Trailer Park</td>
<td>76</td>
<td>86</td>
<td>x</td>
<td>x</td>
<td>88</td>
<td>x</td>
<td>250 (64%)</td>
</tr>
<tr>
<td>State Savings Bank</td>
<td>139</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>139</td>
<td>(53%)</td>
</tr>
<tr>
<td>Dispensary</td>
<td>30</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>32</td>
<td>x</td>
<td>62 (58%)</td>
</tr>
<tr>
<td>South St. EB</td>
<td>54</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>54 (63%)</td>
</tr>
<tr>
<td>South St. WB</td>
<td>36</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>36 (50%)</td>
</tr>
<tr>
<td>Walker St. EB</td>
<td>55</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>55 (47%)</td>
</tr>
<tr>
<td>Walker St. WB</td>
<td>17</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>17 (12%)</td>
</tr>
<tr>
<td>River St. EB</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>69</td>
<td>69</td>
<td>69 (57%)</td>
</tr>
<tr>
<td>Total (Legal %)</td>
<td>797</td>
<td>252</td>
<td>414</td>
<td>338</td>
<td>388</td>
<td>69</td>
<td>2258</td>
</tr>
</tbody>
</table>

Note: “x” indicates the sign was not used.

The overall legal movement rate was 62 percent, and varied between 47 and 66 percent at all but the lowest volume site. Considering sign type, the rate ranged between 57 percent and 69 percent. The legal movement rates were lower than those observed in prior studies, which could possibly be attributed to higher traffic volumes and subsequently longer wait times compared to the prior evaluations.

The results also show a high rate of movements classified as safe. Considering all 2,258 legal and illegal movements, approximately 93 percent (2,094 out of 2,258) were classified as safe. It should be noted that certain unsafe movements, such as driving into a closed lane, are largely influenced by the nature of the work zone configuration and level of traffic control used at the closure. For these types of maneuvers, the use of more prominent traffic control devices (e.g., barricades, drums, delineation) to indicate the closed lanes would help prevent drivers from turning into the closed lanes. Furthermore provision of left and right turn lanes could prevent drivers from maneuvering around the queue leader, who is waiting to turn in the opposing direction, to enter the mainline. Finally, because of the circumstantial nature of the occurrence of safe vs. unsafe movements, particularly as related to the DADs device, a formal analysis of the effects of the auxiliary sign type on movement safety was not performed.

4.7. Analysis of Legal Movements

As one of the major objectives of this study, it was important to understand the impact of the tested sign configuration on rates of legal movement. As not all sign configurations were tested at each of the DAD driveways, inherent differences between the sites would potentially confound the analysis. As such, it was decided to limit this analysis to the data from the McDonald’s driveway, which yielded 1,246 total mainline entry observations and an adequate sample size across each of the sign conditions. Overall, this site experienced 66 percent legal and 93.2 percent safe movement rates. Although the Sav-a-Lot driveway also included data with each test sign, the sample sizes were considerably smaller, and thus, it was decided to exclude the data.
from this site. It should also be noted that only non-through movements at McDonald’s were included, yielding a sample of 1,221 total observations for the statistical analysis. Furthermore, as stated previously, because of the circumstantial nature of the occurrence of safe vs. unsafe movements, particularly as related to the DAD device, a formal analysis of the effects of the auxiliary sign type on movement safety was not performed. The total number of exiting vehicle observations and the corresponding legal movement rates and safe movement rates at the McDonald’s driveway are displayed by sign type in Table 9.

Table 9. Total observations and legal movement rate for vehicles exiting McDonald’s driveway, by sign

<table>
<thead>
<tr>
<th>Actions</th>
<th>Total exiting vehicle observations</th>
<th>% legal movements</th>
<th>% safe movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO TURN ON RED</td>
<td>298</td>
<td>58%</td>
<td>92%</td>
</tr>
<tr>
<td>PROCEED ON FLASHING RED ARROW AFTER STOP</td>
<td>103</td>
<td>64%</td>
<td>92%</td>
</tr>
<tr>
<td>TURN ONLY IN DIRECTION OF ARROW</td>
<td>351</td>
<td>66%</td>
<td>92%</td>
</tr>
<tr>
<td>STOP AND WAIT FOR ARROW BEFORE TURNING</td>
<td>285</td>
<td>72%</td>
<td>93%</td>
</tr>
<tr>
<td>WAIT FOR ARROW BEFORE TURNING</td>
<td>209</td>
<td>72%</td>
<td>98%</td>
</tr>
<tr>
<td>TURN ONLY IN DIRECTION OF ARROW</td>
<td></td>
<td>66%</td>
<td>93%</td>
</tr>
</tbody>
</table>

