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EVALUATION OF ONE-WAY FLAGGING OPERATIONS

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RESEARCH
UDOT Keeping Utah Moving
Utah Department of Transportation - Research Division
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DISCLAIMER

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16. Abstract

One-way flagging operations in Utah are a balance between meeting the needs of UDOT and contractors by allowing time and space on the roadway for work to be done, while also meeting the needs of the traveling public. Currently, UDOT predicts queue lengths and travel time for such operations by using traffic models in order to effectively plan and manage one-way flagging operations. While these models help to provide insights into the impact one-way flagging operations will have, it is important to validate them with real world experience. The objective of this research was to establish a more defined and reliable standard for determining appropriate construction times and limitations to minimize traffic delays and increase safety during one-way flagging operations. This was done by evaluating the roadway capacity, queue lengths, and travel times during one-way flagging operations throughout Utah utilizing linear regression and simulation modeling analysis. Study results include the following:

-Variables including zone length, traffic volumes, and vehicle speeds have quantifiable impacts on flagging zone queue and capacity.
-Flagging-related headways, clearance times, and queue lengths can be predicted using independent variables
-Capacity at flagging projects varies depending on zone lengths and green time
-Queues were generally shorter than expected; the longest queues occurred when vehicles waited multiple cycles

The research team was able to recommend the adoption of new standards acknowledging the impact of these variables to enhance UDOTs one-way flagging processes.

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LIST OF ACRONYMS

AFAD	Moving Automatic Flagger Assistance Device
FHWA	Federal Highway Administration
MUTCD	Manual on Uniform Traffic Control Devices
PTC	Portable Traffic Control
SR-XX	Utah Numbered State Route
UDOT	Utah Department of Transportation
US-XX	United States Numbered Highway

EXECUTIVE SUMMARY

UDOT consistently works to ensure the safety and driving conditions of its highways and preserve mobility for roadway users. However, construction and maintenance activities may require closing a travel lane. This can be problematic on a roadway with only one lane in each direction, of which Utah has over 4,000 miles. This type of roadway requires the contractor to implement a one-way flagging operation, which intermittently restricts travel to one direction at a time. This can significantly impact a roadway's traffic performance. Most of this impact is seen in longer delays and queue lengths entering the work zone. Even relatively low traffic volumes can experience excessive delays and queuing in locations where drivers expect free flow conditions. This in turn can create safety issues as drivers encounter unanticipated congestion resulting in back-of-queue crashes. These conditions can also create safety issues for the workers who are required to maintain the operation and work closely to the vehicle travel lanes.

Maintenance of traffic during construction and maintenance operations is a balance between meeting the needs of the contractor by allowing time and space on the roadway for work to be done, while also meeting the needs of the traveling public. Currently, UDOT predicts queue lengths and travel times using traffic models. While these models help to provide insights into the impact one-way flagging operations will have, it is important to validate these models with real-world experience. Simulation models rely on user inputs which, without real-world experience and data, may be limited in their accuracy to predict capacity, delay, and queue. Due to this, UDOT limited one-way flagging operations to preferred windows of time when the traffic demand is less than 200 vehicles per hour in either direction, or with trepidation up to 400 vehicles per hour in either direction. This approach to identifying when one-way flagging operations can occur is not always reliable. It also has the potential to limit the hours when a contractor can work beyond what is necessary to maintain safe and reliable traffic flow.

The objective of this research was to establish a more defined and reliable standard for determining appropriate construction times and limitations to minimize traffic delays and increase safety during one-way flagging operations. This was done by evaluating the roadway capacity, queue lengths, and travel times during one-way flagging operations throughout Utah. This research could also identify times and locations where one-way flagging operations could

be extended, thereby reducing project timelines and costs. By improving construction operations, the safety of flaggers, other highway workers, and the traveling public would then benefit.

To complete these objectives, the research team collected data at road construction projects throughout the state of Utah which involved a one-way flagging system. The first step of the project involved conducting a literature review which examined previous resources and research conducted on one-way flagging operations in the U.S. The methods and findings of these resources were utilized to enhance the one-way flagging study and better understand flagging characteristics related to performance, safety, and other variables. The research team also created and disseminated a survey in order to gain more contemporary information on one-way flagging practices currently in place amongst state DOTs. This information also provided context and detail on one-way flagging practices which could help enhance the current UDOT process.

The research team identified several projects throughout the state which provided opportunities for one-way flagging data collection. The research team then visited these project sites and collected various data related to one-way flagging, such as the number of vehicles in the flagging zone and vehicle entry/exit timestamps. From this data, the research team derived vehicle clearance time, headways, and other information. The research team then conducted advanced analysis consisting of linear regression and simulation modeling analysis. Regression analysis allowed for the research team to examine the capacity of the one-way flagging operations and gain insight into the experience of travel through the flagging zone, while simulation modeling analysis allowed for the ability to test a range of variables in the traffic data while providing more quality analysis at projects with lower traffic volumes.

Findings from the study showed that numerous independent variables (such as vehicle speeds and grades) are connected to one-way flagging processes, and that headways, clearance times, and queue lengths can be predicted with reasonable confidence using independent variables. Queues were generally shorter than expected (<0.5 miles), and capacity was found to vary depending on flagging zone length and green times in the zone. The research team utilized these findings to suggest recommendations for the enhancement of UDOT one-way flagging procedures, through the adoption of standards recognizing the impact of flagging zone lengths, vehicle volumes, and grade and queue lengths and capacity.

1.0 INTRODUCTION

1.1 Problem Statement

In many instances, construction and maintenance activities require closing a travel lane on Utah roadways. This can be problematic on a roadway with only one lane in each direction. Such a roadway requires the contractor to implement a one-way flagging operation, which intermittently restricts travel to one direction at a time. This can significantly impact a roadway's traffic performance, seen in the creation of longer delays and queue lengths entering the work zone. Even relatively low traffic volumes can experience excessive delays and queuing in locations where drivers expect free flow conditions. This, in turn, can create safety issues as drivers encounter unanticipated congestion resulting in back-of-queue crashes. These conditions can also create safety issues for the workers who are required to maintain the operation and work closely to the vehicle travel lanes. Given that Utah has many one-lane roadways, enhancing the one-way flagging process would create benefit for roadway operations in the state.

1.2 Objectives

The objective is to establish a more defined and reliable standard for determining appropriate construction times and limitations to minimize traffic delays and increase safety during one-way flagging operations. This would be done by evaluating the roadway capacity, queue lengths, and travel times during one-way flagging operations throughout Utah. This research could also identify times and locations where one-way flagging operations could be extended, thereby reducing project timelines and costs. Ultimately, by improving construction operations, the safety of flaggers, other highway workers, and the traveling public will improve. This research would enable UDOT to develop standards for one-way flagging operations that would be implemented in its Special Provision 555, which outlines the maintenance of traffic requirements for construction and maintenance projects. Benefits of having these standards in place include reduced delays and queue lengths entering work zones; improved safety; and potentially expanding the windows of opportunity for these operations to occur thereby reducing the duration and cost of UDOT projects.

1.3 Scope

The scope of this project includes the evaluation of one-way flagging operations and determining the current state of these operations and providing information to be used to determine the expected traffic performance of future projects. Some of the one-way flagging operation data to be collected and used in the evaluation of future projects include:

- The duration of time provided for vehicles to travel through the one-way flagging zone in each direction of travel.
- The duration of time provided for vehicles to clear the one-way flagging zone when both directions of travel are stopped during the transition between directions.
- The travel time through the flagging zone.
- The length of the queue entering the flagging zone.
- The traffic volume throughput during one-way flagging operations.
- The headway of vehicles, both cars and trucks, entering the one-way flagging zone.

This research will provide UDOT with a better understanding of roadway capacity during one-way flagging operations so these operations can be scheduled appropriately reducing driver frustration and increasing safety for future construction projects.

1.4 Outline of Report

This report is organized into five primary sections, as follows:

- Section 2 provides a literature review examining previous research efforts on one-way flagging operations, work zone operations, and other topics pertinent to this research. An overview and justification of research methods for this study is also included.

- Section 3 presents data collection methods and the collected information gathered on variables such as roadway capacity, queue lengths, and travel times during one-way flagging operations in Utah.
- Section 4 presents a quantitative analysis of one-way flagging data.
- Section 5 provides conclusions based upon the data analysis.
- Section 6 outlines recommendations and the implementation plan.

2.0 RESEARCH METHODS

2.1 Overview

This section of the report provides a comprehensive literature review and survey findings on one-way flagging operations, focusing on traffic management, safety, and efficiency. The review reveals that most studies on one-way flagging have centered on safety concerns, including flagger protection and crash mitigation, with less attention paid to roadway performance and traffic flow. Guidelines from the Manual on Uniform Traffic Control Devices (MUTCD) and other sources offer basic management strategies, but there is a gap in data-driven approaches for reducing traffic delays. Studies suggest that optimal gap-out distances and actuated controls can improve flagging performance. Additionally, various technological solutions, such as automated flagger assistance devices (AFAD), pilot cars, and portable traffic signals, are explored to enhance safety and reduce delays, although their impact on crash prevention is less clear.

To supplement the literature review, a survey was conducted across state DOTs to gather current practices and performance data regarding one-way flagging. The survey focused on operational processes, safety strategies, and the use of simulation modeling to assess flagging efficiency. The results will help identify best practices and potential improvements for UDOT's flagging operations. Furthermore, the report details the data collection efforts at UDOT's one-way flagging project sites, aiming to evaluate current challenges and propose solutions for improving traffic flow and safety in future projects.

2.2 Literature Review

As part of this study, a literature review was conducted which examined previous resources and research conducted on one-way flagging operations in the U.S. The methods and findings of these resources were utilized by Avenue to enhance the one-way flagging study and better understand flagging characteristics related to performance, safety, and other variables.

The literature review revealed that the study of one-way flagging operations has traditionally focused on the safety aspect of flagging operations, with both past and more current study focusing on variables such as flagger safety and queuing crash mitigation (Ulman et al., 1987 and Theiss et al., 2022). Several studies put their focus on developing devices or technology to enhance or replace human flaggers (Schrock et al., 2016 and Terhaar, 2017). Not as much research has focused directly on roadway performance measures and one-way flagging, though such studies have been performed intermittently (Washburn et al., 2008). Findings from the literature review are detailed in this document.

2.2.1 Management and Modeling of One-Way Flagging Operations

Several guidelines exist for the management of one-way flagging operations. The Manual on Uniform Traffic Control Devices (MUTCD) contains standards over one-way road usage, which include the following (FHWA, 2009):

- Flagging operations must use control points at each end of the work zone.
- Movements from each end must be coordinated.
- When visibility allows for a full view of each end of work zone, one flagger may be used.
- If visibility does not allow for a view of each end, a traffic control signal or pilot car must control one-way flagging operations.

The MUTCD also contains guidelines for one-way flagging management with details on stop control, pilot cars, and other standards (FHWA, 2009). The Guidelines for Temporary Traffic Control in Work Zones manual developed by the FHWA also provides similar standards governing flagging operations, equipment used, and standard practices (FHWA, 2017). However, these resources do not provide guidance on applying data-driven approaches to reducing traffic backups due to flagging operations, and best practices to balancing queueing with traffic flow. Some studies discussed here were conducted to address this gap.

Proper traffic control during a one-way flagging operation is essential to ensure that traffic flows as smoothly as possible. A study by Hua et al. aimed to identify better control strategies for one-way flagging operations on two-lane highways using mathematical delay and simulation model methodologies (2019). The results found that flagging control with optimal gap-out distance was the best strategy for most conditions, while actuated control methods could serve as a good alternative (Hua et al., 2019). The following suggestions were developed by the study for one-way flagging traffic control implementation and can inform future plans and strategies for one-way flagging procedures (Hua et al., 2019).

- Flagging control after gap-out distance optimization is recommended due to the good performance of average delay, queue length, and throughput, especially under low- or high-volume conditions.

- Because optimal gap-out distance exists for flagging control, simulation modeling can be employed to develop optimal values. A mark can be placed at the optimal gap-out distance ahead of the stop bar. When no vehicles run between the stop bar and the mark, flagging personnel can switch the paddle to the stop side.

- Actuated control, one of the most commonly used intersection control strategies, is not as effective as flagging control but outperforms pre-timed control. Under moderate-volume conditions, actuated control could be a good alternative for work zone areas due to its small queue length and large vehicle throughput.

- Pre-timed control strategies are not as effective for two-lane work zones, they may still be used, as no additional devices (such as loop detectors) are required except for signal lights.

- Speed limit, as well as the average speed at work zone areas, can greatly influence the performance of control strategies. As long as safety can be maintained, vehicle speeds can be increased to lower the stopped delay and queue length and to improve the vehicle throughput. The speed limit should be determined carefully, because higher speeds can increase accident risk.

- After calibration, the mathematical model can be used to describe the stopped delays under most of the work zone control strategies, except for under the flagger control method with low traffic volume conditions.

An important part of one-way flagging management is predicting impacts to traffic. Queuing can cause significant traffic backup during one-way traffic control; as a result, understanding these impacts is important for planning and management of one-way operations. Estimating vehicle delays and possible queue lengths can provide value to a one-way flagging operation by allowing managers to prepare for expected traffic. A study by Cassidy and Han developed a technique for estimating delays and queue lengths on two-lane highways under one-way flagging operations (1993). They suggest utilizing data-driven parameter estimates to determine average right-of-way time, and then compute queue lengths and delays using deterministic theory (Cassidy and Han, 1993). This methodology illustrates the importance of a data-driven approach to estimating traffic impacts at one-way flagging operations. Modeling based on existing data will allow for the development of more accurate models and more effective one-way operation strategies.

Washburn et al. (2008) sought a method to analyze the impact of lane closures on total roadway capacity after finding that such methods were not common. They developed a custom simulation program which utilized data to estimate work zone travel speed, saturation flow rate, queue delay, and queue lengths. The authors found that this procedure, utilized in a spreadsheet format, provided a fairly straightforward method to estimate traffic impacts during one-way flagging procedures (Washburn et al., 2008). However, the authors noted that the procedure required more field data testing to validate the modeling process (Washburn et al, 2008). The study recommends collecting the following data (Washburn et al., 2008).

- Typical values for saturation flow rates/capacities
- Differences in capacity/saturation flow rates due to traffic stream composition.
- Work zone speeds compared to posted speed limits
- Work zone speeds by direction and impact of lane crossover
- Start-up lost time by direction
- Use of gap-out strategies for flagging

- Maximum green time, if used
- Green time extension, if used

These data can be used to predict one-way flagging impacts and develop best methods and practices for flagging operations more effectively.

2.2.2 Alternatives and Enhancements to Manual Flagging Operations

Many studies on one-way flagging operations have focused on technology and devices associated with such operations. Many of these studies revolve around testing devices and strategies intended to improve one-way flagging efficiency, safety for flagging personnel, or both. While many of these studies do not focus solely on using existing traffic data to develop better one-way flagging operations, they do include information on devices and strategies which may improve operations and traffic efficiency.

A number of studies focus on utilizing alternative methods of flagging management than human flagging personnel. A study by Schrock et al., evaluated the use of temporary traffic signals and pilot car operations at work zones for work zone control (2016). The study tested three different methods of traffic control in conjunction with a pilot car, with results as described; effectiveness of each method was determined based on red-light-running violations, vehicle delay estimation, queue lengths, signal timing operations, and other general operations (Schrock et al., 2016). The following statistics were the observed potentials for violations by type of control:

- Flagging only: 1.1%
- Portable Traffic Signal system with the presence of a flagger: 1.3%
- Portable Traffic Signal system without the presence of a flagger: 3.1%

The authors found a significant difference in the number of violations between the three conditions, that flagging operations reduced delays generally by 5%, and that compliance was higher when a human flagger was present (Schrock et al., 2016).

A study by Finley and Theiss notes that the MUTCD requires a flagger to be present when a pilot car is used for one-way flagging operations, negating the advantage of using pilot cars and Portable Traffic Controls (PTCs) to remove flaggers from transition areas (thereby improving safety) (2017). The study involved assessing compliance of vehicles at lane closures under one-way flagging management. The study found that only 2.7% and 2.3% of drivers did not comply with PTCs across conditions with and without a flagger present, respectively, and no significant difference or practical difference was present in violations between the conditions (Finley and Thiess, 2017). This study suggests that the MUTCD could be updated to allow for non-human flagging management to be utilized more frequently (Finley and Thiess, 2017). Other benefits may be provided from technological alternatives to human flaggers. For example, Ullman et al. (1987) found that PTCs provide substantial savings in flagging labor costs ($9-$14 per hour at the time of the study), providing financial benefits to agencies.

Other studies which have investigated the use of technological devices for one-way flagging include the study of a moving automatic flagger assistance device (AFAD) for both stationary and moving work zone operations (Terhaar, 2014 and 2017). These studies primarily focused on use of an AFAD device to prevent placing human flagging operators in dangerous traffic situations. In such cases, the AFAD is placed at the ends of the one-way section, instead of human operators, and signals to incoming vehicles when they are allowed to proceed through the one-way section (Terhaar, 2014). The study found that it is safer to pull flagger personnel out of traffic using these devices, and the devices work well for two-lane road one-way flagging operations. The authors note there has been resistance from agency personnel in the past to using these devices regularly (Terhaar, 2014). The study authors recommend that training and continued field use of AFAD devices be implemented to improve safety conditions at one-way flagging operational zones.

2.2.3 Other Studies

Additional studies were found during the literature review which researched other aspects of one-way flagging operations. These included variables associated with crash safety at work zone areas, mitigation strategies, and evaluating infrastructure implements to assist with one-way flagging operations. A study by Qi et al., worked to identify factors that influence the frequency and severity of rear-end crashes in work zone areas (2012). Given the frequency of such crashes in work zone areas, including where flagging operations are in effect, the study authors utilized count data models to see what factors are most correlated with and influence the severity of rear-end crashes in work zone areas (Qi et al., 2012). Major findings related to flagging operations include the following (Qi et al., 2012):

- Work zones controlled by flaggers are associated with more rear-end crashes compared to those controlled by arrow boards.
- Work zones with alternating one-way traffic tended to have more rear-end crashes compared to those with lane shifts.
- Crashes associated with misunderstanding flagging signals tend to be less severe.

These findings illustrate the importance of effectively planning and executing one-way flagging operations. As a result, one-way flagging operations must be planned and controlled effectively to reduce crashes to the greatest degree possible.

The use of strategies other than standard human flaggers may not always lead to improved safety results. A study from Theiss et al., investigated strategies to mitigate end-of-queue crashes at flagging stations on two-way roads where one-way flagging has been implemented (2022). The authors evaluated different treatments to prevent crashes in flagging queues; these included LEDs displaying a 'be prepared to stop message,' a changeable message sign, and a portable traffic signal in place of a human flagger (Theiss et al., 2022). The study found that these strategies did not show any meaningful differences in vehicle speeds and subsequent safety conditions between the strategies versus the baseline human flagger method, though cost savings of using a portable signal instead of human flaggers were realized in only two years (Thiess et al., 2022). Ullman et al. (1987) also found that PTCs and similar technology may not decrease crashes near flagging areas. These findings reveal that technological advances may not lead to marked improvement of one-way flagging safety and efficiency.

Other infrastructure treatments may provide safety benefits and improved performance to one-way flagging operations or other work zone projects. A study by Hawkins and Knickerbocker observed the impact of temporary rumble strip layouts at different two-lane roadway construction projects (2017). With rumble strips, the authors observed increased driver braking, minimal driver avoidance of the rumble strips, and overall reduced vehicle speeds (Hawkins and Knickerbocker, 2017). These findings note that infrastructure such as rumble strips and temporary installations may provide additional benefit and performance to flagging operations.

