# EVALUATION OF THE VIKING-CIVES TOWPLOW FOR WINTER MAINTENANCE


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*Prepared for*:
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| To maximize efficiency while minimizing costs within ODOT's winter maintenance budget, ODOT is evaluating new methods of snow and ice removal. One method is the use of the Viking-Cives TowPlow. The TowPlow is pulled behind a tandem axle truck and has the ability to treat an additional lane. A thorough evaluation of the TowPlow is conducted to determine the feasibility for implementation into an ODOT garage, including: level of service (LOS), equipment usage in different types of weather, and impacts on the traveling public. To successfully evaluate the TowPlow, three main areas of data (weather, utilization, and speed data) are collected from three counties that used the TowPlow in the 2013–2014 winter season. It is observed that the TowPlow causes slightly higher delays to motorists during all storm severities, except in heavy snow, when the TowPlow's delay is equal to that of the standard truck. There is an annualized cost savings averaging $22,551 when compared to the equivalent standard trucks needed to match the TowPlow's ability. | | |
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- Mr. Paul Ensinger, ODOT District Four Roadway Services Engineer
- Mr. Brian Olson, ODOT District Four Area Maintenance Engineering
- Mr. Mark Griffiths, ODOT District Four Portage County Transportation Administrator

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The authors additionally would like to extend a special thanks to Viking-Cives for all the insight and help provided throughout the course of the project.

| Customary Unit | SI Unit | Factor | SI Unit | Customary Unit | Factor |
|---|---|---|---|---|---|
| Length | | | Length | | |
| inches | millimeters | 25.4 | millimeters | inches | 0.039 |
| inches | centimeters | 2.54 | centimeters | inches | 0.394 |
| feet | meters | 0.305 | meters | feet | 3.281 |
| yards | meters | 0.914 | meters | yards | 1.094 |
| miles | kilometers | 1.61 | kilometers | miles | 0.621 |
| Area | | | Area | | |
| square inches | square millimeters | 645.1 | square millimeters | square inches | 0.00155 |
| square feet | square meters | 0.093 | square meters | square feet | 10.764 |
| square yards | square meters | 0.836 | square meters | square yards | 1.196 |
| acres | hectares | 0.405 | hectares | acres | 2.471 |
| square miles | square kilometers | 2.59 | square kilometers | square miles | 0.386 |
| Volume | | | Volume | | |
| gallons | liters | 3.785 | liters | gallons | 0.264 |
| cubic feet | cubic meters | 0.028 | cubic meters | cubic feet | 35.314 |
| cubic yards | cubic meters | 0.765 | cubic meters | cubic yards | 1.308 |
| Mass | | | Mass | | |
| ounces | grams | 28.35 | grams | ounces | 0.035 |
| pounds | kilograms | 0.454 | kilograms | pounds | 2.205 |
| short tons | megagrams | 0.907 | megagrams | short tons | 1.102 |

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# LIST OF ACRONYMS

BT – Bluetooth

BTN – Bluetooth Node(s)

DOT - Department of Transportation

DVR – Digital Video Recorder

FE – Fuel Economy

FHWA – Federal Highway Administration

GPS/AVL - Geographic Positioning System/Automatic Vehicle Location

I – Interstate

IN – inch(es)

LOS – Level-of-Service

M&R – Maintenance and Repair

MAC – Media Access Control

MPH – Miles per Hour

NOAA – National Oceanic and Atmospheric Administration

ODOT – Ohio Department of Transportation

SR – State Route

TowPlow – Viking-Cives® TowPlow and Truck towing TowPlow Trailer

UR – Utilization Rate

# CHAPTER I INTRODUCTION

Snow and ice management is the single largest expenditure in the maintenance budget for the Ohio Department of Transportation (ODOT), with an annual cost including labor, equipment, and materials reaching approximately $50 million (ODOT, 2011). Given the current financial climate, it is essential to minimize costs while simultaneously maximizing efficiency, especially for maintenance operations. Therefore, ODOT is evaluating new methods, equipment, and materials in order to reduce expenses in its winter maintenance budget. One piece of equipment that is being considered is the Viking-Cives® TowPlow (TowPlow), which is a tow behind trailer unit equipped with a 27-foot snow plow and either a salt hopper or a brine tank. The trailer is capable of rotating out to an angle of up to 30 degrees, allowing the plow to clear a second travel lane when pulled behind a truck fitted with a front plow.