4.7.1. Analytical Method and Model Development

The dependent variables for this analysis included the movement legality for drivers exiting the McDonald’s as a function of the test sign and other factors related to the vehicle, site, and scenario. Because the dependent variable consists of a binary indicator (i.e., legal vs illegal movement), discrete outcome models are an appropriate analysis framework. Binary logistic regression is a technique used to predict the probability of a dichotomous outcome based on values of a set of predictor variables (continuous or categorical) and is similar to linear regression except that the response variable is categorical rather than numeric. The binary logistic regression model has the form:

\[ Y_i = \text{logit}(P_i) = \ln \left( \frac{P_i}{1 - P_i} \right) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} \]  

(1)

where the response variable, \(Y_i\), is the logistic transformation of the probability of legal or safe movement for vehicle \(i\). This probability is denoted as \(P_i\). As in the linear regression model, \(X_{i1}\) to \(X_{ik}\) are independent variables affecting legal movements of vehicles, \(\beta_0\) is an intercept, \(\beta_1\) to \(\beta_k\)
are estimated regression coefficients for each independent variable. The resulting odds ratios may then be interpreted to determine the percent change in the likelihood that would result from a unit change in a specific variable of interest.

Separate binary logistic regression models were developed for the two dependent variables (movement legality and movement safety). The independent variables included the test sign along with other factors of interest, as shown in Table 10.

### Table 10. Logistic regression model for legal movement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Beta</th>
<th>S.E.*</th>
<th>Exp(Beta)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.606</td>
<td>0.454</td>
<td>4.983</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sign = Proceed Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign = Stop and Wait</td>
<td>0.178</td>
<td>0.212</td>
<td>1.195</td>
<td>0.402</td>
</tr>
<tr>
<td>Sign = Turn Only</td>
<td>0.009</td>
<td>0.300</td>
<td>1.009</td>
<td>0.975</td>
</tr>
<tr>
<td>Sign = Wait For Arrow</td>
<td>0.506</td>
<td>0.231</td>
<td>1.659</td>
<td>0.029</td>
</tr>
<tr>
<td>Sign = Wait Turn Only</td>
<td>0.455</td>
<td>0.248</td>
<td>1.576</td>
<td>0.066</td>
</tr>
<tr>
<td>Queue Position = 1 Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue Position = 2</td>
<td>-0.166</td>
<td>0.226</td>
<td>0.847</td>
<td>0.461</td>
</tr>
<tr>
<td>Queue Position = 3</td>
<td>-0.139</td>
<td>0.225</td>
<td>0.870</td>
<td>0.537</td>
</tr>
<tr>
<td>DAD Display = Solid Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAD Display = Right</td>
<td>2.021</td>
<td>0.186</td>
<td>7.546</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>DAD Display = Left</td>
<td>2.305</td>
<td>0.225</td>
<td>10.024</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Full Stop = Yes Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Stop = No</td>
<td>0.223</td>
<td>0.178</td>
<td>1.250</td>
<td>0.211</td>
</tr>
<tr>
<td>Vehicle Type = PC Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle Type = SUV</td>
<td>0.008</td>
<td>0.203</td>
<td>1.008</td>
<td>0.967</td>
</tr>
<tr>
<td>Vehicle Type = Van</td>
<td>0.311</td>
<td>0.308</td>
<td>1.365</td>
<td>0.312</td>
</tr>
<tr>
<td>Vehicle Type = Pickup Truck</td>
<td>-0.189</td>
<td>0.228</td>
<td>0.828</td>
<td>0.406</td>
</tr>
<tr>
<td>Vehicle Type = Other</td>
<td>0.225</td>
<td>0.785</td>
<td>1.252</td>
<td>0.774</td>
</tr>
<tr>
<td>Platoon = Precede Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platoon = Join</td>
<td>-2.073</td>
<td>0.168</td>
<td>0.126</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Direction = Left Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction = Right</td>
<td>0.238</td>
<td>0.165</td>
<td>1.269</td>
<td>0.151</td>
</tr>
<tr>
<td>Time in Queue</td>
<td>0.004</td>
<td>0.003</td>
<td>1.004</td>
<td>0.120</td>
</tr>
<tr>
<td>Ln(Dwell Time)</td>
<td>0.114</td>
<td>0.061</td>
<td>1.121</td>
<td>0.060</td>
</tr>
<tr>
<td>Ln(Gap Time)</td>
<td>-0.711</td>
<td>0.134</td>
<td>0.491</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AIC</td>
<td>1109.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Standard Error

Each of the categorical independent variables were coded as a series of n-1 discrete binary variables that were assessed relative to the specified base condition. To that end, the five sign conditions considered in the models included: “Proceed,” “Stop and Wait,” “Turn Only,” “WAIT For Arrow,” and “WAIT Turn Only,” with the “Proceed” sign serving as the baseline condition. Additionally, the time in queue, dwell time, and gap time are included in the models as
continuous variables, and dwell and gap times are added in their natural log forms. A significance level of 0.05 ($\alpha = 0.05$) was used in this analysis.