2.2.4 Literature Review Conclusions

Developing effective one-way flagging operations at work zone locations on two-lane roads is important to balancing traffic flow with work-zone safety conditions. Flagging operations may lead to a buildup in traffic queuing and potential safety issues. As a result, previous study has researched different variables associated with flagging operations to identify potential strategies to improve flagging practices and safety conditions. Some studies have focused on data-driven approaches to flagging management and control strategies. Many other studies analyzed the use of alternative approaches to flagging, such as PTCs or other advanced warning systems in lieu of human flagger personnel. Safety for flagging personnel and crash studies have also been included within one-way flagging studies. Flagging research by Avenue Consultants will add to existing literature by providing UDOT with a data-driven approach to one-way flagging operations. The ultimate output will be a more defined standard for determining appropriate construction times and limitations to minimize traffic delays and increase safety during one-way flagging operations.

2.3 One-Way Flagging Survey

The literature review conducted in this study provided a good overview of basic one-way flagging operations and the variety in operations that can be found, as well as issues which may be encountered in flagging operations. In order to gain more contemporary information on one-way flagging practices currently in place amongst state DOTs, the research team considered options of reaching out to DOT representatives. It was determined that a survey of best practices would allow for comprehensive information on one-way flagging to be gathered. The research team utilized previous experience with such surveys to develop a list of questions which would be sent to state DOT representatives. The survey questions covered a variety of topics involving one-way flagging, including basic flagging practices, issues which commonly are encountered during operations, previous efforts to mitigate challenges and safety issues, review of flagging performance data, simulation modeling, how flagging practices are determined, etc. These questions would allow for flagging information specific to different DOTs to be gathered. Results could be compared and utilized to enhance UDOTs current practices.

The survey questions developed are included in section 2.3.2. After the questions were drafted, they were sent to UDOT personnel for review and approval. After any adjustments were made, the survey questions were created in the online program SurveyMonkey for dissemination. UDOT personnel then utilized an AASHTO Committee to distribute a link to the survey amongst different state DOTs. Survey results are discussed in Section 3.

2.3.1 Survey Introduction

The text below consists of introductory and explanatory text included in the online survey. This text was seen in conjunction with questions 1, 2, and 3 displayed in Section 2.3.2.

"One-Way Flagging Operations are often a necessary part of roadway maintenance and construction in rural areas where state highways may have only a single lane in each direction. While necessary, these operations add delay for drivers as they wait to pass through one-lane sections of the construction zone, which can create significant queues and further delays when traffic volumes exceed capacity. This UDOT research project aims to review the state of practice for determining if and when one-way flagging operations should be utilized and help to determine the capacity of these operations for future projects."

"Below is a brief survey inquiring about practices of your agency regarding one-way flagging operations. This survey should be directed towards the position or division at the agency who oversees the maintenance of traffic during construction operations. More than one survey could be completed for your agency if one-way flagging guidelines vary. We appreciate your willingness to provide input into this research."

2.3.2 Survey Questions

The following questions compose the survey which was sent to various contacts at state DOTs. The survey was administered online through SurveyMonkey.

1. *Name*
2. *Email Address*
3. *What agency do you work for?*

4. *Does your DOT have an established, agency-wide process for determining if and when one-way flagging operations should be used in construction or maintenance projects?*
   - *Yes*
   - *No*

5. [If question 4 = 'Yes'] *Does this process include evaluating the operational performance (expected delay, queues, or traffic volumes) of the one-way flagging operation?*
   - *Yes*
   - *No*

6. [If question 5 = 'Yes'] *What delay, queue, or volume guidance or policy documents are used to determine if one-way flagging should be used?*
   - ________________________

6. [If question 5 = 'No'] *How are one-way flagging processes managed by the DOT?*
   - ________________________

7. *Are the percentage of heavy trucks or presence of steep grades ever considered when determining if one-way flagging operations should be used?*
   - *Yes*
   - *No*

8. [If question 7 = ‘Yes’] *How do heavy trucks and/or grades determine the use of one-way flagging operations?*

   - ________________________

9. *What department/individuals are responsible for oversight of one-way flagging operations?*

   - ________________________

10. *What general flagging method is utilized by the DOT (select all that apply)?*

    - *Human flagger control of the zone*
    - *Automated Flagger Assistance Device (AFAD)*
    - *Temporary traffic control devices/signal control of the zone*
    - *Other (please specify)* ________________________

11. *What strategies or treatments does your agency use for one-way flagging that you feel contribute to the safety of one-way flagging operations?*

    - ________________________

12. *Please select any safety-related issues your DOT experiences regarding one-way flagging operations (select all that apply).*

    - *Speeding vehicles*
    - *Drivers entering the one-way zone despite being told to stop*
    - *Equipment malfunctions*
    - *Communication between flaggers/devices*
    - *Sight distance issues in flagging zone*
    - *Sight distance issues at the end of the queue to enter flagging zone*
    - *Other (please specify)* ________________________

13. *What strategies or treatments does your agency use for one-way flagging that you feel contribute to effective one-way flagging operational performance?*

    - ________________________

14. *Please select any traffic operation-related issues your DOT experiences regarding one-way flagging operations (select all that apply)?*
    - *Long queues*
    - *Long delays*
    - *Imbalanced performance (one entering direction experiencing short wait times and short queues while the other direction experiences long wait times and long queues)*
    - *Other*________________________

15. *Has the DOT previously collected or reviewed any performance data for one-way flagging procedures?*
    - *Yes*
    - *No*

16. [If question 15 = 'Yes'] *Please identify what type of data was collected and how this data is used.*
    - ________________________

17. *Has the DOT used simulation modeling in evaluating the performance of one-way flagging operations?*
    - *Yes*
    - *No*

18. [If question 17 = 'Yes'] *What parameters were used to calibrate the simulation model?*
    - ________________________

2.4 UDOT One-Way Flagging Projects and Analysis

In addition to the data collected on other state practices through an online survey, a significant portion of this project included gathering of data at ten UDOT sites where one-way flagging operations are utilized as part of the MOT. The research team worked with UDOT personnel to identify what projects the department was planning to carry out in the spring and summer of 2024 which involved one-way flagging, which could be used for data collection.

The data collected included GPS travel times to determine the travel times and speed through the one-way flagging operations along with counts of vehicles entering the one-way flagging zone separated into passenger cars and trucks, the headway or time gap between vehicles, and the duration of green time, clearance time, and stopped time for the one-way flagging operation.

This data was collected to help identify how one-way flagging zones are currently operated, including the traffic performance, and to provide insights into the capacity of future one-way flagging operations. To help with predicting future performance the team utilizing regression analysis along with simulation modeling. This process is described in section 3.3 in this document.

2.4.1 Linear Regression Analysis

Linear Regression analysis was selected as a method to examine vehicle headways, clearance time, queue length, and travel times related to one-way flagging operations and provide equations to evaluate future one-way flagging sites. Vehicle headways and clearance times were examined due to their importance in predicting the capacity of a one-way flagging operation while queue and travel time provide valuable insights into the traffic operation experienced during one-way flagging. Regression analysis also enabled the research team to predict these values based on data that would be readily available for UDOT staff, namely the length of the one-way flagging zone, percentage of trucks, typical vehicle traffic, and grade leading up to the one-way flagging zone.

2.4.2 Simulation Modeling Analysis

Simulation modeling would be used to determine the expected capacity of one-way flagging operations and was selected for the ability to test a range of variables including holes in the collected traffic data. This method was used due to the majority of one-way flagging operations taking place on lower-traffic-volume roadways below the capacity of a one-way flagging operation and being restricted on higher-traffic-volume roadways to periods when the traffic volumes are unlikely to reach the capacity of a one-way flagging operation. For this analysis the simulation models were calibrated to match the observed headways and clearance times from the one-way flagging data collection.

2.5 Summary

This section provides an overview of the literature review and survey findings on one-way flagging operations in roadway construction, with a focus on traffic management, safety, and efficiency. The literature review revealed that while safety concerns, such as flagger protection and crash reduction, have been widely studied, less attention has been given to optimizing traffic flow and reducing delays. Existing guidelines, such as those from the MUTCD, offer basic strategies but lack data-driven approaches for improving flagging efficiency. Technological solutions like automated flagger assistance devices (AFAD) and pilot cars have been explored for enhancing safety and reducing delays, though their effectiveness in crash prevention remains inconclusive. The research methods utilized in this study for data collection included developing a survey to be sent to state DOTs which would provide information on standard practices and processes utilized for one-way flagging in the U.S. The project team would then conduct data collection on one-way flagging queues at various project sites around the state of Utah. The project team would then conduct linear regression analysis and simulation modeling on the collected data. This would allow the project team to identify what is effective about current one-way flagging procedures, where issues may be occurring, and how the process may be enhanced moving forward.

3.0 DATA COLLECTION

3.1 Overview

Data collection processes in this study involved the administration of the survey discussed in Section 2 and collection of one-way flagging data at project sites throughout the state of Utah. The survey was administered to state DOTs, and provided information such as typical standards for one-way flagging, typical operations, safety issues encountered, and other information from the DOT perspective on one-way flagging management. The project team then worked with UDOT personnel to select locations around Utah where construction involving one-way flagging was being carried out. Once these sites and a day appropriate for collection was selected, the research team enacted an on-site data collection process utilizing a probe vehicle, GPS technology, and manual observations. The data was then cleaned and prepared for evaluation, discussed in Section 4.

3.2 One-Way Flagging Survey

As described in section 2.3, a survey was sent to various state transportation agencies inquiring about their basic one-way flagging practices. The survey was distributed with assistance from the project TAC and UDOT Champion to different state agencies through various committees and organizations. This survey was created to gather information on how other agencies throughout the United States define and execute one-way flagging operations, with a focus on if and how they determine the traffic operation impacts.

Information gathered included whether there are standard practices for one-way flagging at the agency, how operations are managed and by whom, what methods are commonly utilized during flagging, common safety issues with one-way flagging, what strategies have been implemented to improve safety and efficiency of operations, and whether data analysis and modeling have previously been utilized to evaluate programming. Responses to these questions indicate if there are common trends in how one-way flagging is managed among state DOTs and highlight what differences may be present.

Twenty agencies responded to the survey and provided information on their one-way flagging practices and operations. Table 3.1 below displays the responding organizations and their corresponding state, city, or region, along with the acronym used to refer to the organization in this document. Figure 3.1 below visually displays the 20 states from which responses were received. As seen in the table and figure, a wide range of DOTs responded to the survey and provided information on their one-way flagging practices. This provided the research team with a good base of understanding regarding such practices across the U.S.

Table 3.1 Survey Response Information

Organization	Acronym	State/Region	Responses
Alaska Department of Transportation & Public Facilities	DOT&PF	Alaska	1
Arizona Department of Transportation	ADOT	Arizona	1
Arkansas Department of Transportation	ARDOT	Arkansas	1
California Department of Transportation	CalTrans	California	2
Delaware Department of Transportation	DelDOT	Delaware	1
Georgia Department of Transportation	GDOT	Georgia	1
Kansas Department of Transportation	KDOT	Kansas	1
Kentucky Transportation Cabinet	KYTC	Kentucky	1
Louisiana Department of Transportation and Development	LADOTD	Louisiana	1
Maine Department of Transportation	MaineDOT	Maine	2
Michigan Department of Transportation	MDOT	Michigan	1
Missouri Department of Transportation	MODOT	Missouri	1
Montana Department of Transportation	MDT	Montana	1
New York State Department of Transportation	NYSDOT	New York	1
North Carolina Department of Transportation	NCDOT	North Carolina	1
South Carolina Department of Transportation	SCDOT	South Carolina	1
South Dakota Department of Transportation	SDDOT	South Dakota	1
Vermont Agency of Transportation	VTrans	Vermont	1
Virginia Department of Transportation	VDOT	Virginia	1
Washington Department of Transportation	WSDOT	Washington	1

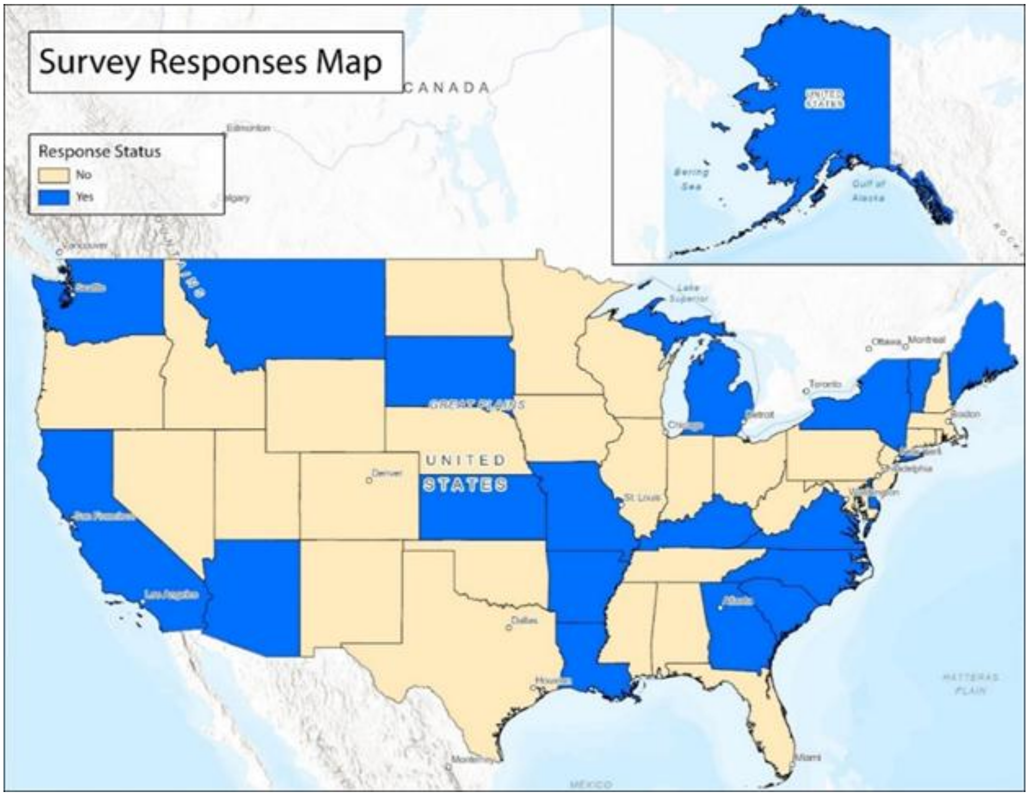

Figure 3.1 Survey Response Map

3.2.1 Survey Takeaways

Twenty state DOTs responded to the survey and provided information on their standards and practices for one-way flagging operations. These results are included in full in Appendix A of this document, including written responses where applicable, and statistics on the answers to each question. Several key takeaways and results from the survey results are summarized below:

- One-way flagging operations are widely used across DOTs and transportation agencies. However, only about half of respondents indicated that they have an agency-wide standardized process for determining when one-way flagging operations should be implemented.
  - Agencies without a standardized process largely approach one-way flagging management project by project.

- There is significant variation in how one-way flagging projects are implemented and managed. While some basic factors such as traffic and geometric characteristics inform one-way flagging procedures, agencies utilize various criteria for one-way flagging implementation and operation.
    - For example, only about half of agencies utilize grades and/or heavy truck counts to determine one-way flagging. Among these agencies, the standards behind grades or truck count use are not uniform.
- Construction and/or maintenance departments typically oversee one-way flagging; however, multiple departments (e.g., construction AND traffic engineering) often coordinate one-way flagging management.
- Agencies report similar safety issues and operational issues as part of one-way flagging operations.
    - The most reported safety issues include speeding vehicles and issues with sight distance in the one-way flagging zone. Notably, several agencies reported distracted drivers as an issue.
    - A similar number of agencies reported long queues, delays, and imbalanced performance as operational issues inherent to one-way flagging operations.
- No agency indicated that they collected any performance data as part of one-way flagging evaluations. Only four agencies have utilized simulation modeling for evaluations.

This survey shows that a state DOT implements one-way flagging procedures specific to its own requirements and existing processes. Typically, a department or division in the agency directly associated with one-way flagging operations manages the one-way flagging processes, and several common safety and operational issues may be encountered. There is variety in how DOTs and agencies implement one-way flagging; incorporating the analysis of performance data and modeling introduces new possibilities and options for agencies to improve their procedures.

3.3 Data Collection Locations and Selection

The project team aimed at collecting data from several different locations throughout Utah to gain one-way flagging operations from a variety of roadways and roadway conditions. The team coordinated with UDOT staff and monitoring of active transportation construction projects throughout the state, as described in Section 2.4, to locate and select projects for data collection.

3.3.1 Initial Location Selection Process

UDOT first provided a list of construction projects that were being carried out throughout the state during the spring, summer, and fall of 2024, which involved one-way flagging traffic control. These projects typically involved paving, resurfacing, chip seal, or similar operations which require the closing of roadways down to one lane. The project team reviewed the list and began selecting projects which occurred within 2024 and provided an opportunity to analyze the one-way flagging process. A list of roughly thirty projects was initially determined by the research team to provide the most realistic opportunity to collect data. These projects were located around the state of Utah on various roadways.

After initial review of the list and coordination with UDOT personnel, the research team reached out to the UDOT project manager and resident engineer over the projects identified. Through this effort it was identified that many of the projects would be delayed until the following year or one-way flagging would not be needed for the MOT during construction. The research team also found that a few projects were very remote and were unlikely to experience higher traffic volumes. A final consideration was that the research team chose certain projects over others based on expected traffic volumes and roadway types; roads with more volume and higher classes were prioritized to ensure that plentiful data would be available. As a result, the research team selected a portion of these sites for selection. This determination is described in Section 3.3 in this document.

3.3.2 Final Data Collection Locations

Due to the factors described in Sections 3.3.1, the research team focused on selecting as many projects for data collection as possible within project timeline constraints. The team also ensured that the projects selected would provide enough usable data to provide value for the study and supply quality information on one-way flagging.

Ultimately ten construction projects were used for data collection. These projects occurred across a variety of locations in Utah and provided ample opportunity for good data collection on one-way flagging. Table 3.1 below displays the projects utilized for data collection. Figure 3.2 displays the location of data collection locations in the state of Utah.