Recently, the Ashtabula County garage in ODOT District 4 completed a pilot evaluation of the TowPlow (Griesdorn, 2011). The favorable initial results obtained from this evaluation have encouraged ODOT to pursue further research to compare the cost-effectiveness of using the TowPlow compared to the costs for using ODOT's current equipment and procedures for snow and ice removal. As with any new equipment, a thorough assessment of the TowPlow is needed to determine its effectiveness. The assessment should include the following metrics:

- Baseline travel speeds,
- Travel speeds during winter weather events,
- Data obtained from the manufacturer and from other evaluations of the TowPlow unit (i.e. truck specification for pulling TowPlow and public opinions of TowPlow),
- A survey of users of similar TowPlow units,
- Data analysis on the cost-effectiveness of utilizing the TowPlow as compared to ODOT's current snow and ice removal process,
- In-field performance evaluation of the TowPlow unit, which includes a cost–benefit analysis, maintenance, labor costs, equipment purchase costs, road level-of-service (LOS) factors, material usage, and environmental benefits, and
- Applicability assessment for utilization in ODOT's winter maintenance process (i.e. materials application guidelines and route application guidelines).

Travel speeds are recorded using Bluetooth data collection systems (BT). Once data are collected and analyzed, a cost–benefit analysis is performed to determine the potential for wider implementation of the TowPlow in ODOT's maintenance procedures.

## 1.1 Purpose and Objectives

The research team proposes that four objectives must be met to ensure that project PS-2013-12 *"Evaluation of the Viking-Cives® TowPlow for Winter Maintenance"* is considered a success. These four objectives include:

- Objective 1 - Evaluate existing data reports on the Viking-Cives® TowPlow unit including evaluations performed in Maine, Missouri, New Hampshire, North Dakota, and Wisconsin (at a minimum),
- Objective 2 - Assess the in-field performance of the Viking-Cives® TowPlow,
- Objective 3 - Perform a cost–benefit analysis of the Viking-Cives® TowPlow, and
- Objective 4 - Propose a deployment strategy for the Viking-Cives® TowPlow that is consistent with current ODOT practices.

The research team believes that meeting these four objectives, as well as meeting additional goals and guidelines identified during the course of the project, will ensure the success of this project.

## 1.2 Benefits from this Research

Several benefits are expected from the outcome of this project. One important benefit is the information ODOT may gain regarding the operation of the TowPlow. This knowledge may be used in the decision making processes for widespread incorporation of the TowPlow and other new technologies into ODOT's winter maintenance fleet.

## 1.3 Organization of this Report

This report is divided into seven chapters. Chapter 1 introduces the topic and includes a list of the research objectives. Chapter 2 presents the project setting, including details about ODOT's winter maintenance routes and equipment available at ODOT garages in and near the study area. Chapter 3 presents the research methodology employed to collect the appropriate data for use in the analysis. Chapter 4 summarizes the results from the data collection and presents a general summary showing how three ODOT TowPlows are utilized over the 2013–2014 winter season. Chapter 5 summarizes the speed data collected in Portage County to determine the LOS of the TowPlow as compared to a standard ODOT plow truck. Chapter 6 presents the calculation of costs associated with the TowPlow. Chapter 7 presents an implementation plan that includes the training of maintenance personnel in the proper use of the TowPlow and a conclusion based on the field data collected of the evaluation.

# CHAPTER II PROJECT SETTING

This chapter provides information about the geographical setting for the project as well as descriptions of the equipment used in this study, the selected ODOT routes within the test areas, and a description of the TowPlow unit. This chapter is divided into two sections:

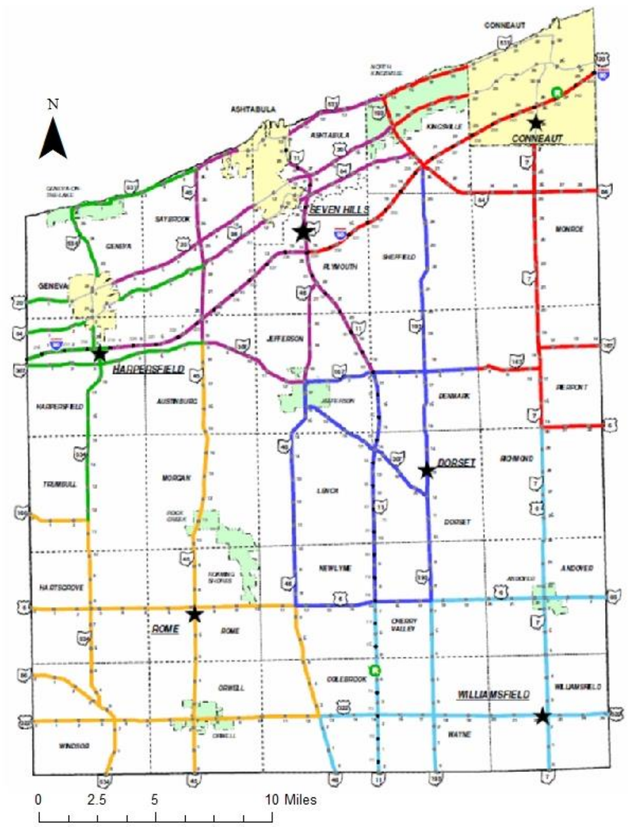
- Section One – Project Setting, and
- Section Two – Snow and Ice Removal Systems.