4.7.2 Model Results – Movement Legality

The results for the binary logistic regression model for movement legality for vehicles exiting the McDonald’s driveway with the DADs in place are presented in Table 10. Results from this analysis provide further evidence to the influence of the various auxiliary signs on legal movements. Among the five different signs analyzed, those that included “WAIT” messages (i.e., WAIT For Arrow and WAIT Turn Only) were associated with a statistically significant increase in the likelihood of legal movements compared to the base condition (i.e., the MDOT standard “Proceed” sign). It is worth mentioning that these two signs with WAIT messages were also the highest rated signs from the survey. Keeping all other factors constant or fixed at the average values, the models show that the WAIT For Arrow and WAIT Turn Only signs improved the likelihood of a legal movement, expressed as an increase in the odds of a legal movement, by 65.9 and 57.6 percent, respectively, compared to the base condition. The other two signs had slight, but not statistically significant, improvements in legal movements, including the version of the Turn Only sign without the prominent WAIT message. It is also important to note that the “WAIT Turn Only in Direction of Arrow” sign had the highest rate of safe movements of all signs tested in this study. Given the strong positive impacts of the “WAIT” message on legal turning movements at the DAD signal, it is recommended that the signs including this prominent message be considered for future DAD experimentation.

Additionally, the DAD display upon arrival to the queue was found to be statistically significant. Not surprisingly, when a vehicle arrived viewing either right or left arrow compared to the solid display, they had much better odds of making a legal movement. Overall, this provides evidence that vehicles either accepted arrows quickly, or when seeing an opposite arrow, correctly waited in the queue until their respective arrow appeared. Conversely, vehicles initially arriving on a solid red circular indication may be tempted to enter based on observing the direction of a mainline platoon, which although illegal, would not necessarily be an unsafe maneuver assuming that the offending driver joins the platoon. It follows that drivers who joined a platoon had much lower odds of a legal movement, nearly an 87 percent reduction in odds compared to vehicles preceding a platoon. However, this result is likely an artifact of the signal phasing at this location, which generally experienced the platoons arriving during the solid circular red indication.

Moreover, although, queue and dwell times did not have any influence on legal movement, gap time was found to have a negative association with legal movements (i.e., increase in gap time reduced the likelihood of legal movement) and this relationship was statistically significant. This finding can be explained as vehicles that are faced with long gap times may be tempted by a clear site line on the mainline and might be less likely to result in legal movement. Implications of the gap time result could be attributed to the importance of ensuring appropriate relative PTCS distance, and maintaining clear stopping points at driveways. It also suggests that lengthy clearance intervals provide additional opportunity for illegal driveway exits, especially when the
clearance intervals (and the steady circular red ball at the DADs) are active when the platoons pass by the driveway.

Lastly, other variables including, vehicle type (private car, SUV, minivan, pickup truck and other), vehicle’s queue position (1, 2, or 3), vehicle direction (left or right), and whether the vehicle came to a full stop did not have any significant impact on the likelihood of a legal movement.
5. CONCLUSIONS AND RECOMMENDATIONS

Research was performed to determine the DAD display design that best directs motorists to safely enter the one-lane, two-way operation and proceed in the proper direction of travel. Two primary methods were employed to accomplish this objective. First, a nationwide online survey of drivers was implemented to determine the DAD signal configurations and auxiliary sign messages that elicited the highest rates of proper driver action when encountering the DAD or most effectively communicated the proper action. The survey was supplemented by a field study that evaluated driver compliance to the DADs as a function of five different auxiliary signs. The conclusions and recommendations resulting from these efforts are presented in the sections that follow.

5.1. Conclusions

First, from a high-level standpoint, the DAD generally resulted in a high proportion of safe movements during the field study, with an overall safe movement rate of nearly 93 percent, which was consistent with the rates experienced in previous evaluations (Finley 2016, MDOT 2019, Finley et al. 2014). Although the overall legal movement rate (62 percent) was lower than observed in prior studies, this could possibly be attributed to the DADs being employed at commercial driveways and minor side-streets with higher traffic volumes and longer wait times compared to the prior evaluations.