Table 3.2 Data Collection Locations

Route	Milepoint Range	Geographical Area	Date
US-40	18.13 – 27.78	Heber	08-06-2024
US-40	86 – 97.5	Duchesne	09-06-2024
SR-35	0 – 12.35	Kamas	09-06-2024
SR-7	7.15 – 18.315	St. George	06-13-2024
SR-199	8 – 21.952	Tooele	08-14-2024
US-6	204.295 – 211.408	Spanish Fork Canyon	07-12-2024
SR-132	34 – 38	Nephi	08-20-2024
SR-39	9 – 9.8	Ogden Canyon	08-29-2024
US-191	280 – 282	Indian Canyon	07-11-2024
US-191	138.6 – 142.3	Moab	10-06-2023

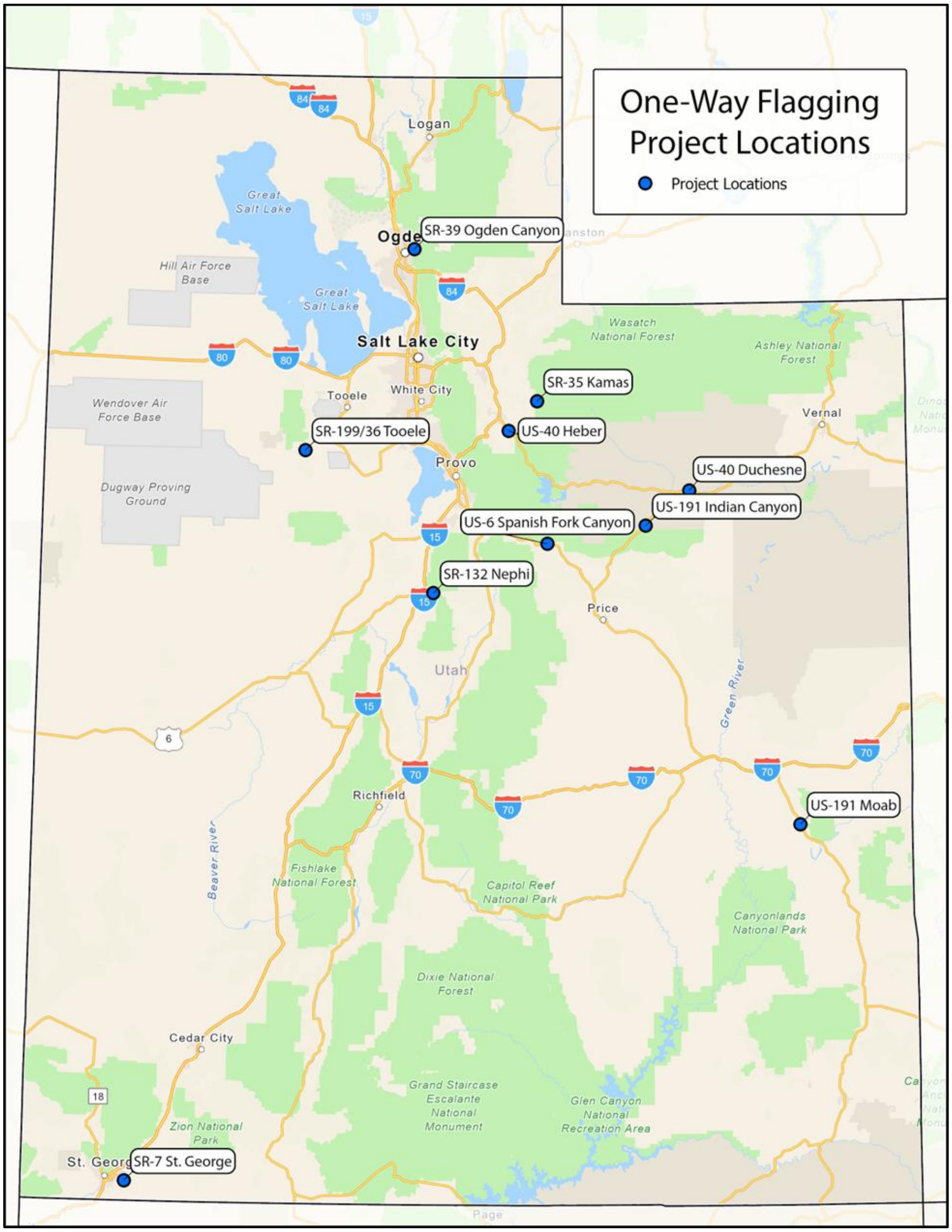

Figure 3.2 One-Way Flagging Project Locations

3.3.3 Coordination Process

The research team continually coordinated with project managers via email and telephone for each project to receive updates on when projects were in operation and specifically when one-way flagging processes were underway. When project managers informed the research team that one-way flagging procedures were in operation, personnel from the research team would organize and go out to the project for data collection. In this way, projects were identified and collection performed on an as-available basis.

3.4 On-Site Data Collection Process

The following section describes the data collection process which was utilized in this study. Data collection utilized two key methods: a probe vehicle to provide GPS output while driving through the one-way flagging zone and data collected at the one-way flagging entrances. These two methods were conducted simultaneously at the data collection sites by a data collection team. The data collected from both methods was utilized for analysis later in the project.

3.4.1 GPS Probe Vehicle Data

The probe vehicle was equipped with GPS which provided latitude, longitude, elevation and a timestamp every second. The data collected by the probe vehicle data was used to determine travel speeds approaching and through the one-way flagging zone, the grade of the roadway approaching the flagging zone, the length of the one-way flagging operation by marking the entrance to the flagging zone, a sample of the delay for vehicles entering the one-way flagging operation, and a sample of the queue lengths experienced at the entrance to the one-way flagging operation.

3.4.2 One-Way Flagging Entrance Data

At the project site, an individual from the project team was positioned at each end of the one-way flagging zone to collect information about vehicles entering the one-way flagging zone and about the one-way flagging operation.

For vehicles entering the one-way flagging zone the individual recorded the number of vehicles, the class of each vehicle, and a timestamp of when each vehicle passed the flagger. The timestamp will be used to provide information about the headway and flow rates for vehicles entering the flagging zone.

For the one-way flagging operation, the individual recorded with a timestamp when the flagger transitioned from the stop sign condition to the slow sign condition to allow the vehicle to enter the one-way flagging zone and when the flagger transitioned back to the stop sign condition. This provided information about how long vehicles at each entrance of the one-way flagging operation were stopped and how long vehicles were allowed to enter the flagging zone, in addition to how long it took to clear the queue of vehicles. Combining the data from the individual on each end of the one-way flagging zone provided additional information about the length of the clearance time or when both approaches to the one-way flagging operation are in the stop condition to allow vehicles from one direction to clear the one-way flagging zone.

3.4.3 Additional Observations from the Data Collection Process

During data collection, the research team noticed a variety of characteristics at each of the study sites, which were recorded by team members outside of the data collection. Notable observations recorded at the project sites include the following:

- Some projects utilized pilot vehicles guiding traffic through the flagging zones
    - These pilot vehicles were used only at one way-flagging projects with a long project corridor.
- Some sites had multiple accesses within the study area where additional vehicles could enter/exit the one-way flagging zone.
- The research team also noted that some flagging zones required more all-red time to clear out construction vehicles between cycles of through traffic.
    - In some cases, both directions of traffic were stopped while construction equipment and trucks were moved in the one-way flagging zone

3.5 Data Cleaning and Preparation

Data cleaning and preparation played a crucial role in ensuring the reliability and quality of the data for this study. The team utilized Python-based scripts to process and clean multiple data sources, including GPX files for probe vehicle tracking, KML files for geographic points, and vehicle counts. Each dataset underwent systematic transformations, such as filtering outliers, converting raw data into usable metrics, and aligning the datasets for integration. GPX data was processed to calculate distances, road grades, and directional labels, while KML files helped identify significant intersections and their geographic coordinates. Vehicle count data was cleaned to address inconsistencies, and vehicle classifications were standardized across the data.

The cleaned datasets from the various sources were then integrated into a unified dataset, which included key traffic metrics such as average speed, duration of green, clearance and stopped times, and truck percentages. A validation process ensured data accuracy through cross-checks, outlier detection, and visualizations. This rigorous data cleaning and integration process allowed for a comprehensive analysis of one-way flagging operations, ensuring that the final dataset was reliable for drawing meaningful conclusions.

3.6 Summary

This section provides an explanation of the data collection and cleaning methods for the survey and on-site data. The survey data showed that DOTs lack detailed processes for one-way flagging with only half utilizing heavy truck and roadway grade data for example. This reveals a gap in knowledge of one-way flagging which this study seeks to address. On-site data collection employed both probe vehicles for GPS tracking and manual vehicle counts at flagging zones to capture critical metrics such as travel times, queue lengths, and signal cycle characteristics.

Data cleaning and preparation were central to ensuring the quality and reliability of the datasets. GPX data from probe vehicles were processed to derive key parameters like travel speed, roadway grade, and length of the flagging zone, while KML files identified significant geographic points for segmenting data. Manual vehicle count data from Excel files were cleaned to address inconsistencies and compute metrics like headways and cycle lengths. The cleaned datasets were integrated to create a unified dataset, and validation steps ensured their accuracy. This comprehensive approach provided a robust foundation for subsequent analysis, allowing the team to evaluate the efficiency and safety of one-way flagging operations effectively.

4.0 DATA EVALUATION

4.1 Overview

After the data collection, the data was evaluated to determine the distribution of key parameters of the one-way flagging operation and traffic performance data, the relationship between these parameters and known variables for future projects through a regression analysis, and simulation models were developed to determine capacity. The key parameters reviewed included the duration of the green time, clearance times, and stopped times during the one-way flagging operations observed along with vehicle information such as vehicle headways, truck percentage, travel times, and queue lengths. Using this data, the project team developed regression models to estimate the expected headway, clearance times, queue length and travel times based on data which will likely be readily available for state routes and could be reviewed for future projects. A simulation analysis was performed, after the calibration of the simulation model using the data collected, to determine the expected capacity of one-way flagging operations at various truck percentages and flagging operation lengths. Simulation models were used due to the determination that most of the observed one-way flagging operations were at a traffic demand below capacity.

4.2 Data Evaluation Definitions and Calculations

As the research team collected, cleaned, and evaluated the data, different elements of one-way flagging data and procedures were referred to using certain nomenclature. These key elements relate directly to the data evaluation process and are referred to repeatedly in this document. See section 4.2.1 for these definitions. Similarly, the research team evaluated the data and made certain calculations based on evaluation. These calculations helped guide the evaluation process and are defined in Section 4.2.2.

4.2.1 Key Definitions

- Clearance Time: The amount of time in which both flaggers hold the sign in the “stop” position to allow traffic to clear the construction area.

- Green Time: The amount of time in which vehicles may enter the route where construction is occurring or the amount of time a flagger holds the sign in the “go” position.

- Cycle Length: The sum of the Green Time and Clearance Time for both directions of travel.

- Stopped Time: The amount of time in which vehicles may not enter the route or the amount of time a flagger holds the sign in the “stop” position.

4.3 Data Collection Route Characteristics

The research team calculated basic summary statistics for each route in the study, in order to gain information on route characteristics. This included recording the physical characteristics of each area (grades, one-way flagging zone distance), vehicle volumes through the flagging zone, average speeds of traffic through the flagging zone, and if a pilot car was being used to guide traffic through the flagging zone at the site. These characteristics could provide additional nuance and context to further data analysis and provide a general idea of the characteristics at each study site. Results of these calculations are provided in table 4.1.

Table 4.1 Data Collection Location Characteristics

Route Name	Location	Distance (mi)	Avg Speed (mph)	Grade (%)	Volume Per Hour	Pilot Car
SR-132	Nephi Canyon	0.79	41.8	3.04	328	No
SR-199	Rush Valley	3	18.33	1.58	53	Yes
SR-35	Francis	1.63	17.05	0.83	144	Yes
SR-39	Ogden Canyon	0.67	22.88	2.47	551	No
US-40	Heber	1.17	28.96	1.68	272	Yes
US-40	Duchesne	2.62	35.37	0.61	488	Yes
SR-7	St. George	4.49	45.28	0.02	122	Yes
US-191	Castle Gate	2.23	25.19	3.42	74	Yes
US-6	Tucker	0.52	36.58	3.37	646	No

4.4 One-Way Flagging Operation Analysis

This section details the evaluation of various one-way flagging parameters in relationship to the operations of the flagging, including the length of the green time, stopped time, and clearance time. These parameters vary significantly due to the number of vehicles arriving at the one-way flagging zone, length of the one-way flagging zone, and other variables such as the need to allow trucks to enter the flagging zone or the presence of other driveways or roadways within the flagging zone. The one-way flagging operation, especially the clearance time needed, directly impacts the capacity and traffic operation performance.

Figure 4.1 shows a histogram of green time aggregated by flagging location, direction, and cycle. The average amount of green time is about 133 seconds or 2.2 minutes. This means flaggers were generally observed to allow this much time for vehicles to enter the flagging zone. However, the minimum of 3 seconds green time indicates that there were at least a few instances where little green time was allowed, perhaps due to low traffic demand. The max green time was 646 seconds or 10.8 minutes, but most of the green times are below 250 seconds or 4.2 minutes. While observing the operation of the one-way flagging zone it was noted that the flagger typically provided enough green time to clear the queue of vehicles for that approach.

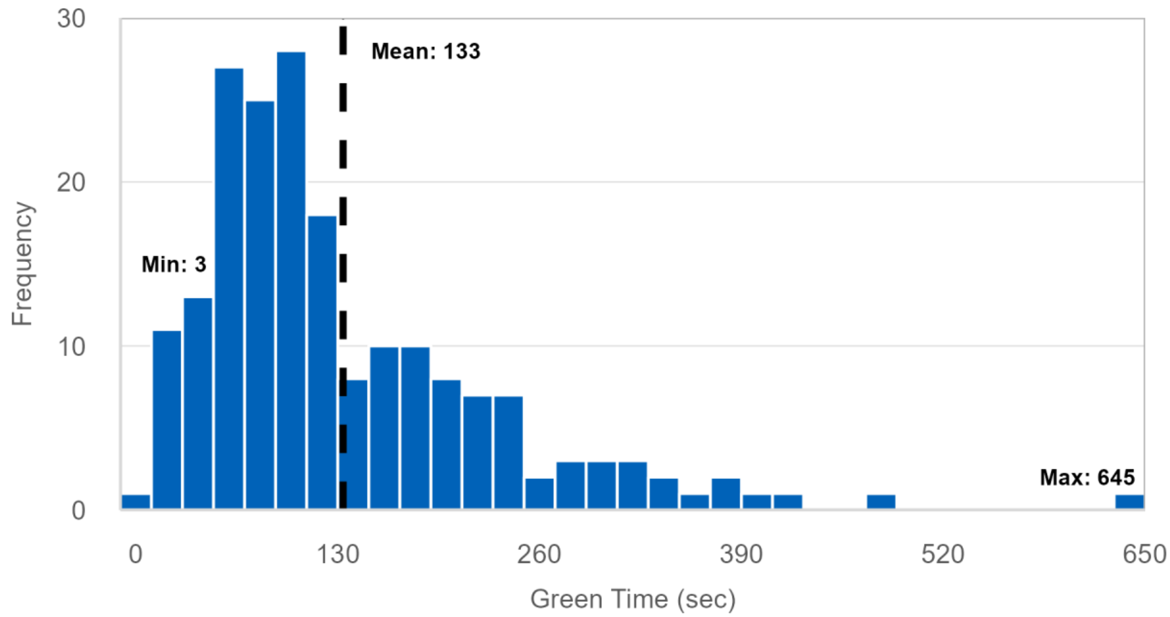

Figure 4.1 Distribution of Green Time

Figure 4.2 shows a plot of green time versus traffic volume entering during the green time, colored by flagging location. This chart shows a linear trend in which green time and volume increase together at a consistent rate. The observed data points appear to follow this trend and match the observed conditions that the flaggers based the amount of green time on the number of vehicles present. However, this figure only shows the volume served, not the traffic volume demand. At higher demand where the capacity of a one-way flagging operation is reached it may not be possible to completely clear the queues and still provide an acceptable delay for the opposing direction.

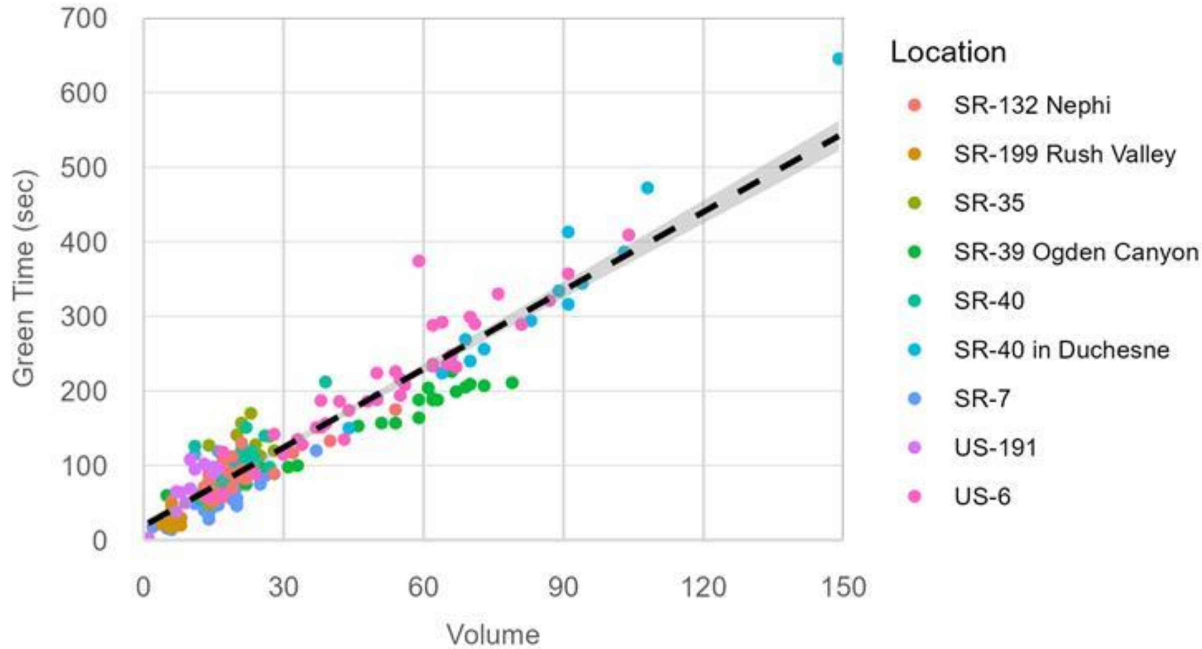

Figure 4.2 Traffic Volume vs. Green Time

The next chart – a histogram of stopped time aggregated by location, direction, and cycle – shows two distinct groups. If we separate the data from these groups, one has a median of about 400 seconds or 6.7 minutes and the other has a median of about 900 seconds or 15 minutes. Further investigation reveals that the first group mostly consists of flagging locations on US-6, SR-132, SR-40 in Heber, and SR-39 while the second group mostly consists of US-191, SR-35, SR-7, SR-40 in Duchesne, and SR-199. Based on the information shown in Table 4.1, the main difference between these two groups is the length of the flagging zone. Shorter lengths have shorter stopped times and longer lengths have longer stopped times. Since longer flagging zones take longer to clear, flaggers are required to prevent entry into the flagging zone for longer amounts of time leading to longer stopped times. Additionally, longer flagging zones are also more likely to have more accesses within them, requiring flaggers to prevent entry for additional time while internal traffic clears the area. The discrepancy between the two groups in Figure 4.3 also highlights a gap in the data for locations with medium lengths.