## 2.1 Project Setting

Due to the complexity of this project, which includes operational and weather-related components, the research team felt that it is beneficial to include evaluations of the TowPlows operating out of Ashtabula County and Mahoning County in addition to the evaluation of the TowPlow at Portage County. The three counties vary in how they implement the TowPlow within their fleets. The TowPlows in Mahoning County and Ashtabula County are used as a secondary truck, which is not assigned to a specific route and is therefore available to assist other ODOT trucks in snow and ice removal activities in areas where the highest snowfall is occurring during a particular storm. If there is little to no snowfall, the maintenance managers may choose not to deploy the TowPlow. In contrast, Portage County uses its TowPlow unit as a primary truck, and it is assigned to clear Interstate 76 (I-76), which runs in an east-to-west direction across the southern portion of the county.

### *2.1.1 Ashtabula County*

The main county garage in Ashtabula County is located in the Plymouth Township. In Ashtabula County, the ODOT maintenance routes are divided into six areas, which are presented in Figure 2.1.




Note: Please see Table 2.1 for more information. (Image provided by ODOT)
Figure 2.1: Ashtabula County ODOT Routes.

In addition to the main garage in Plymouth Township, ODOT has five additional posts, which are located in Conneaut, Dorset, Harpersfield, Rome, and Williamsfield. The main garage in Plymouth Township is referred to as Seven Hills Rd since the garage is located on Seven Hills Road. Table 2.1 shows the routes each garage and outpost is responsible for maintaining, the total lane miles maintained, and the number of trucks used for winter maintenance.

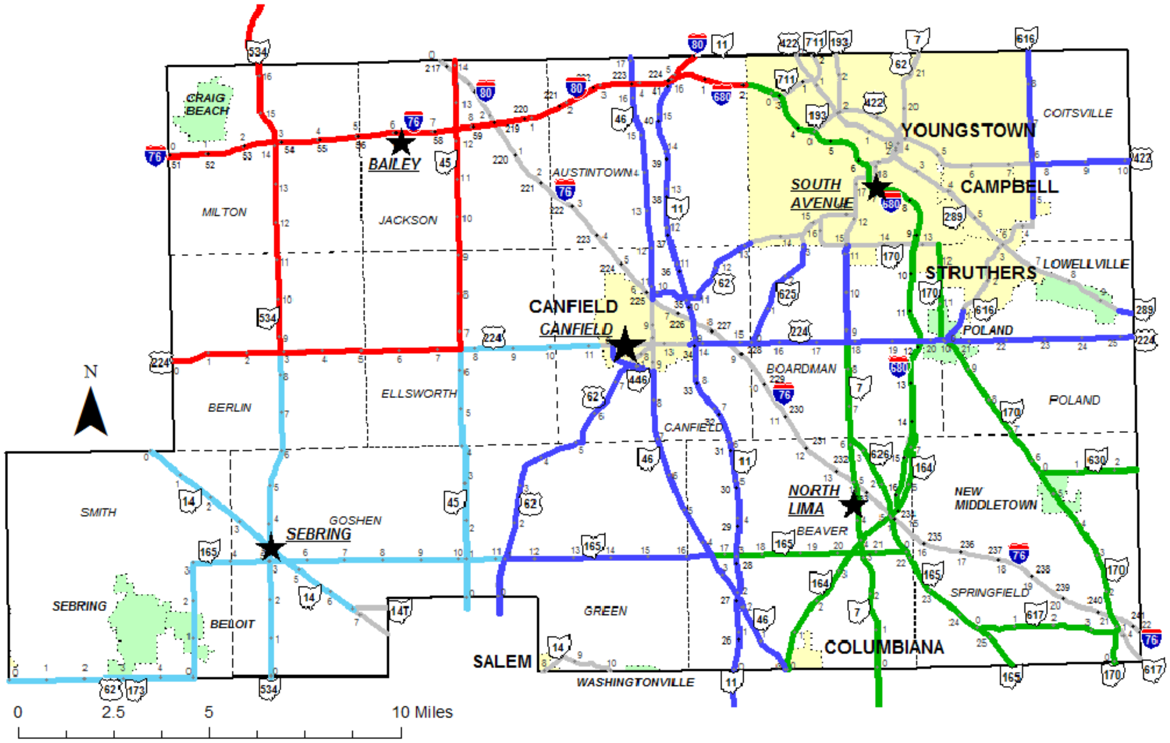
Table 2.1: Characteristics of the Garages and Routes Maintained in Ashtabula County.