Beginning with the assessment of sign message effectiveness, the survey results suggested that signs more effectively conveyed the proper driver action if the message included the word “Turn” as opposed to “Yield.” The message effectiveness was further strengthened if it included the prominent “WAIT” text at the top of the sign, and this result was consistent between the survey and the field study. Perhaps the strongest signing related component for the DADs was the inclusion of the NTOR sign, which was found to improve the message effectiveness in all cases. Additionally, the inclusion of the NTOR sign by itself beneath the DAD signal substantially increased the rate of proper response to the circular red indication. Specifically, with the NTOR sign in place, greater than 87 percent of survey respondents indicated the correct action (i.e., stop and remain stopped until the signal changes), which was a greater than 8 percent improvement over the DAD without any signage. The NTOR sign was particularly effective toward reducing “Stop and turn right when clear of traffic” responses, which decreased by nearly one-half after the NTOR sign was added. This finding is particularly encouraging due to the typically permissive nature of right turns on red at most traffic signals in the US when an NTOR sign is not present.

Turning to the characteristics of the signal indication, yellow flashing arrows contributed to an improved response rate over red flashing arrows in terms of proper driver action when encountering the DAD signal. The red flashing arrows seemed to present considerable uncertainty amongst the survey respondents, as evidenced by the red arrows being greater than six times more likely to result in an “Unsure” response for the appropriate driver action compared to the yellow arrows. However, the red flashing arrows showed improvements over the yellow arrows toward reducing “Turn at any time” responses.
Finally, in terms of DAD signal head configuration, the survey respondents indicated that horizontal and doghouse configurations more effectively conveyed the proper driver action compared to the red-over-yellow arrows configuration. This result is not surprising due to the low level of implementation of such signal configurations nationwide.

5.2. Recommendations for Future DAD Implementation

Based on the collective results of the survey and field study, the following recommendations are provided regarding various design and operational aspects of DADs:

- DADs are recommended for continued experimental use at work zones that include one-lane, two-way traffic where it is not practical or feasible to provide a continuous flagger operation.

- Auxiliary signage should be implemented in conjunction with any implementation of any DAD signal. This signage may be posted on the DAD pole itself, or posted separately beside the DAD. Such signage should utilize messages that provide direction toward what action drivers should take both during the flashing arrow phase and the steady circular phase. For the flashing arrow phase, sign messaging should include “Turn” rather than “Yield.” For the steady circular red phase, a separate NTOR sign should be utilized in combination with any auxiliary sign, or as a standalone sign if no other auxiliary sign is provided. A prominent “WAIT” message may be included at the top of the auxiliary sign to further enhance the appropriate action during the steady circular red. The following signs given in Figure 17 are recommended based on the results of this research. It is important to note that these signs may be used in conjunction with red or yellow flashing arrows. It is also important to note that the “WAIT Turn Only in Direction of Arrow” sign had the highest rate of safe movements of all signs tested in this study.
• Horizontal and doghouse signal configurations, as shown in Figure 18, are recommended for future DAD implementations. Additional testing of red-over-yellow arrows is recommended prior to further implementation.

• Although yellow flashing arrows contributed to an improved response rate and decreased uncertainty compared to red flashing arrows in terms of proper driver action when encountering the DAD signal, the authors do not make a recommendation on flashing arrow color. Rather, the decision to use flashing red or flashing yellow directional arrows should remain at the discretion of the particular agency, based on the policies and practices within
the jurisdiction. In many states, the flashing red arrow is either uncommon or unknown, thus leading to motorist confusion. Furthermore, at higher-volume locations, it may be more operationally more efficient to utilize flashing yellow arrows to eliminate the need for each vehicle to make a complete stop while exiting.

- It is evident that controlling the available gap time and dwell time at each DAD would add value toward influencing legal, safe movements. Thus, the DAD should be timed in a way such that gap time is optimized to allow platoon clearance, but deter drivers from joining the end of a platoon illegally on the steady circular red. It is also recommended that further investigation be made into the DAD signal timing with respect to the device location relative to portable traffic control signal.

- Providing left and right storage lanes could improve DAD operations at higher-volume access points. As experienced in this field study, impatient queued motorists often created ad hoc turn lanes if their desired turn was blocked by the queue leader. This leads to numerous illegal and/or unsafe movements. At wider access points, and especially those with higher traffic volumes, separate left and right turn lanes could reduce the possibility of long queues by improving flow and also reduce unsafe movements.

- There is a need to investigate DADs at 4-leg locations, both intersections and driveways. The current DAD design has two issues at 4-leg locations. There is no provision to permit a legal crossing maneuver. There is also conflict between right turns and opposing lefts during a permitted turning phase. Thus, it is necessary to modify the DAD or provide additional auxiliary signage to operate correctly at 4-leg locations, and further testing is recommended.
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