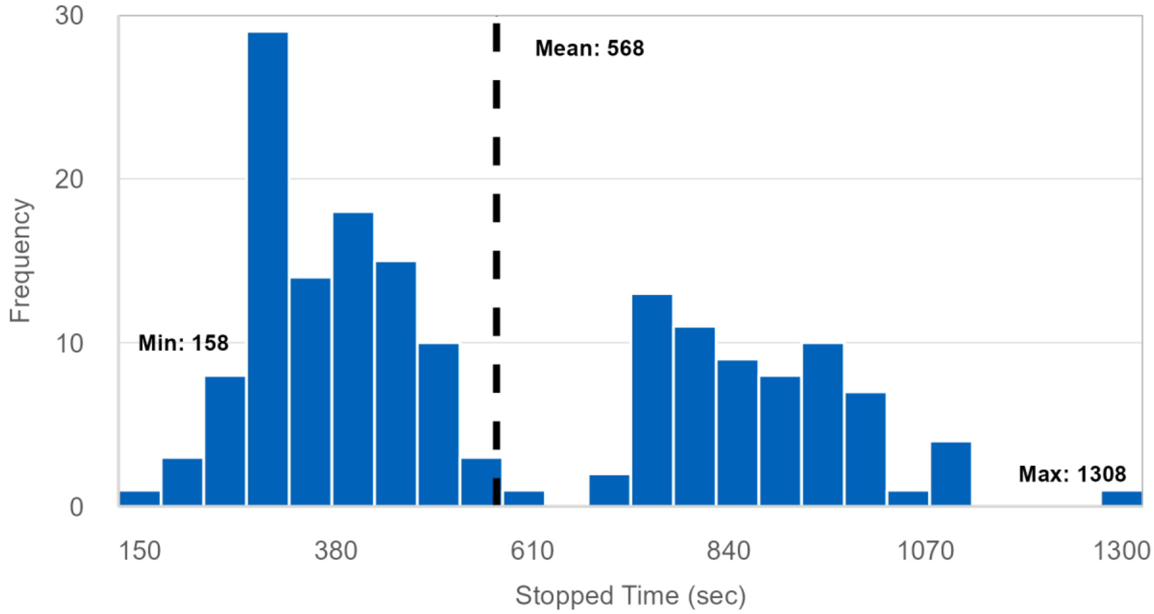

Figure 4.3 Distribution of Stopped Time

Very similar to stopped time, clearance time is the amount of time in which both flaggers prevent entry into the flagging zone, rather than just stopping entry in one direction. This time is provided for the last car in a direction to clear the one-way flagging zone before the opposing direction is allowed to proceed into the flagging zone. The histogram for clearance time shown in Figure 4.4 is very similar to the histogram for stopped time shown in Figure 4.3. Unlike the stopped time we don't see as much of a gap between the shorter and longer one-way flagging project.

To illustrate the relationship between flagging zone length and clearance time, Figure 4.5 shows that clearance time generally increases linearly with flagging zone length. There is some variation to this trend which may be explained by trucks entering and exiting the flagging zone, internal traffic clearing the flagging zone, or other variables related to traveling through a flagging zone.

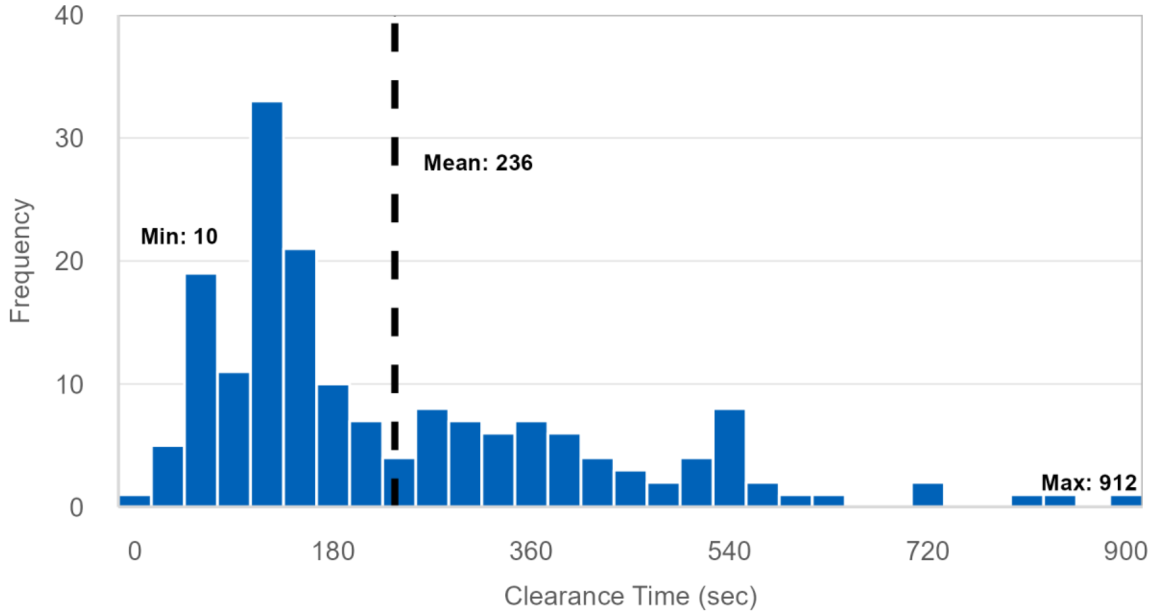

Figure 4.4 Distribution of Clearance Time

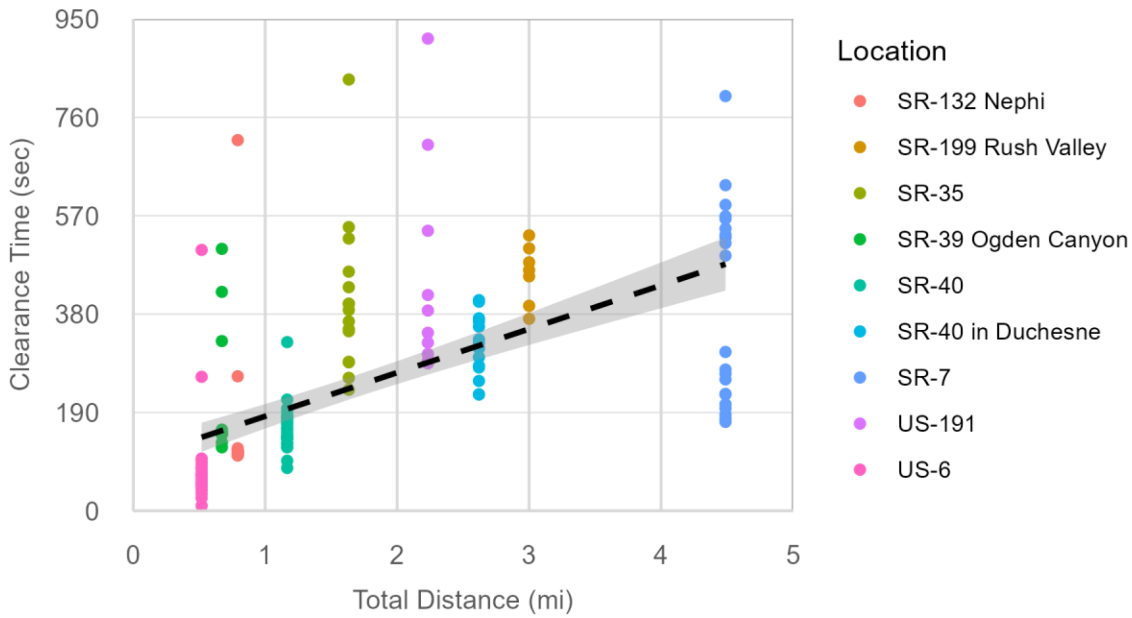

Figure 4.5 Flagging Zone Length vs. Clearance Time

The operational data for each of the one-way flagging zones used in the research project and presented in this section confirms expectations about the data, such as the relationships between traffic volume and green time and between flagging zone length and clearance time.

4.5 Traffic Performance Analysis

This section details the evaluation of various one-way flagging parameters in relationship to the operations of the vehicles traveling through the flagging zone, including vehicle headways, queue lengths as determined by the number of vehicles in the queue, and longest wait time or delay experienced by the vehicles.

Vehicle headway is a useful metric for traffic performance as it is the direct inverse of vehicle flow rate, a measure typically used in the calculation of roadway capacity. A knowledge of headways at potential one-way flagging locations would help practitioners determine if a location would function well under one-way flagging. Figure 4.6 shows the measured headways based on position in queue colored for passenger vehicles and heavy trucks. For both passenger vehicles and trucks, there seems to be a slight trend of longer headways at the start of queue. This may represent the increased startup lost time experienced in queues of vehicles starting from a stopped condition.

It was expected that heavy trucks would have longer headways than passenger vehicles since they take longer to accelerate. Figure 4.7 shows the headway distribution from all data samples collected. From the sample of headway data it was determined that passenger cars had an average headway of 3.2 seconds while trucks had an average headway of 4.9 seconds, an increase of 1.7 seconds. The calculated headways vary significantly even though the sample size for cars is much larger than the sample size for trucks.

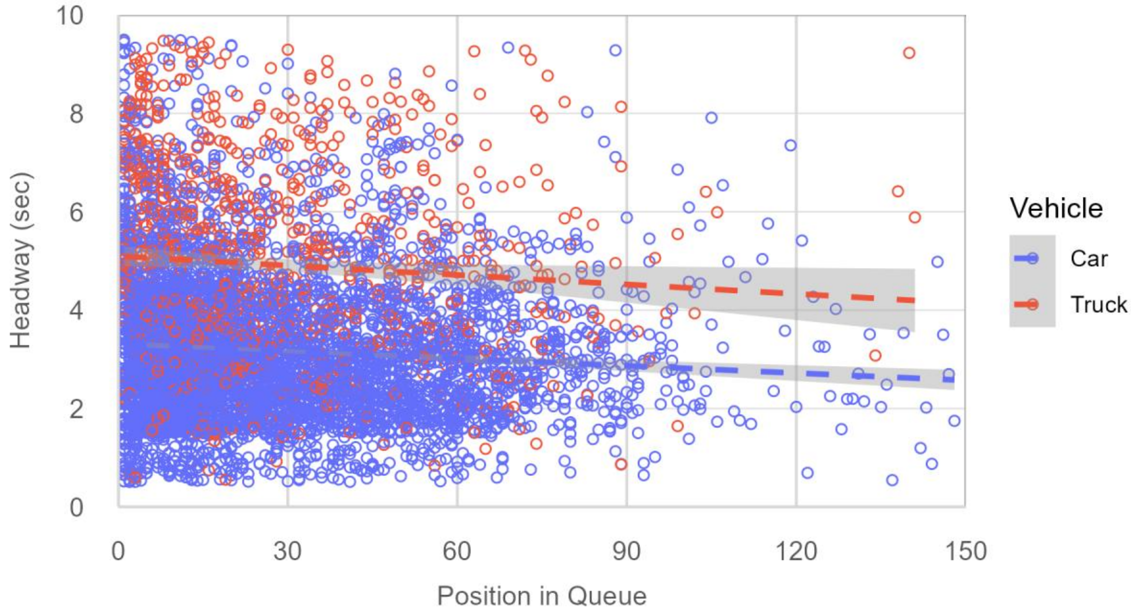

Figure 4.6 One-Way Flagging Headways

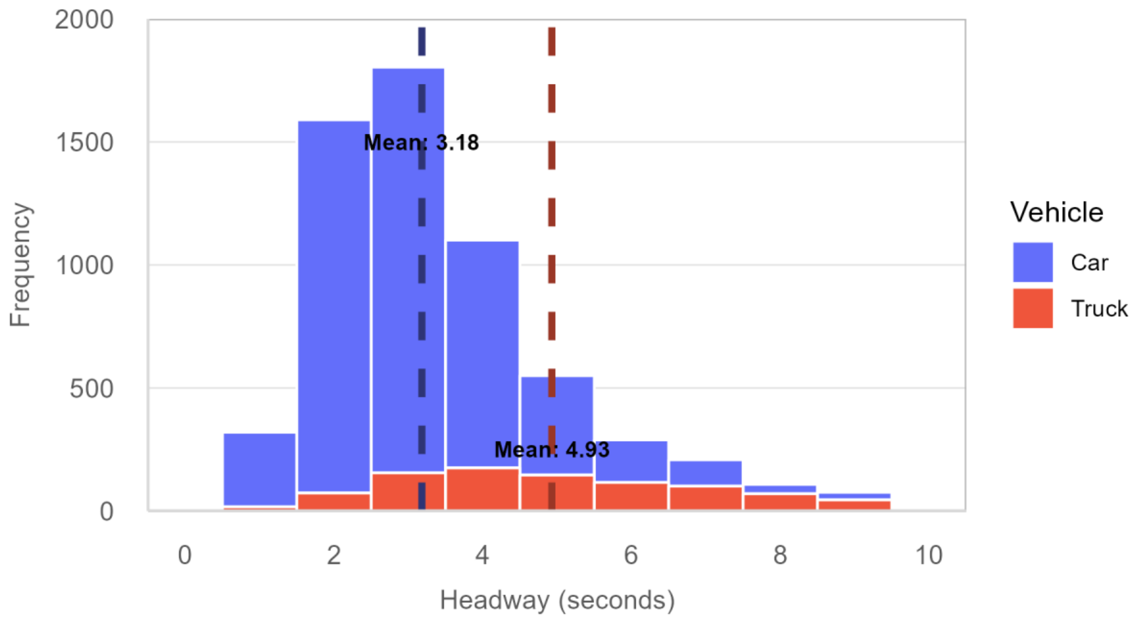

Figure 4.7 Passenger Cars vs. Trucks

Another one-way flagging performance metric, queue length, is critical as one-way flagging operations often occur at locations where long queues could create traffic performance and safety issues. This is especially true on routes with only a single lane in each direction near an intersection or interchange with another state route or local road. Based on the GPS data provided by the probe vehicle, a sample of maximum queue lengths at each approach into the one-way flagging operations were collected. The vehicle arrivals were also used to estimate queue lengths for each split as an alternative measure. Cars were assigned 25 feet of queue length and trucks were assigned 75 feet of queue length. Ideally, the entire queue should be served during the green time but this is not always possible such as with SR-40 in Duchesne where some vehicles were observed waiting multiple cycles to enter the flagging zone. The maximum queue lengths shown in Figure 4.9 have clearer linear trend with volume per hour than the estimated queue lengths in **Error! Reference source not found.** with the exception of SR-40 in Duchesne where the whole queues weren't served.

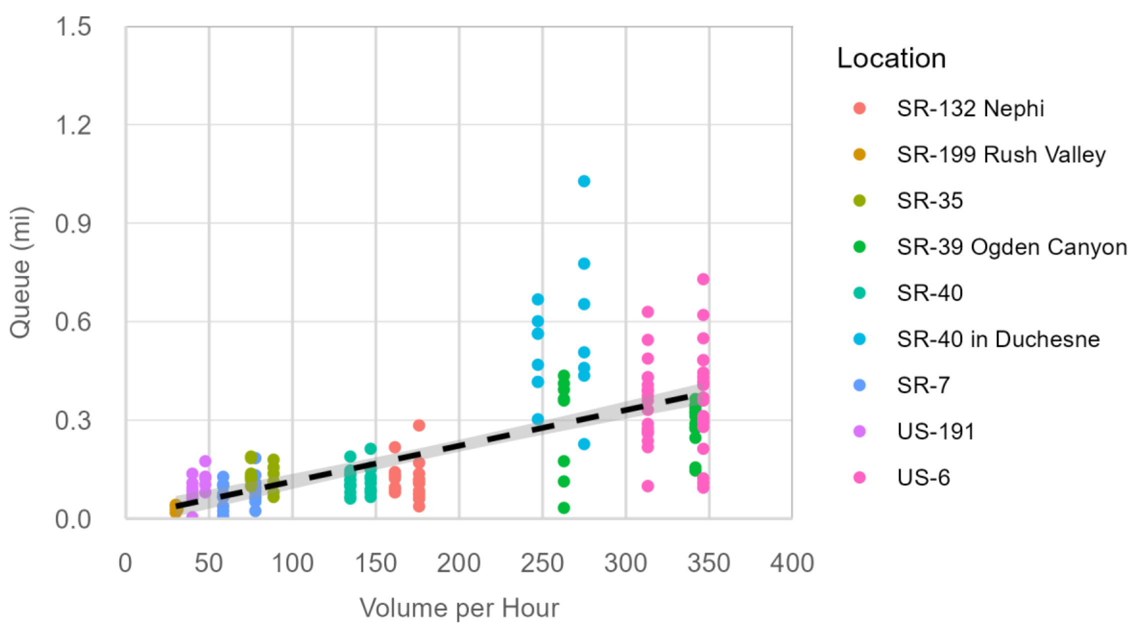

Figure 4.8 One-Way Flagging Queue Length

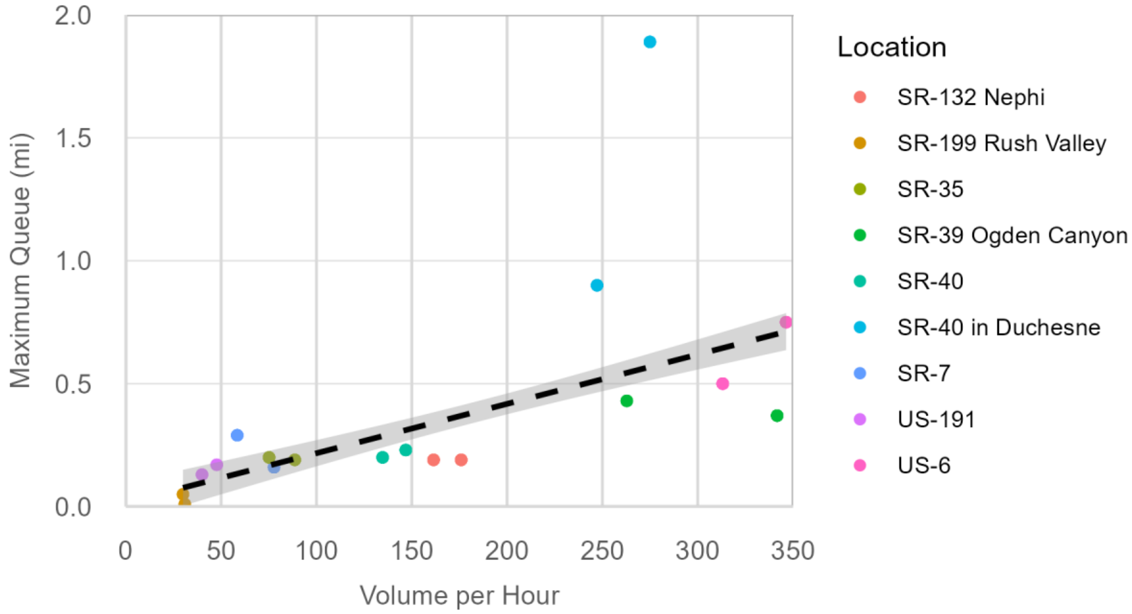

Figure 4.9 One-Way Flagging Max Queue Length

In addition to calculating maximum queue lengths, probe vehicle GPS data were also useful for visualizing delay at the observed one-way flagging scenarios. **Figure 4.10 Distribution of Average Probe Speed During Splits**

shows that the probe traveled at speeds of 22 MPH on average during splits with rare instances of traveling above 45 MPH. The probe also spent a considerable amount of time stopped during splits. **Error! Reference source not found.** shows that it took the probe an average of 3.1 minutes to cross the flagging zone, with a maximum travel time of 15.1 minutes and a minimum travel time of 0.7 minutes. Probe speeds and travel times varied significantly depending on the probe's position in queue and the accuracy of the GPS data. Additionally, one-way flagging operations where the traffic demand is above the capacity are likely to experience significantly higher delay and travel times.