| Garage | Color on Figure 2.1 | Routes Maintained | Lane Miles | Number of Snow Plow Trucks |
|---|---|---|---|---|
| Seven Hills Rd | Purple | SR-11, SR-167, SR-84, SR-167, US-20, SR-45, SR-531, SR-46, SR-307, and SR-531. | 160 | 6 |
| Conneaut | Red | I-90, SR-11, US-20, SR-193, SR-84, SR-531, US-6, SR-7, and SR-167. | 149 | 3 |
| Dorset | Dark Blue | SR-11, US-6, SR-46, SR-167, SR-193, and SR-307. | 142 | 3 |
| Harpersfield | Green | US-20, SR-84, SR-534, SR-531, I-90, and SR-307. | 89 | 3 |
| Rome | Yellow | US-6, SR-45, SR-46, SR-86, SR-534, US-322 and SR-166. | 128 | 4 |
| Williamsfield | Light Blue | SR-11, US-6, SR-7, SR-85, US-322, SR-46, and SR-193. | 122 | 3 |

The TowPlow unit in Ashtabula County is stationed at the Plymouth Township garage. As presented in Table 2.1, the Seven Hills Rd garage maintains the highest number of lane miles of all ODOT garages in Ashtabula County. However, the TowPlow may be used to assist in treating routes at the other ODOT garages.

### *2.1.2 Mahoning County*

The main county garage in Mahoning County is located in the city of Canfield. The ODOT routes in this county are divided into four areas, which are presented in Figure 2.2.




Note: Please see Table 2.2 for more information. (Image provided by ODOT)
Figure 2.2: Mahoning County ODOT Routes.

In addition to the main garage in Canfield, ODOT has three outposts, which are located in North Lima, Sebring, and Bailey. Table 2.2 shows the routes that are maintained by each garage, the total lane miles maintained, and the number of trucks used for winter maintenance.

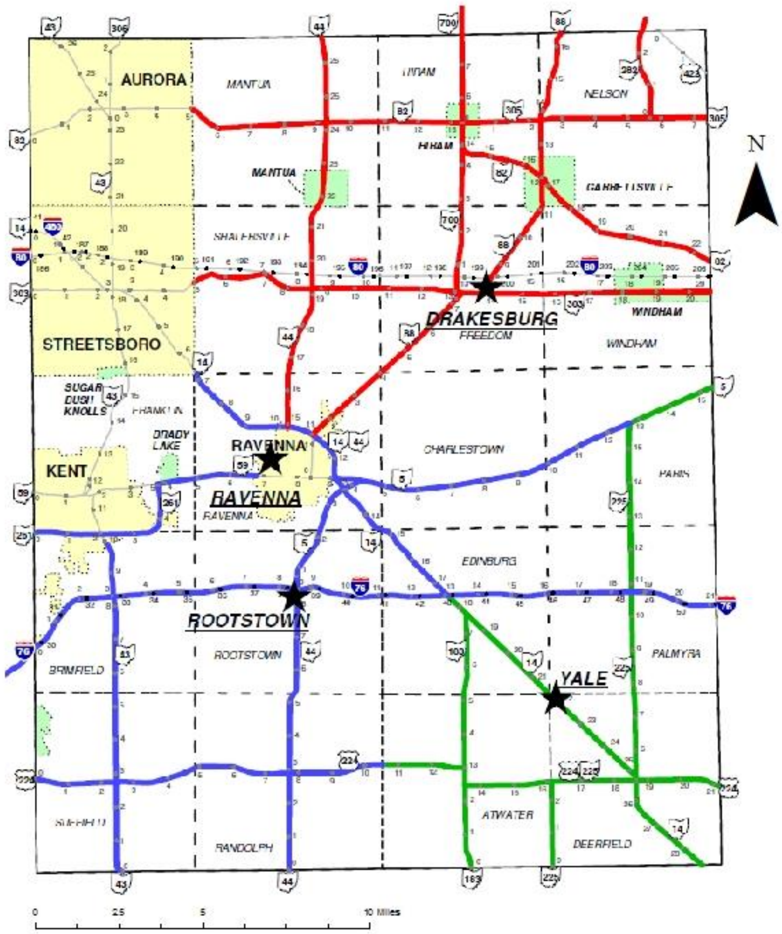
Table 2.2: Characteristics of the Garages and Routes Maintained in Mahoning County.

| Garage | Color on Figure 2.2 | Routes Maintained | Lane Miles | Number of Snow Plow Trucks |
|---|---|---|---|---|
| Canfield | Dark Blue | SR-11, US-224, I-80, SR-46, US-62, SR-446, SR-165, SR-625, SR-7, SR-616, and SR-289. | 249 | 6 |
| Bailey Rd | Red | I-76, I-80, I-680, SR-45, US224, and SR-534. | 131 | 3 |
| North Lima | Green | I-80, SR-46, I-680, SR-165, SR-7, SR-170, SR-617, SR-630, SR-7, SR-164, SR-165, SR-626, US-224, SR-711, US-62, US-422, and SR-193. | 183 | 5 |
| Sebring | Light Blue | US-224, SR-45, SR-165, SR-534, SR-14, and US-62. | 86 | 2 |

The TowPlow in Mahoning County is stationed at the Canfield garage. As presented in Table 2.2, the Canfield garage maintains the highest number of lane miles of all garages in Mahoning County. However, the TowPlow may be used to assist in treating routes at the other garages.

### *2.1.3 Portage County*

The main county garage in Portage County is located in the City of Ravenna. The ODOT routes are divided into three areas, which are presented in Figure 2.3.




Note: Please see Table 2.3 for more information. (Image provided by ODOT)
Figure 2.3: Portage County ODOT Routes.

In addition to the main garage in Ravenna, ODOT has two outposts, the Yale Outpost in Deerfield and the Drakesburg Outpost in Windham, as well as a salt storage dome located in Rootstown. Table 2.3 presents the routes each garage and outpost is responsible for maintaining, the number of lane miles maintained by each, and the number of trucks used for winter maintenance.

Table 2.3: Characteristics of the Garages and Routes Maintained in Portage County.

| Garage | Color on Figure 2.3 | Routes Maintained | Lane Miles | Number of Snow Plow Trucks |
|---|---|---|---|---|
| Ravenna | Dark Blue | I-76, SR-14, SR-59, SR-43, US-224, SR-44, SR-5, and SR-261. | 314 | 9 |
| Drakesburg | Red | SR-82, SR-305, SR-700, SR-303, SR-88, SR-282, and SR-44. | 161 | 4 |
| Yale | Green | SR-14, US-224, SR-183, SR-225, and SR-5. | 87 | 3 |

The TowPlow is stationed at the Ravenna garage. As presented in Table 2.3, the Ravenna garage maintains the most lane miles when compared to the other garages in Portage County. The TowPlow is used as a primary truck for treating I-76, a four-lane divided highway that runs east to west across Portage County.

## 2.2 Snow and Ice Removal Systems

This section provides more detail regarding the snow and ice removal systems employed by ODOT, including a comparison of the standard ODOT systems and the TowPlow system as well as discussion regarding the implementation of each system into ODOT's winter maintenance fleet. Subsection 2.2.1 provides information on the standard ODOT snow and ice removal systems used in this study. It should be noted that ODOT utilizes both single and tandem axle trucks with and without wing plows; however, the truck used for comparison with the TowPlow system is a tandem axle truck equipped with a 14-ft front plow and a mid-mounted wing plow attached to the right side of the truck. Subsection 2.2.2 presents the TowPlow theory and describes the TowPlow units acquired by ODOT.