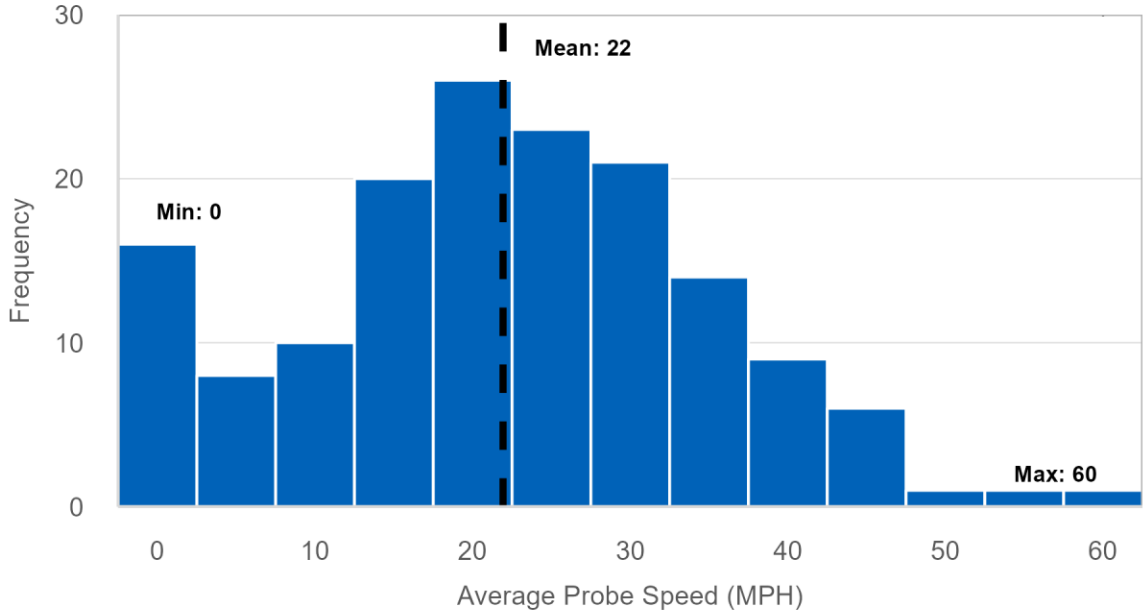

Figure 4.10 Distribution of Average Probe Speed During Splits

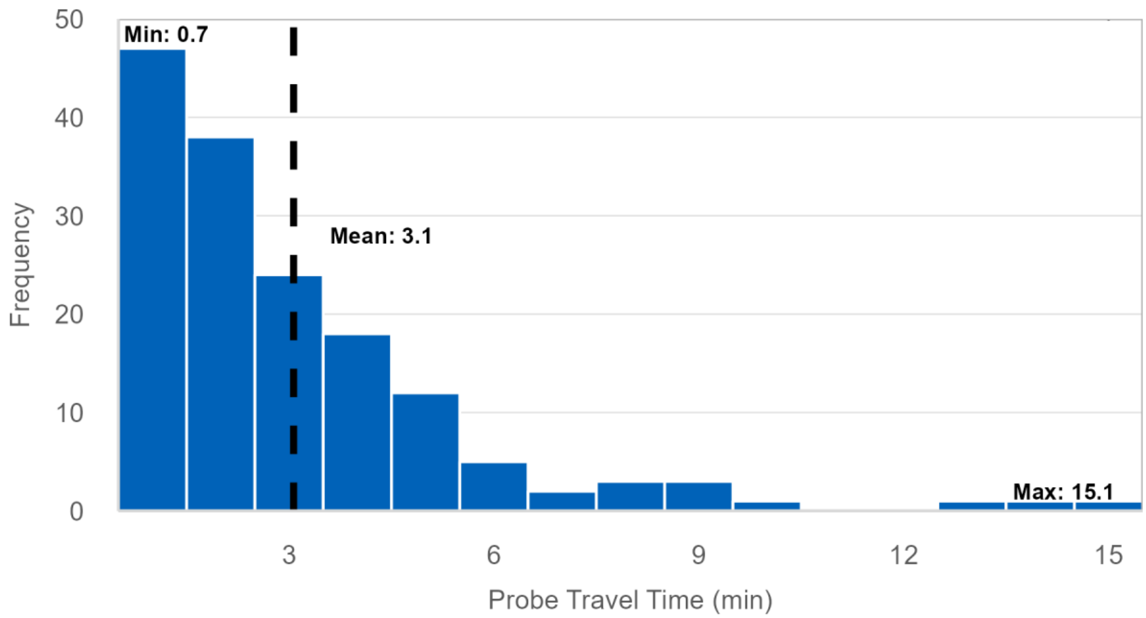

Figure 4.11 Distribution of Probe Travel Times

4.6 Regression Analysis to Predict Operational Performance

To analyze the data collected and provide actionable insights for future UDOT projects, multiple regression analysis was chosen as the primary analytical method. This method is well-suited to this study as regression analysis allows for identification of significant predictor variables, ensuring that variables with impacts to capacity, queue length, or delay were included Additionally, regression analysis provided the following information:

- Quantify relationships and trends between multiple independent variables
- Account for complex interactions such as grade and truck percentage
- Produce practical, equation-based models that UDOT can implement in future projects
- Offer statistical measures to assess model reliability and the significance of variables
- Handle both continuous and categorical predictor variables

To ensure that the regression models in this study were comprehensive, the following independent variables were evaluated as part of the regression analysis:

- Flagging zone length (distance) – distance from stop bar to stop bar of the one-way flagging zone.
- Grade – slope of the roadway within the flagging zone and along the segments of road where the queues were waiting to enter the flagging zone.
- Truck percentage – proportion of trucks among the total vehicle count.
- Hourly volumes – traffic flow rates at the time that data was collected
- Presence of a pilot car – whether a pilot vehicle was used to guide traffic through the flagging zone.

4.6.1 Headway Prediction

While individual headways were evaluated in Section 4.5, it was more practical to calculate the average headways aggregated by splits for the statistical analysis. Average headways can give UDOT a more useful metric which represents the overall efficiency of traffic movement during one-way flagging operations. It was determined that truck percentage and grade were the two most important contributing factors to headway so both were included in the model. The research team developed equation 4.2 to calculate average headway.

$$Average\ Headways\ (sec) = 3.17 + 0.055 \times Percent\ Trucks(\%) + 0.10 \times Grade(\%) \qquad (4.2)$$

Error! Reference source not found. shows the predicted values calculated from this equation versus the actual observed values. Ideally, the points should follow a slope of 1, indicating a perfect fit. While the model fit isn't perfect, it follows the data reasonably well.

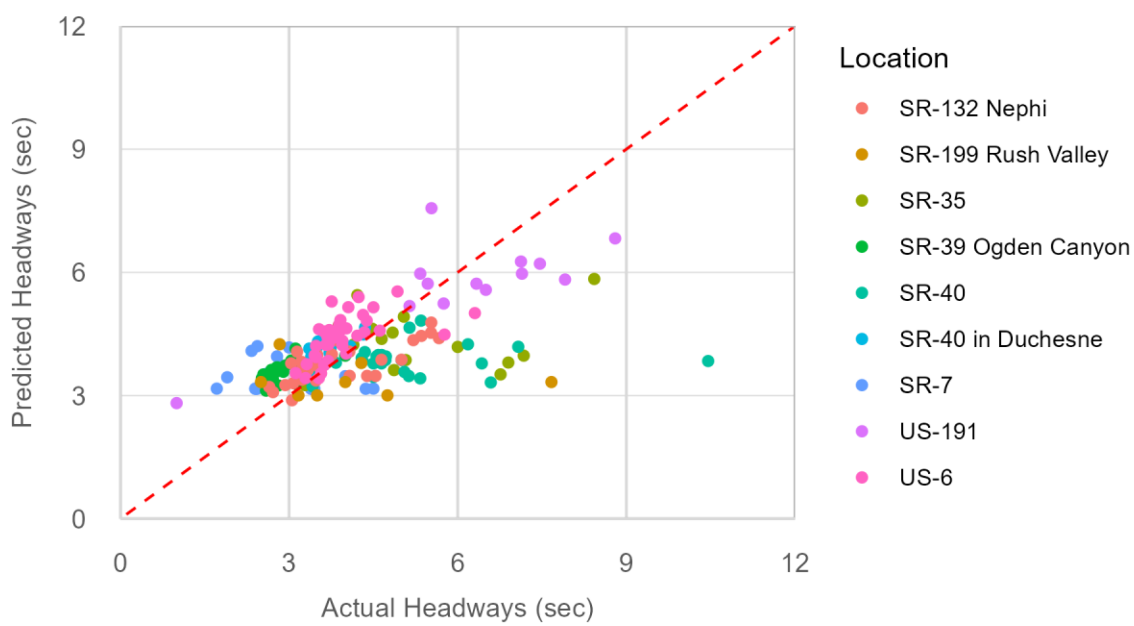

Figure 4.12 Predicted vs. Actual Headways

The independent variables used in this model (truck percentage and grade) were all significant at the $p < 0.001$ level and the model performs reasonably well with an R^2 value of

0.35. The coefficients of this model indicate that an increase in percent of trucks or grade correlates to a linear increase in headways. Key findings from this model include the following:

- Each one percent increase in trucks adds about 0.055 seconds to the average headway
- Each one percent increase in roadway grade adds about 0.10 seconds to the average headway

While this model functions well to represent average headway, there is a lot of variability to headway data which is not represented by the model. Random factors such as driver distraction, vehicle deficiencies, individual driving habits, and other factors may contribute to average headways. However, the model is still a good indicator of overall trends.

4.6.2 Clearance Time Prediction

Stopped time and clearance time were discussed in Section 4.4 as potential metrics for delay at one-way flagging operations. However, stopped time failed to produce a useful model from the regression analysis, so clearance time was evaluated instead. Section 5.3 discusses these limitations in more detail. It was determined that flagging zone distance was the most important statistically significant contributing factor to clearance time so it was included in the model. The research team developed equation 4.3 to calculate clearance time as a measure of delay.

$$\mathit{Clearance\ Time\ (sec)} = 98.59 + 84.25 \times \mathit{Distance} \qquad (4.3)$$

Error! Reference source not found. shows the predicted versus actual values for clearance times using this equation. While there is a significant amount of variance, the bulk of the data follows the model well.

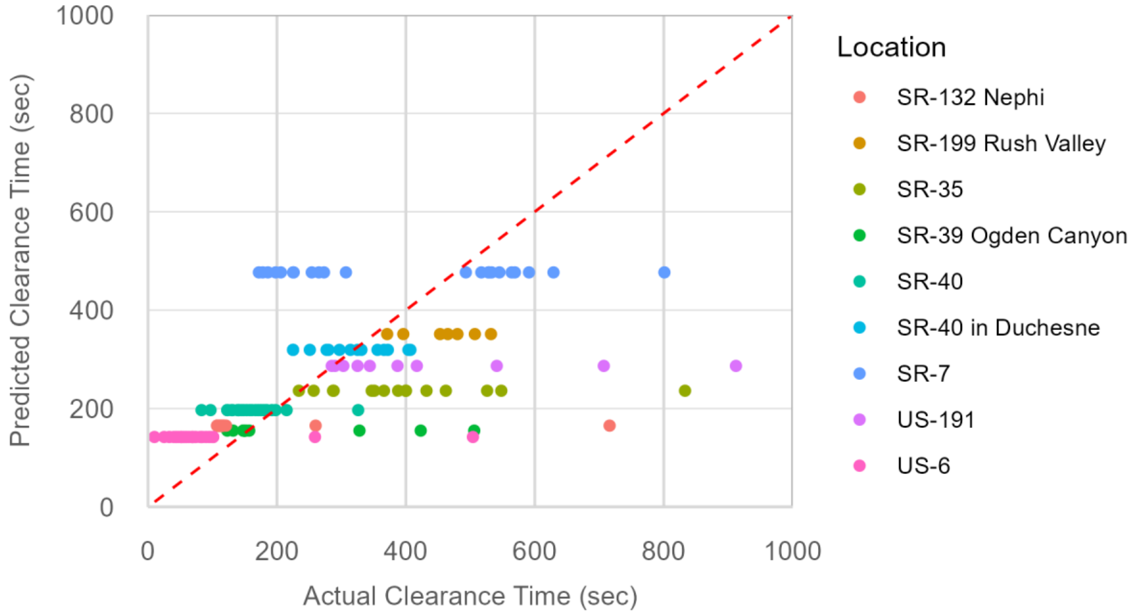

Figure 4.13 Predicted vs. Actual Clearance Times

The model uses the independent variable flagging zone distance. This variable was highly statistically significant at the $p < 0.001$ level and provided for a model with an R^2 value 0.37. The model indicates that increases in distance correlate to a linear increase in clearance time. Key findings from clearance time estimation include the following:

- Each mile of flagging zone correlates to a 60.52 second increase in clearance time

There are several reasons why longer flagging zones correlated to increased clearance time besides the fact that it takes longer to travel longer distances. Longer corridors may have required additional clearance time to clear out construction vehicles behind the queue of traffic exiting the flagging zone. They also may have included multiple access points (e.g., SR-35 in Francis), requiring additional clearance time.

<u>4.6.3 Maximum Queue Length Prediction</u>

As discussed in Section 4.5, it was determined that maximum queue length was a better metric for regression analysis than queue length. The maximum queue length is also a useful measure when determining if a one-way flagging operation will impact nearby intersections or interchanges. However, it should be noted that the sample size is smaller for maximum queue length since there is only one measurement for each location. Queue length increases as long as there are more vehicles at the one-way flagging area than the number exiting. Queue length in this study was measured in miles as observed at the project sites. Multiple independent variables and interactions were tested, and it was determined that the distance of the one-way flagging zone, the hourly volume, and truck percentage all contribute to the length of the queue. The research team developed equation 4.4 to calculate queue length.

$$\begin{aligned} \textit{Maximum Queue Length (mi)} = & -0.13 + 0.042 \times \textit{Distance} \\ & +0.002 \times \textit{Hourly Volume} \\ & +0.003 \times \textit{Percent Trucks}(\%) \end{aligned} \quad (4.4)$$

Error! Reference source not found. shows the predicted versus actual values for maximum queue length using this equation. The actual values follow the predicted values remarkably well, even for the outlier SR-40 in Duchesne showing that the model is potentially a good predictor of maximum queue lengths at one-way flagging operations.

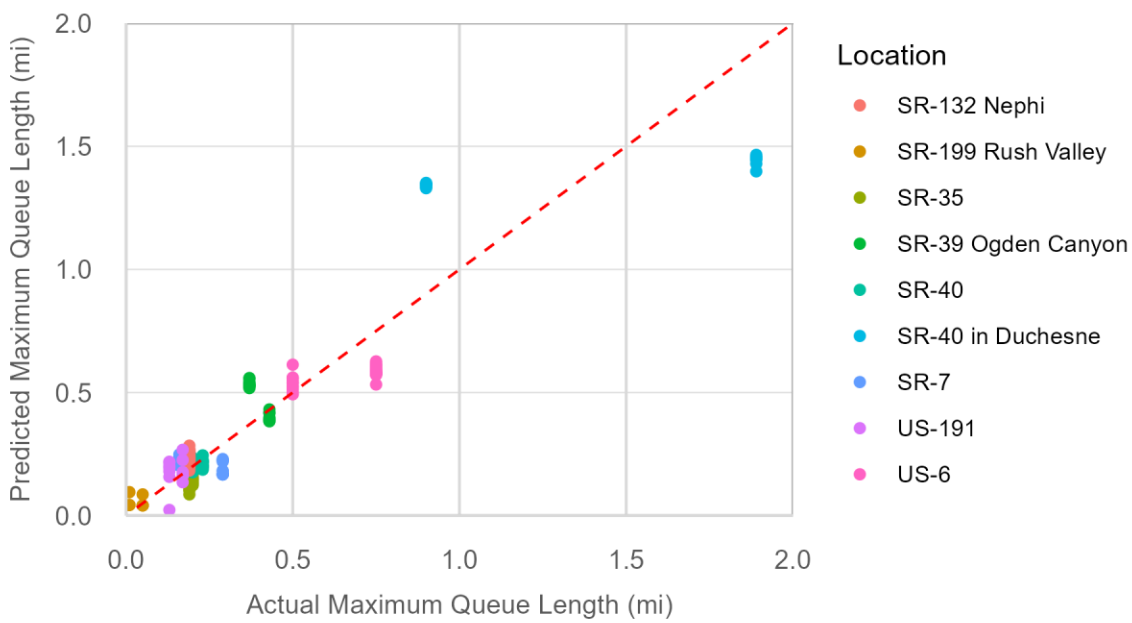

Figure 4.14 Predicted vs. Actual Maximum Queue Lengths

This model can be used to predict the length of the queue in miles. The independent variables used (distance, hourly volume, and truck percentage) were all significant at the $p < 0.005$ level and the model performs well with an R^2 value of 0.84. The interpretation of the coefficients is such that any increase in the independent variables results in a linear increase in queue length. Key findings from queue length estimation include the following:

- Each mile of flagging zone adds about 0.042 miles (222 feet) to the maximum queue
- Every 100 additional vehicles per hour adds 0.2 miles (1,056 feet) to the maximum queue
- Every 1% increase in trucks adds about 0.003 miles (15 feet) to the maximum queue

It should be noted that since most of the measurements used from operation were under the capacity, one-way flagging operations above capacity could experience much longer queues.

4.6.4 Delay Calculation

It is possible to use the regression equations for headway, clearance time, and maximum queue length to calculate total delay (stopped and clearance time) at one-way flagging operations for various scenarios given the percent grade, percent trucks, flagging zone length, and hourly volume. Equation 4.3 was used to calculate clearance time and a combination of Equations 4.2 and 4.4 were used to calculate stopped time as shown in Equation 4.5. This equation also used the assumption that each car takes up approximately 25 feet of queue length and each truck takes up approximately 75 feet of queue length.

$$Stopped\ Time\ (sec) = (Equation\ 4.2)\left(\frac{(Equation\ 4.4)\times 5280ft\ per\ mile}{25ft\left(\frac{100-Percent\ Trucks}{100}\right)+75ft\left(\frac{Percent\ Trucks}{100}\right)}\right) \tag{4.5}$$

The calculated total delays converted to minutes for several scenarios are shown in Table 4.2. These scenarios included percent grades of 0 and 6 percent, percent trucks of 10 and 35 percent, flagging zone lengths of 0.5, 1.5, and 2.5 miles, and hourly approach volumes between 100 and 450 vehicles per hour. The calculated delay times shown represent a scenario that is under the capacity of the one-way flagging operation, as it is based on the measured data from operations that were under the capacity of the operation. For traffic demand over the capacity of a one-way flagging operation the delay will grow exponentially.

Table 4.2 Total Delay Calculations

Hourly Approach Volume (vehicles per hour)	Percent Grade (%)											
	0	0	6	6	0	0	6	6	0	0	6	6
	Percent Trucks (%)											
	10	35	10	35	10	35	10	35	10	35	10	35
	Flagging Zone Length (mi)											
	0.5	0.5	0.5	0.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5
	One-Way Flagging Total Delay Calculation (min)*											
100	4	4	4	5	6	6	6	7	7	8	8	9
150	5	6	5	6	7	7	7	8	9	9	9	10
200	6	7	6	7	8	8	8	9	10	10	10	11
250	7	8	8	8	9	9	10	10	11	11	12	12
300	8	9	9	9	10	11	11	11	12	12	13	13
350	9	10	10	11	11	12	12	13	13	13	14	14
400	10	11	12	12	12	13	13	14	14	14	15	16
450	11	12	13	13	13	14	15	15	15	16	17	17

*When the bidirectional volumes are above the capacity of the one-way flagging operations the delay will grow exponentially

4.7 Simulation Modeling Capacity Evaluation

In most of the observed one-way flagging scenarios, it was expected that traffic flows would be lower than capacity since reasonable efforts were made to perform one-way flagging during times of day when traffic flows would be low. Because of this and the limited sample size of the data, regression models created using only the data to predict capacity and evaluate effective green time lengths were mostly unsuccessful. However, traffic microsimulation can be used in place of actual data to model high-traffic-volume scenarios that would rarely occur in the real world, providing a larger sample size of one-way flagging scenarios with traffic flows at capacity. If properly calibrated, a traffic microsimulation model could provide valuable insights into predicted traffic capacity and effective green time durations during one-way flagging operations.

For this study, the research team created a traffic microsimulation model using VISSIM software and calibrated it with observed relationships in the data to model capacity and green time at one-way flagging operations. The simulation models were developed and calibrated using the following factors:

- Clearance time based on the regression analysis and the length of the one-way flagging operation being analyzed
- Vehicle headways for both passenger vehicles and trucks based on the average values collected during the data collection

All of the simulation models were run for ten runs and averaged to ensure variation in the model runs did not significantly change the results of the analysis. The following sections describe the results of the VISSIM analysis including an evaluation of capacity at one-way flagging operations and an evaluation of appropriate green times at one-way flagging operations.