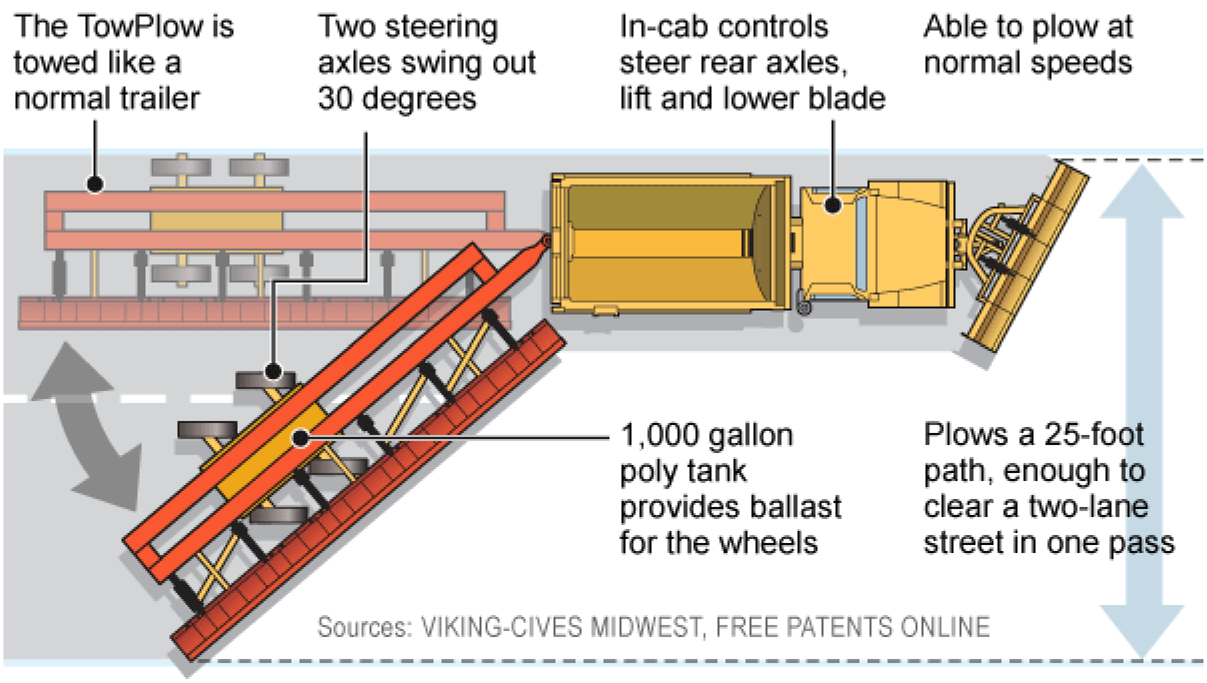
### *2.2.1 ODOT Snow and Ice Removal Systems*

Most ODOT plow trucks plow and treat a single lane with a combination of salt and brine. ODOT deploys single and tandem axle trucks equipped with an 11-ft or 12-ft front plow, but several ODOT county garages also have standard trucks that are equipped with an additional wing plow. This mid-mounted wing plow system consists of a 9 ft. long plow that may be attached to either side of a standard tandem axle truck (many of ODOT's wing plow systems are attached to the right side of the truck), and it may be deployed to an angle of approximately 39 degrees. A wing plow has the ability to plow 6.5 ft. of a driving lane or shoulder of a roadway. The area cleared by the wing plow is not included in the treatment area of the salt spreader on the plow truck and is therefore not treated with chemicals after plowing. In Portage County, the trucks equipped with wing plows are used for clearing the shoulders of the road. In many counties, a single plow truck may not deploy the wing plow in a traveling lane due to safety concerns, as the wing plow is not as visible as the TowPlow to other vehicles on the road. When multiple trucks are traveling in tandem, however, the truck in front may deploy the wing plow in the traveling lane, since the truck in the rear is able to block any vehicles from traveling near the wing plow, as seen in Figure 2.4.

Figure 2 4: Standard ODOT Trucks with Wing Plows Maintaining I-76 in Portage County.

### *2.2.2 TowPlow System*

The concept of the TowPlow system is to plow and treat two lanes simultaneously using a single plow truck by employing a tow-behind plow at the rear of the truck. The TowPlow unit has a hopper and liquid tanks and is towed behind the plow truck like a normal trailer. Two steering axles allow the TowPlow to swing out at an angle up to 30 degrees. When combined with the front plow, the TowPlow-equipped plow truck has the ability to plow a path up to 25 feet wide. The TowPlow has the ability to treat with both dry and liquid material, depending on the specifications of the TowPlow model chosen. The TowPlow is controlled by an in-cab system that allows operators to steer the rear axles and to lift and lower the TowPlow blade. Hence, the in-cab controls allow the operators to deploy the TowPlow unit at will in order to treat and/or plow the lane or shoulder to the right of the truck. While the unit may be operated safely at speeds ranging from 30 to 40 mph, ODOT garages operate their TowPlow units at speeds ranging from 30 to 35 mph. The TowPlow system is shown in Figure 2.5 below.




(Image from Viking-Cives, www.vikingcives.com)
Figure 2.5: Diagram of Viking-Cives TowPlow System.

The three TowPlow systems currently used by ODOT are all operated using Pengwyn hydraulic systems (Pengwyn, Inc., Columbus, Ohio). This hydraulic system is connected to both the TowPlow and the truck, allowing the operator to control the TowPlow position as well as to vary the amount of salt and liquid being applied by both the truck and the TowPlow. The control panels are shown in Figure 2.6.


Figure 2.6: Pengwyn Hydraulic Controllers for TowPlow and Truck.

The TowPlow system requires a tandem axle truck. The TowPlow may be attached to a truck with at least a 350-horsepower engine, a 90,000-lb pintle hook, one double-acting hydraulic remote, one single-acting hydraulic remote, a 7-wire trailer plug, an anti-lock braking system, and a standard trailer air package (Viking-Cives, 2010). ODOT uses two different types of trucks to pull the TowPlow units: two of the units are pulled by International trucks (International Truck and Engine Corp., a division of Navistar in Lisle, Illinois) and one unit is pulled by a Western Star truck (Western Star Trucks, Fort Mill, South Carolina).

# CHAPTER III DATA COLLECTION METHODOLOGY

This chapter is divided into four sections:

- Section One – Weather Data Collection,
- Section Two – Speed Data Collection,
- Section Three – Snow Plow Truck Data Collection, and
- Section Four – Data Fusion.

Figure 3.1 presents the field data collection process used in this study for evaluating the TowPlow unit over the 2013–2014 winter season.

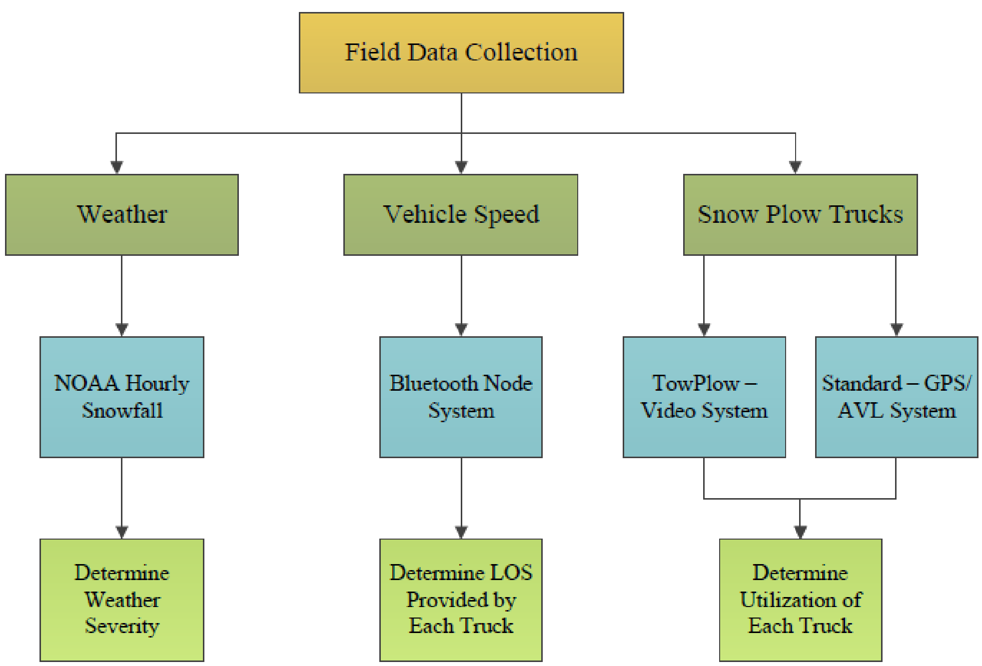



Figure 3.1: Field Data Collection Methodology for the TowPlow.

As seen in Figure 3.1, field data collection in this study involved gathering several types of data. Weather data are collected by using hourly snowfall data for the study area obtained from the National Oceanic and Atmospheric Administration (NOAA). Vehicle speed data are collected through the use of Bluetooth nodes (BTNs). Data collected from the plow truck included data from the truck's geographic positioning system/automatic vehicle location (GPS/AVL) system as well as recorded video data for analysis on the utilization of the TowPlow while it treated routes throughout the winter season. The collection of these data aids the research team in conducting the cost–benefit analysis and in determining the optimal implementation of the TowPlow in ODOT fleets.

## 3.1 Weather Data Collection

Considering the frequency at which weather changes occur and the precision desired for this evaluation, hourly data are the minimum timeframe required for weather data. A timeframe that is too long will not provide the desired temporal deviations required for this study. The NOAA's National Operational Hydrologic Remote Sensing Center is used to collect the weather data used in this evaluation, since it provides interactive snow information from weather stations near the study area. The research team selected three weather stations for the data collection in this study: Seven Hills (Ashtabula County) where IR-90 crosses SR-11; Canfield (Mahoning County), located on SR-46; and Ravenna (Portage County), located at SR-44 and I-76.