4.7.1 Capacity Evaluation

Using the calibrated Vissim simulation models, 35 one-way flagging scenarios were tested to see the total number of vehicles able to pass through the one-way flagging zone in an hour period. The 35 scenarios varied the length of the one-way flagging zone from 0.5 miles to 2.5 miles in increments of 0.5 miles and truck percentage from 5% to 35% in increments of 5% trucks. Both trucks and grade were identified as significant variables in determining the average headway entering a one-way flagging zone, but grade was not varied due to the truck percentage varying more widely throughout the state. This simulation analysis also assumed a 10-minute split for each direction of travel comprising a 20-minute cycle length. Figure 4.16 shows the throughput achieved and estimated capacity of one-way flagging operations based on the simulation analysis.

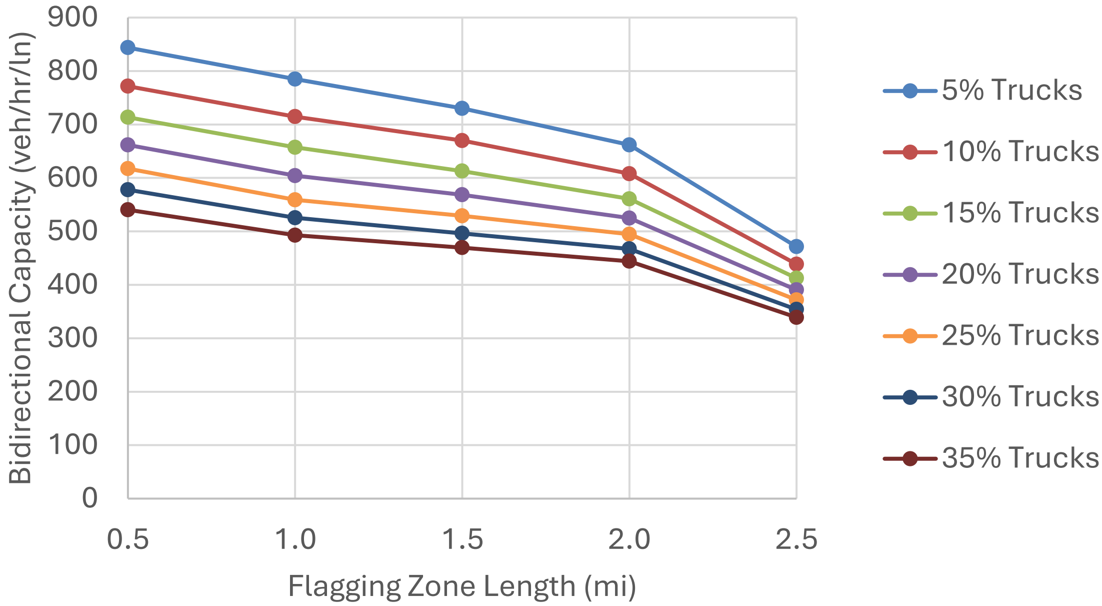

Figure 4.15 Capacity at One-Way Flagging Operations from Simulation

This figure shows that the capacity at a one-way flagging operation decreases when the zone is longer, which is due to the increase in clearance time needed. Additionally, a higher percentage of trucks lowers the capacity at all lengths. Even though this figure doesn't include grade, using the coefficient ratio between trucks and grade along with the grade expected in the one-way flagging operation to estimate its impact. For example, each increase in grade would equal a 1.81 increase in truck percentage. Therefore a 6% grade would add an additional 10.9% trucks to the truck percentage before consulting Figure 4.16.

4.7.2 Green Time Evaluation

A limited evaluation of optimal green time at one-way flagging operations was performed using the calibrated Vissim simulation models. For this evaluation, scenarios used one mile of flagging zone distance and 10 percent trucks. There were five scenarios using split times, the green time plus clearance time, between 5 and 15 minutes to calculate capacity. Figure 4.17 shows that capacity increases as green time increases with diminishing improvement for longer green times. While some benefit may be derived from longer one-way flagging split times, there is also an increase in stopped time for vehicles waiting to enter the one-way flagging zone.

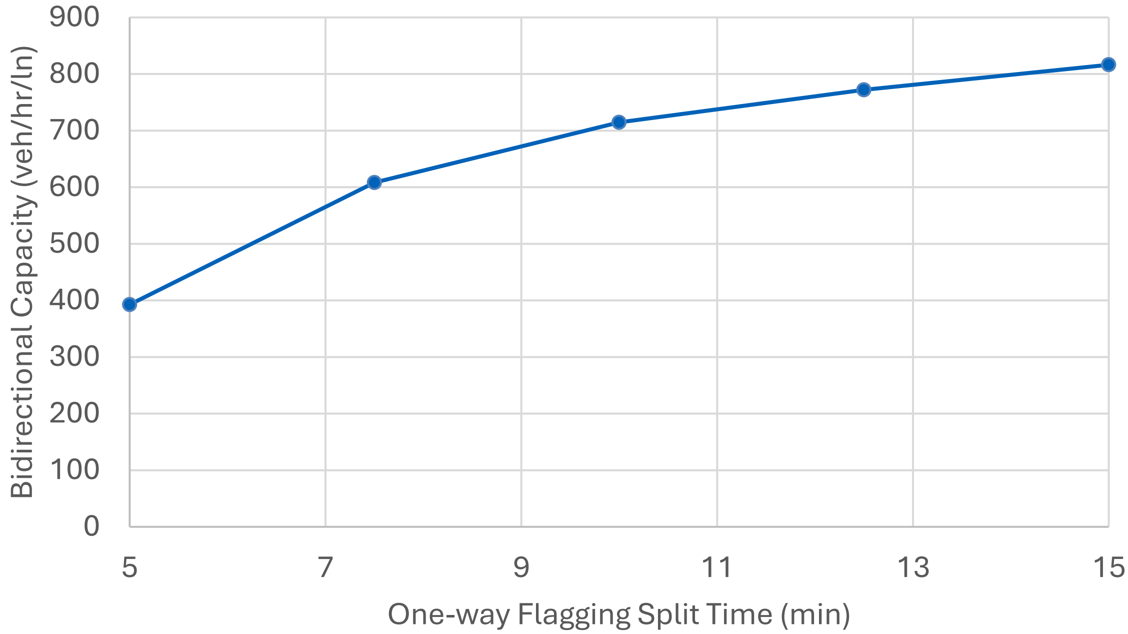

Figure 4.16 Bidirectional Capacity by Split Time for One-Mile Flagging Zone with 10% Trucks and 0% Grade

4.7.3 Maximum Queue Length vs. Vehicle Volume

To build upon the analysis maximum queue length prediction discussed earlier in this document (see section 4.6.3) an analysis of maximum queue lengths against vehicle volumes was included in simulation modeling. Figure 4.17 below displays the results of calculated maximum queue lengths compared to hourly vehicle volumes. As seen in the figure, maximum queue lengths increase to greater lengths after vehicle volumes rise above 250. Maximum queue lengths overall quadrupled as vehicle volumes rose from 300 to 600.

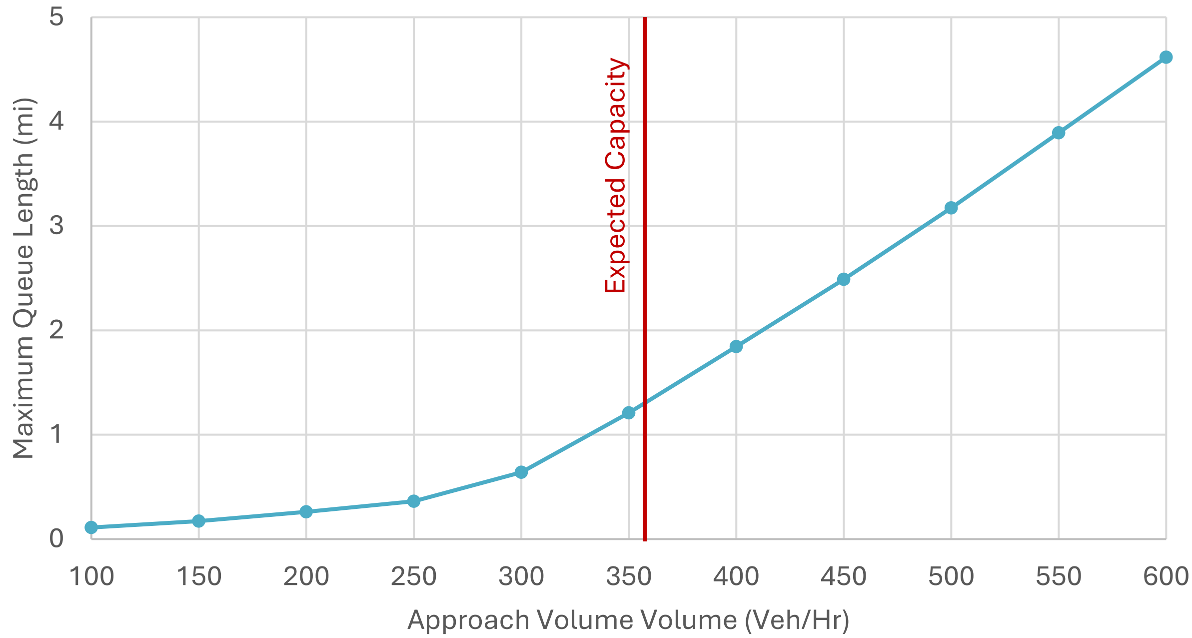

Figure 4.17 Maximum Queue Length by Vehicle Volumes for One-Mile Flagging Zone with 10% Trucks and 0% Grade

4.7.4 One-Way Flagging Delay

To provide additional information on delays experienced by vehicles at one-way flagging queues, simulation modeling was utilized to estimate average vehicle delays based on the approach volume. The simulations looked at a scenario of a one-mile one-way flagging zone with 10% trucks and 0% grade. The average delay per vehicle in minutes was calculated across vehicle volumes ranging from 100 to 600. Results of the analysis are shown in Figure 4.18. Results from the figure show a gradual increase in delays with traffic volumes up to approximately 300 vehicles. At these volumes, the average delay remains relatively low, between roughly five and twelve minutes per vehicle. However, once volume exceeds 300 vehicles, delay increases rapidly, reaching over 55 minutes per vehicle at 600 vehicles.

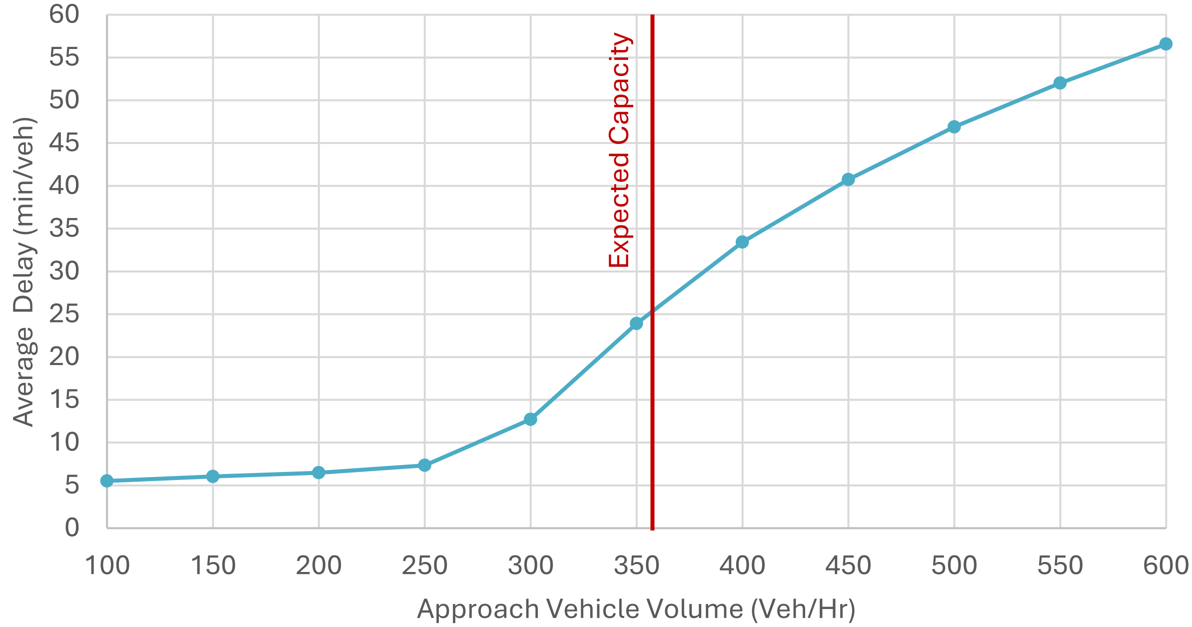

Figure 4.18 One-Way Flagging Delay by Vehicle Volume for One-Mile Flagging Zone with 10% Trucks and 0% Grade

4.8 Summary

After data was collected at projects involving one-way flagging, the research team utilized a data analysis process to determine parameters of one-way flagging processes and traffic performance data, and their subsequent relationships. The research team developed regression analysis models and performed a simulation analysis as part of the overall data evaluation. Key findings from regression analysis indicate that longer one-way flagging zones will typically see increases in traffic performance metrics (vehicle headways, clearance times, stopped time, etc.). Notable examples include the findings that one mile of flagging zone correlates to roughly a minute in increased clearance time for vehicles and roughly 0.042 miles added to queues, while every 100 additional vehicles per hour added 0.2 miles to the queue. Results of the simulation modeling found that capacity decreases on longer one-way flagging zones due to more clearance time needed, while trucks also decrease the capacity at one-way flagging zones. These findings helped determine study conclusions, discussed in Section 5.

5.0 CONCLUSIONS

5.1 Summary

Operating a one-way flagging zone poses many complications to agencies like UDOT, requiring a balance between meeting the needs of the construction process and roadway users. The objective of this research was to establish a more defined and reliable standard for determining appropriate construction times and limitations to minimize traffic delays and increase safety during one-way flagging operations in Utah. In this study, the research team collected and derived data at several one-way flagging operations throughout the state. This data was then analyzed through linear regression and simulation modeling to evaluate roadway capacity, queue lengths, and travel times at these one-way flagging operations.

5.2 Findings

Preliminary research in this study included conducting a literature review and surveying DOTs to understand more about national one-way flagging standards. Results from these efforts were helpful in informing and developing the methods used in data collection and evaluation. The research team then utilized data collected at one-way flagging zones in Utah and subsequent evaluation efforts to develop findings.

The key findings from this research are summarized below. These findings can be used for establishing reliable standards to minimize traffic delays and increase safety during one-way flagging operations. The findings on headways, clearance times, and queue lengths are useful for determining appropriate construction times for one-way flagging operations since they demonstrate a specific relationship with independent variables like flagging zone length and traffic volume. The findings on capacity show the limitations of one-way flagging operations since they define an upper limit to reasonable traffic volumes at one-way flagging operations. Based upon key findings in this study, the research team was able to develop recommendations and implementation strategies to help enhance the UDOT one-way flagging process, which are described in Section 6.

Key findings from this study include the following:

- There are several independent variables which are intrinsically related to one-way flagging, which include the following:
    - Zone length
    - Traffic volumes
    - Truck percentages
    - Vehicle speed through the flagging zone
    - Roadway grade
- Headways, Clearance Times, and Maximum Queue Lengths can be predicted with reasonable confidence using independent variables.
- Capacity seems to generally be in line with previous assumptions of roughly 400 vehicles per hour but varies depending on flagging zone length and green time.
- Queues were generally shorter than expected (<0.5 miles); the longest queue occurred when vehicles waited multiple cycles.

5.3 Limitations and Challenges

Some limitations were present in the data collection and analysis performed for this study. While these limitations had some influence on outcomes of the study, they are not expected to negatively impact the findings and value presented by the analysis.

- One limitation was noted in the data collection for the project. While the research team was able to collect sufficient data for headways, volumes, and cycle lengths, more data would have been beneficial to this study in providing additional opportunities for analysis. For future projects regarding one-way flagging practices, it is recommended that more data generally be collected related to queue length, delay, and capacity. Such data would provide additional context to the study of one-way flagging impacts.

- The research team found that at many of the project sites used for data collection, lower roadway volumes were observed. High-volume roadways where a one-way flagging project is present would observe different conditions and greater potential delays for roadway users. Specific collection of data at projects with high roadway volumes would be beneficial to analysis of one-way flagging operations and provide additional information on issues experienced at these locations.

- It should be noted that clearance time as discussed in this study is not a complete measure of delay. Total stopped time may be more indicative of the actual time each vehicle waits at a one-way flagging zone. Stopped time includes red clearance time and the green time given to the opposite direction. Because of this, the only significant variables in the stopped time model (distance, pilot car, and volume per hour) would not be the most useful variables in application.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Based upon the findings and conclusions of this research, the following recommendations have been developed for UDOT by the research team regarding one-way flagging practices at the agency.

1. One-way flagging standards should reflect the findings that headways increase by approximately 0.055 seconds for each 1 percent increase in percent trucks and 0.10 seconds for each 1 percent increase in roadway grade

2. One-way flagging standards should reflect the finding that clearance time increases by approximately 84.25 seconds for each additional mile of flagging zone length

3. One-way flagging standards should reflect the findings that maximum queue length increases by approximately 0.042 miles (222 feet) for each additional mile of flagging zone length, 0.2 miles (1,056 feet) for each additional 100 vehicles per hour, and 0.003 miles (15 feet) for each 1 percent increase in percent trucks

4. One-way flagging standards should be established to reflect the findings on bidirectional capacity at one-way flagging operations. That capacity ranges between 350 vehicles per lane per hour and 850 vehicles per lane per hour depending on the flagging zone length and percent trucks

These recommendations were utilized to develop the implementation plan for this study, described in Section 6.2 below.

6.2 Implementation Plan

The recommended Implementation Plan regarding one-way flagging was developed in conjunction with UDOT based upon the conclusions and findings in this study, as well as the recommendations listed in Section 6.1.

Standards should be created for when one-way flagging operations may be performed. That is, one-way flagging operations should only be performed when the expected traffic volume is below capacity. The capacity values used for this determination are based on the findings and recommendations of this study. Where the roadway grade, percent trucks, or flagging-zone length values are between the values presented in these scenarios, interpolation may be used to determine an appropriate capacity value. Unique one-way flagging operation scenarios, including locations with multiple major approaches should use the headway and clearance time values determined by this research to determine capacity of the operation, and may be used for simulation analysis of multiple scenarios.

REFERENCES

Cassidy, M. J. and L. D. Han. (1993). Proposed Model for Predicting Motorist Delays at Two-Lane Highway Work Zones. Journal of Transportation Engineering. 119(1). https://doi.org/10.1061/(ASCE)0733-947X(1993)119:1(27)

FHWA. (2009). Manual on Uniform Traffic Control Devices (MUTCD) Chapter 6C: Temporary Traffic Control Elements. Federal Highway Administration. https://mutcd.fhwa.dot.gov/htm/2009/part6/part6c.htm

FHWA. (2017). Guidelines for Temporary Traffic Control in Work Zones. Federal Highway Administration. https://trid.trb.org/View/1126663

Finley, M. D. and L. Theiss. (2017). Field Evaluation of Pilot Vehicles and Portable Traffic Control Signals With and Without a Flagger. Transportation Research Record: Journal of the Transportation Research Board. 2617(1). https://doi.org/10.3141/2617-01

Hawkins, N. and S. Knickerbocker. (2017). Field Measurements on the Effect of Temporary Rumble Strips in Work Zone Flagging Operations. Midwest Transportation Center. https://trid.trb.org/View/1467824

Hua, X., Wang, Y., Yu, W., Zhu, W. and W. Wang. (2019). Control Strategy Optimization for Two-Lane Highway Lane-Closure Work Zones. Sustainability. 11(17). https://doi.org/10.3390/su11174567

Kettle, S. (2017). Distance on a sphere: The Haversine Formula. ESRI Community. https://community.esri.com/t5/coordinate-reference-systems-blog/distance-on-a-sphere-the-haversine-formula/ba-p/902128#:~:text=All%20of%20these%20can%20be,longitude%20of%20the%20two%20points.

Qi, Y., Srinivasan, R., Teng, H. and R. Baker. (2012). Analysis of the Frequency and Severity of Rear-End Crashes in Work Zones. Traffic Injury Prevention. 14(1). 61-72. https://doi.org/10.1080/15389588.2012.675109

Schrock, S. D., Patil, S. S. and E. J. Fitzsimmons. (2016). Portable Traffic Signals in Conjunction with Pilot Car Operations at Two-Lane, Two-Way Rural Highway Work Zones. Transportation Research Record. 2555(1). https://doi.org/10.3141/2555-0

Terhaar, E. F. (2014). Implementation of Automatic Flagger Assistance Devices (AFADs) for Minnesota Department of Transportation Flagger Operations. Minnesota Department of Transportation. Report No. MN/RC 2014-44.

Terhaar, E. F. (2017). Development of a Moving Automatic Flagger Assistance Device (AFAD) for moving work zone operations. Minnesota Department of Transportation. https://trid.trb.org/View/1464672

Thiess, L., Finley, M. D., Rista, E. and G. L. Ullman. (2022). Evaluation Of End-Of-Queue Crash Mitigation Strategies at Flagging Stations on Two-Lane Roads. Texas Department of Transportation. FHWA/TX-23/0-6998-R1

Ullman, G. L., Levine, S. Z., and S. C. Booker. (1987). Flagger Safety and Alternatives to Manual Flagging. Texas State Department of Highways and Public Transportation. FHWA/TX-87/38+406-lf

Washburn, S. S., Hiles, T. and K. Heaslip. (2008). Impact of Lane Closures on Roadway Capacity: Development of a Two-Lane Work Zone Lane Closure Analysis Procedure (Part A). Florida Department of Transportation. https://trid.trb.org/View/851649

<u>APPENDIX A: Full One-Way Flagging Survey Results</u>

Appendix A contains full results from the survey which was administered to gain information on one-way flagging practices at other state DOTs. See Section 3.2 in this report for a summary of this survey.

The following describes survey results, organized by question. The question is displayed in italics, while the possible answers for respondents (if applicable) are in a lettered list below the corresponding question. For multiple choice questions, a chart containing response statistics is included. For open-ended questions, the response per agency is included in a list to highlight individual data. A brief summary of responses from the survey is included with each question. With this method, survey responses can be compared and contrasted to highlight trends, similarities, and differences between agencies and their one-way flagging operations.

1) Does your DOT have an established, agency-wide process for determining if and when one-way flagging operations should be used in construction or maintenance projects?

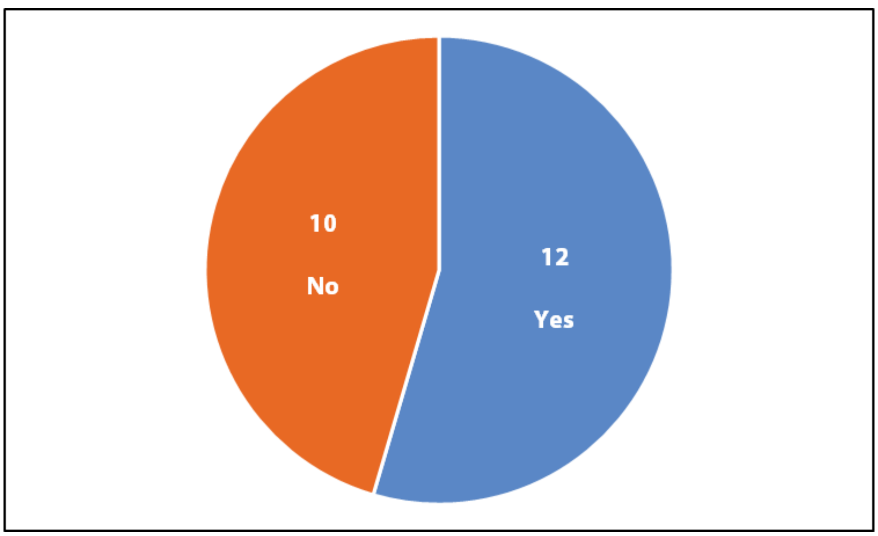

Figure A.1 Question 1 Response Statistics

12 of 22 responses confirmed that their organization has agency-wide one-way flagging processes which determine how operations should be carried out during construction or maintenance projects. Ten responses indicated that they do not have agency-wide processes. This

response indicates a nearly even split between agencies with and without established processes for one-way flagging.

2) [If question 1 = 'Yes'] Does this process include evaluating the operational performance (expected delay, queues, or traffic volumes) of the one-way flagging operation?

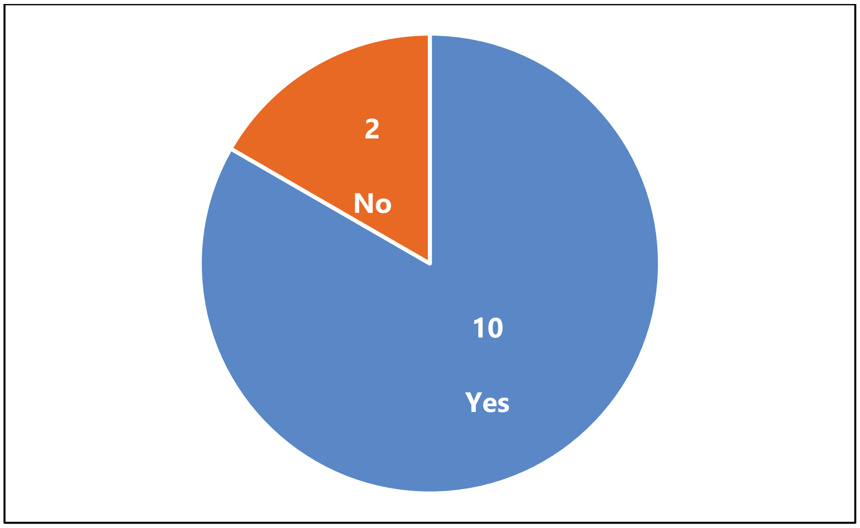

Figure A.2 Question 2 Response Statistics

Among the 12 responses which confirmed that their agency has an established one-way flagging process, ten indicated that the process includes evaluation of operational performance, suggesting a majority of agencies include such evaluations within their typical procedures. This includes evaluating expected delays, expected queuing, planning for traffic volumes, and other aspects of operational performance. The two responses which said their agency did not include operational performance evaluations within one-way flagging processes came from MODOT and VTrans.

3) [If question 2 = 'Yes'] What delay, queue, or volume guidance or policy documents are used to determine if one-way flagging should be used?

The ten responses which confirmed they have established agency-wide one-way flagging procedures and use operational performance evaluations as part of such processes have a wide range of documents and guidance which determine if one-way flagging should be used. A common guiding factor for one-way flagging operations appears to be Average Annual Daily

Traffic (AADT) values and historical traffic counts. Several states including Louisiana, Maine, New York, South Carolina and Virginia directly cite traffic count values in their guidelines for one-way flagging. Outside of this, however, guidelines may differ by state. A variety is seen in the level of detail on guidelines and standards for one-way flagging use. Agencies such as MaineDOT, VDOT, and WSDOT have developed processes explicitly stated in manuals with higher details which guide one-way flagging use, while the other DOTs stated that factors such as AADT (or other traffic volumes) determined if one-way flagging should be used without reference to specific standards. It can be assumed that agencies will generally evaluate AADT and other traffic counts to determine if one-way flagging should be utilized, but there is more variability in how detailed these guidelines will be. Responses from agencies are listed below.

Responses:

- ARDOT: No formal policy documents. Provide time limit restrictions for lane closures on construction projects as needed based on traffic volumes. Try to limit single lane closures to off-peak hours when possible.
- CalTrans: Safety
- GDOT: non-peak times
- LADOTD: We limit the work zone length according to ADTs
- MaineDOT (1): Essentially any sort of traffic impact, flaggers would be used. Some cases detours, or for long-term concerns temporary signals may be needed.
- MaineDOT (2): Every project is required to go through a TAMEing (Traffic Analysis and Movement Evaluation) process that establishes restrictions on time of day, number of lanes, work zone length, etc. For higher volume roads internal tools have been developed based on the HCM to assist in making these decisions. These tools primarily use historical traffic counts and adjustment factors to help calculate delays.
- NYSDOT: AADT

- SCDOT: Prohibited when volumes are greater than 800 vehicles per hour. The maximum time a direction can be stopped is 5 minutes for lengths of 1 mile or less and 7.5 minutes for lengths between 1 to 2 miles.

- VDOT: The VA Work Area Protection Manual (VWAPM - VDOT's version of Part 6 of the MUTCD) does not explicitly set delay/queue/volume thresholds for flagging, but we do state that flaggers should not stop traffic more than 8 minutes on roads > 500 ADT or more than 12 minutes on roads < 500 ADT. If stoppages of greater duration are unavoidable due to emergency situations, then PCMSs or additional static signs should be deployed. Also, Districts will sometimes use capacity analysis to set Allowable Work Hours for paving contracts; for example, on higher-volume two-lane roads, we might restrict paving work to overnight hours based on the capacity analysis (typically done just using simple spreadsheet-based calculations using HCM or similar methods.)

- WSDOT: See WSDOT Traffic Manual Exhibit 5-10 for capacities. See Section 5-6 through 5-8 for queue and extended/long-term closure information. We'll queue mitigation systems (typically mini-PCMS 1 mile in advance) to inform approaching traffic to WATCH 4 STOPPED TRAFFIC).

4) [If question 2 = 'No'] How are one-way flagging processes managed by the DOT?

Agencies without agency-wide standards for one-way flagging or who do not incorporate operational evaluations to determine when one-way flagging should be used were asked how their processes are managed by the DOT when one-way flagging may be needed. Responses to this question were very diverse. In some cases, while there may not be a centralized process for one-way flagging overall, there are still documents which agencies use to manage one-way flagging. For example, MODOT has an Engineering Policy Guide (EPG) and NCDOT uses roadway standard drawings and specifications along with traffic volumes. In many cases, agencies indicate that the Project Manager (PM) or project crew in conjunction with the PM are responsible for determining one-way flagging based on specificities of each project. Of note, KYTC is currently developing a policy for one-way flagging (the current process varies by location), and KDOT indicated that they do not use any one-way flagging. Overall, procedures vary by state or agency (and often by project) when the state or agency has no centralized procedure for one-way flagging operations or for determining when one-way flagging should be used.

Responses:

- ADOT: Project Team during Project Development determines if Flagging, AFAD, or Temp Traffic Signal should be used based on experience and Project Type. Most are managed by Construction, some by District Maintenance.
- CalTrans: Field Supervisors
- DelDOT: Typical Applications are used as they are needed for the roadway configuration.
- KDOT: KDOT does not utilize one-way flagging.
- KYTC: Used at various locations but policy is under development.
- MDOT: paid for on a per project basis via a bid item.
- MODOT: MoDOT's Engineering Policy Guide (EPG) establishes the guidelines for one-way flagging.
- MDT: They are managed at the project level by the PM.
- NCDOT: Contractors follow a roadway standard drawing and standard specification. We have a general rule of thumb for traffic volumes that are acceptable.
- SDDOT: The decision on whether to use one-way flagging is decided by the crew performing the work based on past experience with traffic volumes at each specific location.
- DOT&PF: Individually by each work zone foreman, engineer, permitting officer, etc.
- VTrans: They are part of the provided TMP when MUTCD compliant conditions allow.

5) Are the percentage of heavy trucks or presence of steep grades ever considered when determining if one-way flagging operations should be used?

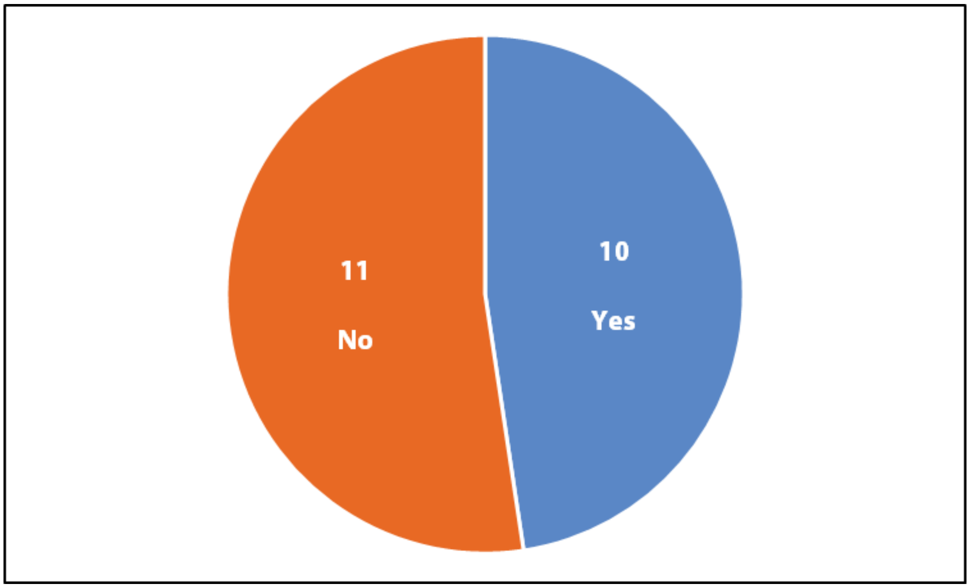

Figure A.3 Question 5 Response Statistics

The presence of heavy truck volumes or steep grades is an important consideration in one-way flagging, particularly for reasons of safety of the overall operation. Survey respondents were asked whether there is consideration of heavy truck presence or steep grades in determining if one-way flagging should be used. The responses show a nearly even split, with ten responses indicating that their agencies do consider these conditions, while eleven indicated that they do not.

6) [If question 5 = 'Yes'] How do heavy trucks and/or grades determine the use of one-way flagging operations?

The ten responses which confirmed that their agencies do consider heavy truck volumes and grades were asked for more detail on how they integrate these concerns into one-way flagging decisions. Although there are no consistent processes between agencies, trucks and grades are considered on a case-by-case basis. ADOT and WSDOT specified certain grade percentages considered in the decision process, which influence where stations are located and how lanes are closed. DOT&PF and SDDOT indicated that significant grades or trucks will lead to discouragement of one-way flagging use. WSDOT also noted that one-way flagging is not used on heavy-truck corridors due to safety concerns. A common thread is that agencies which consider grades and trucks often take a case-by-case basis approach, considering grades above a certain point, and perhaps avoiding flagging on corridors with a high volume of heavy trucks.

Responses:

- ADOT: Grades greater than 2% - 3% will be taken into consideration when locating a flagging station.
- CalTrans: Additional buffer zones.
- DOT&PF: The presence of heavy truck traffic or steep grades discourage the use of single flagging operations. Their inherent impact to visibility also impacts other flagging operations.
- MaineDOT: They do not determine the use of, but where the flagger stations should be set.
- MDOT: The entire work area and volumes play a role in the MOT, there is not a specific number but could be a factor.
- NCDOT: There is nothing hard and fast, but it is considered and discussed ahead of time.
- NYSDOT: optional increased protection w/ attenuator
- SDDOT: The crew takes this into account when deciding if they should use one-way flagging at a location.
- VDOT: If the District uses capacity analysis to determine Allowable Work Hours for a paving contract, then I believe trucks and grades would be some of the inputs used in that analysis. Note: VDOT maintains almost all roads in Virginia's Counties, including low-volume secondaries and residential subdivision streets that typically carry low traffic volumes. On such roads, most Districts likely don't bother with capacity analysis; they

would only take that step for higher-volume roads such as roads functionally classified as arterial or major collector.

- WSDOT: For grades 5% or more, we'll move the flagging operation with pilot car to the top of the downgrade. If available, we'll close the left upgrade passing lane and shift the downgrade lane over into it to avoid having to stop traffic. Practice varies from Region to Region, but it's our guidance at statewide level. On other heavy-truck corridors (SR18 over Tiger Mountain, 6% grade) we do not flag traffic—instead, we close the roadway directionally or completely.

7) What department/individuals are responsible for oversight of one-way flagging operations?

While there is some variation in the oversight of one-way flagging among agencies, the most common approach involves construction and maintenance departments, with traffic engineering/management departments also often engaged. Another common response is joint responsibility between construction/maintenance and traffic management departments. While some agencies stress collaboration between multiple individuals or departments, including with those directly involved at the site, there are others where responsibility rests solely on one department, or even one individual.

<u>Responses:</u>

- ARDOT: District Admin, Resident Engineer, or Area Maintenance Supervisor

- ADOT: Construction; Maintenance, both roadway and traffic systems divisions.

- CalTrans: Maintenance Field Supervisor

- DelDOT: Inspection teams with Construction, Public Works, and Maintenance. Additional oversight is provided by supervisors, Traffic Operations, and Traffic Safety.

- DOT&PF: Each individual operations supervisor (Project Engineer, M&O Foreman, ROW Agent, etc.).

- GDOT: State Construction Office (policy) and District Construction (compliance).
- KDOT: Traffic Engineering - Nick Rogers
- KYTC: Occupational Safety & Construction
- LADOTD: The contractors TCS
- MaineDOT (1): Jointly with the Contractor and Construction Inspection Staff.
- MaineDOT (2): TAMEing is done by a traffic engineer. Crew supervisors and flaggers are all flagger-certified internally.
- MDOT: Project level inspectors or maintenance supervisors (for internal)
- MODOT: Maintenance and Construction
- MDT: Project managers and work zone safety engineer
- NCDOT: Resident Engineer's Office
- NYSDOT: Maintenance/Traffic Safety & Mobility/Construction
- SCDOT: State Work Zone Engineer
- SDDOT: The individual crews, Operations Support
- VDOT: VDOT Central Office Traffic Operations Division is responsible for the VWAPM, flagging/AFAD/portable signal policies, and flagger/work zone certifications. Individual VDOT Districts oversee permitting, inspecting, and implementing individual flagging operations (including work by in-house forces, contractors, or utility companies or other permittees).
- VTrans: Construction - Resident Engineer or District personnel
- WSDOT: Region Transportation Operations (Region Traffic) has authority. They'll contact State Work Zone Engineer for guidance as needed.

8) What general flagging method is utilized by the DOT (select all that apply)?

- Human flagger control of the zone
- Automated Flagger Assistance Device (AFAD)
- Temporary traffic control devices/signal control of the zone
- Other (please specify)

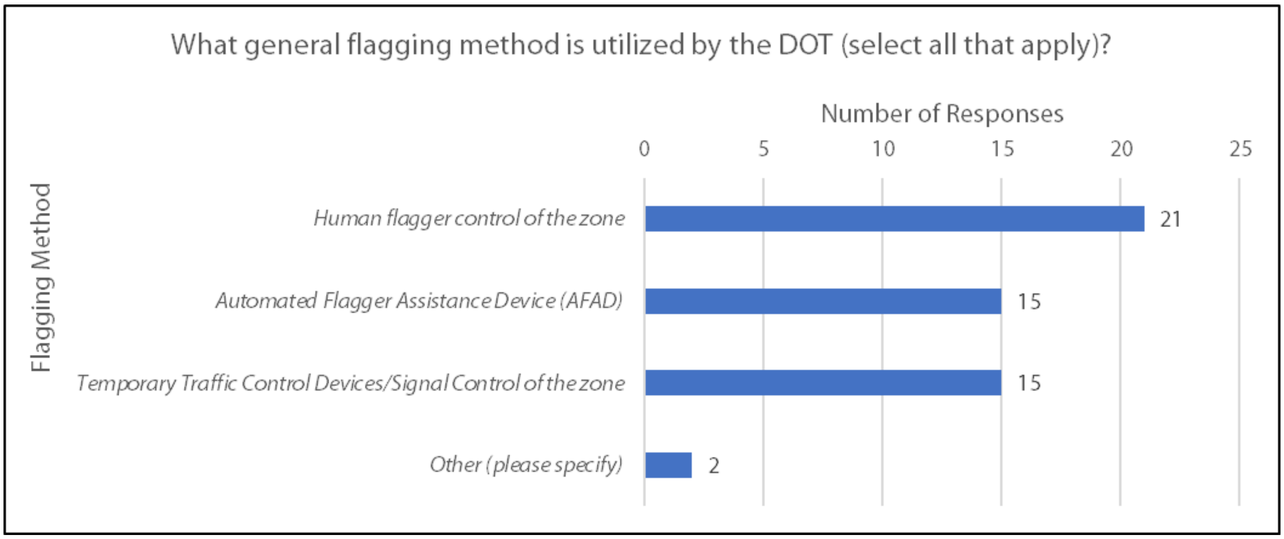

Figure A.4 Question 8 Response Statistics

With use by all agencies, human flagging is the dominant method of one-way work zone control. Fifteen of the responses indicated that they also use AFAD and Temporary Traffic Control/Signal Control Devices. Two 'other' responses included "Stop/Yield Control" from SDDOT and "Driveway Assistance Devices (FHWA Test)" from VTrans.

9) What strategies or treatments does your agency use for one-way flagging that you feel contribute to the safety of one-way flagging operations?

Responses show that agencies employ a wide variety of practices regarding strategies and treatments to improve safety. There appears to be no general trends in the responses, with some strategies including pilot vehicles, speed reduction zones, additional oversight of one-way flagging zones, increased use of AFAD devices, and others. Some agencies indicated that safety considerations may change based on location. For example, DOT&PF considers even the presence of foliage along roadways, while VTrans implements speed reductions based on design criteria of roadways being constructed. A few agencies indicated using the Manual on Uniform Traffic Control Devices (MUTCD) as a guideline for improving safety conditions in one-way flagging zones; VDOT implements even stricter standards than the MUTCD to ensure all needs are met. Another common strategy is the use of temporary rumble strips in one-way flagging zones. Overall, many options are available to improve safety, and their use varies significantly from agency to agency.

Responses:

- ARDOT: Use of pilot vehicles controls speed through work zone. Primarily used on chip sealing projects and roadways with hilly/curvy terrain.
- ADOT: Speed reductions, transverse rumble strips, and additional law enforcement.
- CalTrans: Our flaggers wear Class 3 apparel at all times, and we utilize AFADs when available. We also have our Maintenance Zone Enhanced Enforcement (MAZEEP) program that allows us to have a uniformed officer in a marked vehicle at our job site.
- DelDOT: MUTCD typical applications. We are in the early stage of using portable rumble stripes.
- DOT&PF: Ensuring visibility. Due to foliage along most of our rural two-lane, two-way roads, the visibility available changes in Alaska depending on the time of year.
- LADOTD: Reduced speed limits
- MaineDOT (1): Visibility is key, proper advanced warning signs and, for night work, light plants at the flagger station.
- MaineDOT (2): All work zones are MUTCD compliant. Traffic calming options such as radar feedback signs, work zone speed limits, and temporary rumble strips are used as needed, generally on higher volume/speed roadways.

- MDOT: Temporary Rumble Strips, pilot cars
- MODOT: Use of the automated flagger keeps the boots off the ground.
- MDT: Rumble strips in the advanced warning. We have moved mostly to using signal controlled by a pilot car as well.
- NYSDOT: Standard Sheets have options for increased protection.
- SCDOT: Flagger Training, approved traffic control devices
- SDDOT: Vehicle-mounted oscillating lights, channelizing devices, advance warning signs.
- VDOT: VDOT has several requirements stricter than the MUTCD, including: (1) requiring 24" paddles (flags only allowed in emergency situations); (2) requiring flaggers to stand off to the side of the road; (3) prohibiting use of distractions like cell phones or Bluetooth earbuds; (4) stating that flaggers should be given 15-minute breaks every 2 hours; (5) require at least limited English proficiency; (6) require hard hats, zipped-up class 3 vests, hi-vis leg garments, and steel-toed shoes. We are transitioning to a new mandate to require ATSSA flagger certification starting in 2025 and are currently piloting changed specifications language to encourage use of AFADs. We are also exploring ways to promote/encourage portable "cart" signal use but remain concerned about potential for misuse.
- VTrans: Depending on the location, temporary speed reductions are sometimes used based on design criteria needed for the roadway to be constructed.
- WSDOT: We now have Typical TCPs with Temporary Portable Rumble Strips for Flaggers & AFADs (Series TC320s & TC330s for 45+ mph) to help alert approaching drivers. On temporary signal ops, we use adhesive temporary rumble strips (see TC340 and TC341). WSDOT Typical TCP Library: https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/plan-sheet-library/work-zone-typical-traffic-control-plans-tcp

10) Please select any safety-related issues your DOT experiences regarding one-way flagging operations (select all that apply)?

- Speeding vehicles
- Drivers entering the one-way zone despite being told to stop
- Equipment malfunctions
- Communication between flaggers/devices
- Sight distance issues in flagging zone
- Sight distance issues at the end of the queue to enter flagging zone
- Other (please specify)

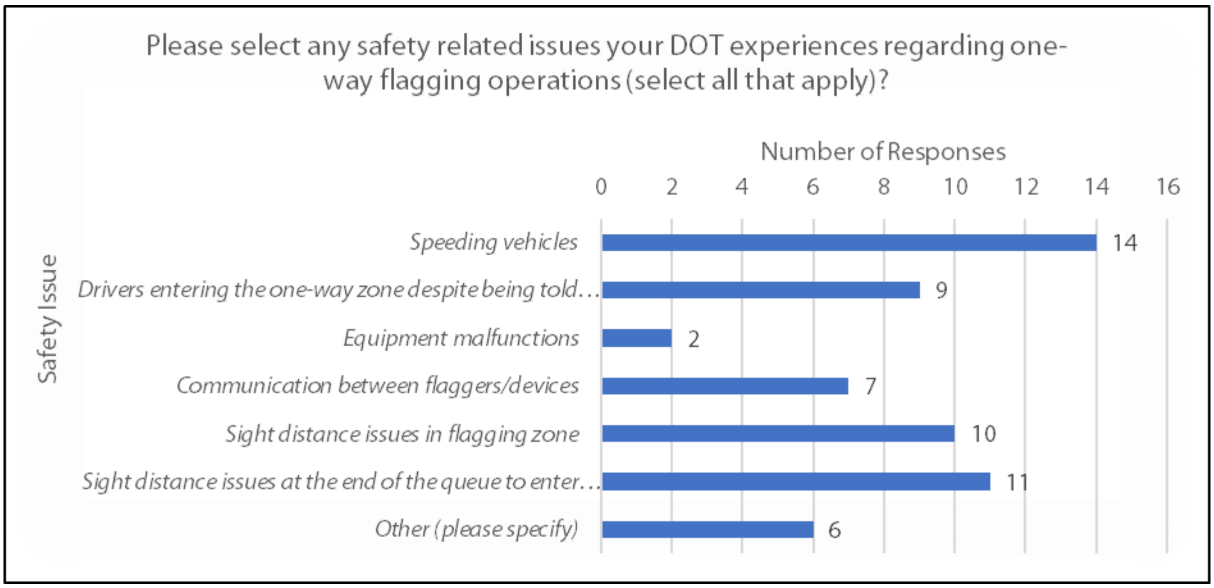

Figure A.5 Question 10 Response Statistics

Agencies were asked to identify common safety-related issues experienced during one-way flagging operations which may pose a risk to personnel at the site. The most common issue is speeding vehicles, identified by 14 responses. Other common problems include sight distance issues at the end of the queue (11 responses), general sight distance issues in the flagging zone

(10 responses), and drivers entering the one-way zone despite being told to stop (nine responses). Equipment malfunctions were the least selected issue (two responses). Six responses provided 'other' issues they experience, five of which cited distracted drivers. Two responses meanwhile noted that distractions for flaggers also cause serious safety issues. Distractions for drivers (and to a lesser extent, human flaggers in control of the zone) should be considered a notable safety issue, given that all the 'other' responses indicated some sort of distraction as the issue.

11) What strategies or treatments does your agency use for one-way flagging that you feel contributs to effective one-way flagging operational performance?

Like other open-ended questions, responses for strategies and treatments that lead to effective one-way flagging operational performance varied substantially. Options include the use of speed limit reductions in the zone, use of rumble strips, additional lights and cameras, and use of high visibility equipment and specialized equipment by personnel at the site. Several agencies specifically referenced the importance of proper training for one-way flagging crews, to ensure that personnel are prepared to carry out the proper operations onsite. These responses overall were similar to those given about safety strategies, illustrating an important overlap between strategies to improve safety and those to improve operations.

<u>Responses:</u>

- ARDOT: Keep lane closure/work zone to minimum distance necessary.
- ADOT: Speed reductions, transverse rumble strips, additional law enforcement.
- CalTrans: Our flaggers wear Class 3 apparel at all times, and we utilize AFADs when available. We also have our Maintenance Zone Enhanced Enforcement (MAZEEP) program that allows us to have a uniformed officer in a marked vehicle at our job site.
- DOT&PF: Ensuring visibility and most are not confident in their ability to correctly use the single flagger method. We typically see multiple flaggers used and the single flagger method is rare.
- GDOT: Signage, use of cones, personnel safety attire for flagger

- LADOTD: Using only ANSI CLASS 2 lime green vest.
- MaineDOT (1): Daily monitoring by the Contractor and DOT Staff. Adjusting operations or locations to enhance safety.
- MaineDOT (2): Flagger training, situational awareness on when to use flaggers versus temporary signals.
- MDOT: Temporary Rumble Strips, increasing the amount of AFADs in use.
- MODOT: Traffic can be held a maximum of 15 minutes on lower volume routes.
- MDT: Smart signals and end of queue protection systems.
- NYSDOT: Many options. Hoping to add cameras soon.
- SCDOT: Flagger training, advance warning signs.
- SDDOT: Vehicle-mounted oscillating lights, channelizing devices, advance warning signs.
- VDOT: See response to question #11.
- VTrans: Speed reductions are necessary, managing length of lane closure to be as short as possible so as not to introduce additional queues. Limiting lane closures to off-peak traffic flow.
- WSDOT: Pilot car operations to control speed and direct vehicles within work zone (also provides accommodations to peds + bicycles). If workers on bridge or paving crew working at/near centerline—pilot car slows to 5 mph or so. Also gives ability to deal with wrong way drivers—typically coming out of driveways.

12) Please select any traffic operation-related issues your DOT experiences regarding one-way flagging operations (select all that apply)?

- Long queues
- Long delays
- Imbalanced performance (one entering direction experiencing short wait times and short queues while the other direction experiences long wait times and long queues)
- Other______________________

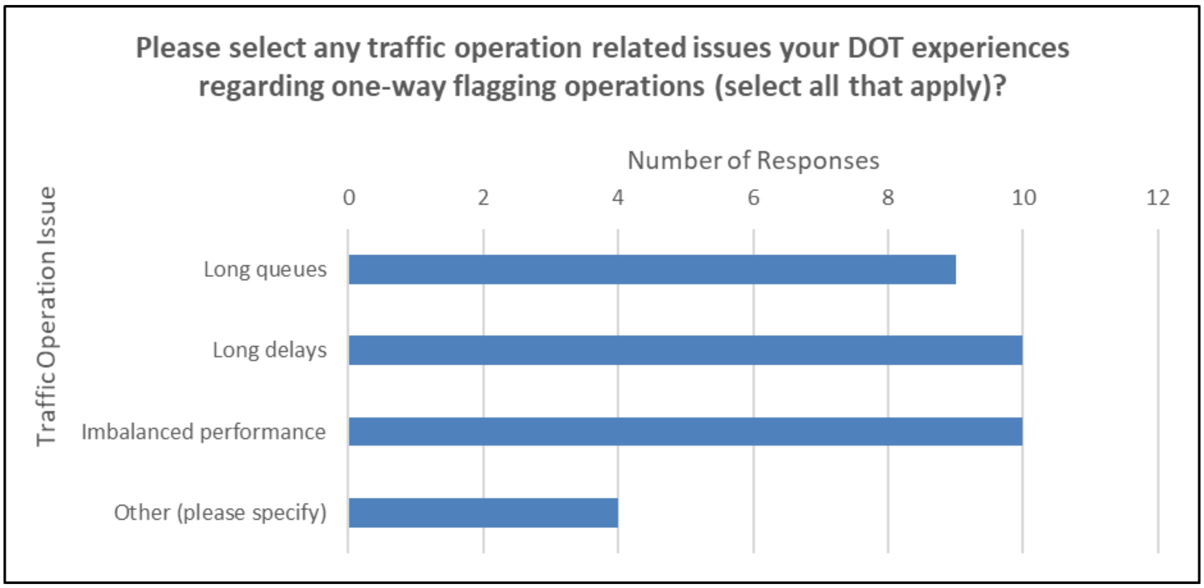

Figure A.6 Question 12 Response Statistics

Regarding traffic operation issues during one-way flagging processes, responses were split fairly evenly between long queues (nine responses), long delays (10 responses), and imbalanced performance (10 responses). This indicates that issues of delay, queuing, and imbalanced performance are experienced universally during one-way flagging operations. Four responses indicated that other issues occur. Two of these noted that a common issue is unsafe flagger behavior, while another discussed issues that may occur due to giving one direction priority over another. The final 'other' comment was from DOT& PF, who indicated that they rarely use single-flagger setups and don't experience issues related to that situation.

13) Has the DOT previously collected or reviewed any performance data for one-way flagging procedures?

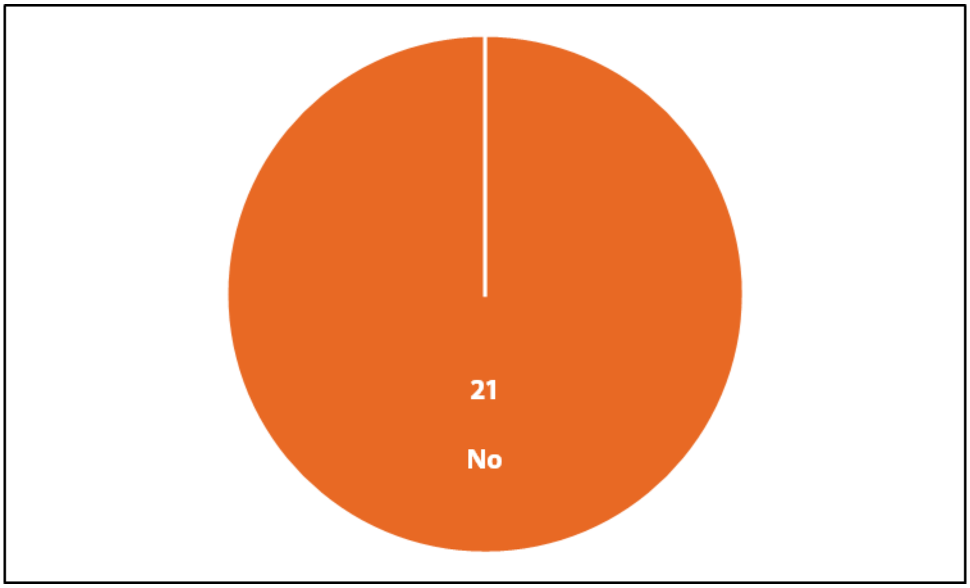

Figure A.7 Question 13 Response Statistics

No agency indicated that they have collected and analyzed any performance data for one-way flagging procedures. This shows there is strong potential for new developments in understanding one-way flagging performance and providing useful benefits from generating improved procedures.

14) [If question 13 = 'Yes'] Please identify what type of data was collected and how this data is used.

Responses: N/A

15) Has the DOT used simulation modeling in evaluating the performance of one-way flagging operations?

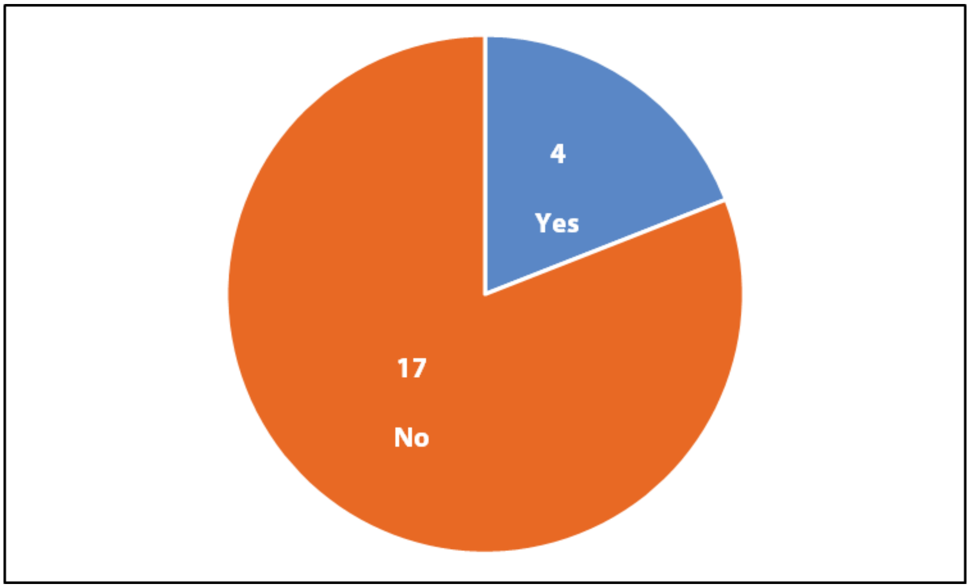

Figure A.8 Question 15 Response Statistics

Four responses have used simulation models to evaluate performance of one-way flagging methods. While this indicates that at least some agencies have considered advanced modeling and analysis for one-way flagging evaluation, it has not been widely adopted. There is potential for more agencies to utilize modeling to improve one-way flagging procedures.

16) [If question 15 = 'Yes'] What parameters were used to calibrate the simulation model?

Regarding calibration parameters, responses varied among the four agencies which utilize modeling. MDOT provided a link to notes on calibration of 'Construction Congestion Cost (CO3). CO3 measures impacts of variables such as delay, diverted vehicles, etc., while also examining the sum of traffic impacts compared with construction costs. MaineDOT indicated they use Synchro SimTraffic programs for calibration (though this is not common). VTrans meanwhile limits traffic volumes and lane closure lengths to calibrate models. DelDOT did not expand on what calibration is utilized. These responses indicate that the exact calibration methods vary among the few agencies that utilize modeling.

<u>Responses:</u>

- DelDOT: Modeling
- MDOT: https://www.michigan.gov/mdot/business/construction/co-analysis - see flag link to file with notes.
- MaineDOT (2): Synchro SimTraffic has been used to model alternating one-way traffic flow but is not common.
- VTrans: Limiting traffic volumes, limiting length of lane closure.