Using NOAA data, weather is categorized into the following five weather severities:

- <u>No Snowfall</u> – Appling anti-icing liquid before a storm or when there is a chance for a storm,
- <u>Trace Snowfall</u> – Less than 0.10 inches of total accumulation and with peak snowfall rates less than 0.10 inches per hour,
- <u>Light Snowfall</u> – Between 0.10 and 2 inches of total accumulation and with peak snowfall rates between 0.10 and 0.25 inches per hour,
- <u>Moderate Snowfall</u> – Between 2 and 6 inches of total accumulation and with peak snowfall rates between 0.25 and 0.75 inches per hour, and
- <u>Heavy Snowfall</u> – Greater than 6 inches of total accumulation and with peak snowfall rates greater than 0.75 inches per hour.

If a storm event meets one of the two criteria and is near the minimum requirement for the higher category, it may be placed in the more severe classification.  Categorizing the weather severities allows the research team to normalize the data and facilitates comparisons.

## 3.2 Vehicle Speed Data Collection

Motorists will travel at speeds they feel are safe; therefore, vehicle speeds are used as surrogate measurements of road conditions and effectiveness of the TowPlow on traffic flow. In this study, the research team compared the speeds of vehicles traveling along roads that are maintained by both the TowPlow as well as the standard truck, which are collected using BTNs. Speeds along both sections are evaluated using speed profiles as a surrogate measure for LOS. The BTN data are collected throughout the 2012–2013 winter season and the 2013–2014 winter season.

The BTN data collection system consists of several individual BTNs placed along the selected roadway as well as a server for processing the data collected from these nodes. Figure 3.2 shows a BTN placed in the field.

Figure 3.2: Bluetooth Node Secured along Interstate 76.

Each BTN records the media access control (MAC) address of a passing vehicle's Bluetooth-enabled device along with a timestamp. As the Bluetooth device passes through several BTN, a vehicle's speed may be calculated by matching the MAC address on multiple BTNs. More details regarding the BTN data collection system and the placement of BTNs in the field may be found in Schneider et al. (2012). Additional information is also provided in Section 5.2.1 of this report.

### *3.2.1 Winter 2012 to 2013 Bluetooth Nodes Deployment*

In the first year of this study (winter of 2012–2013), the research team placed the BTNs in Portage County along I-76 east of state route (SR) 44. In the first winter season, the data collected from the BTN are used for determining baseline traffic speeds to use as a comparison data set for the 2013–2014 winter season. Figure 3.3 presents the locations of the BTN in the 2013–2014 winter season.

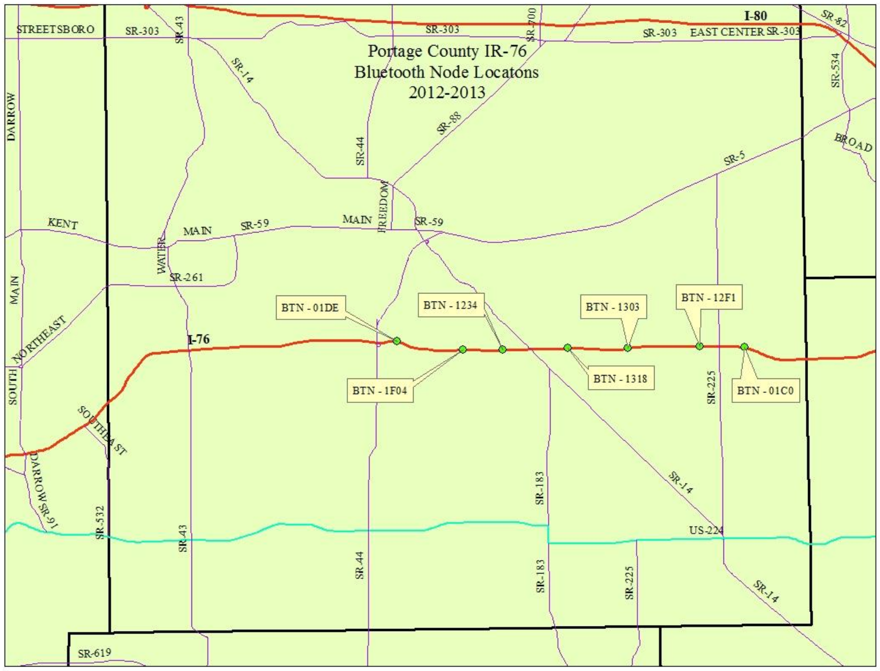



Figure 3.3: Location of Bluetooth Nodes for Winter 2012–2013.

A total of seven BTNs are placed on I-76 east of SR-44, as shown in Figure 3.3. The BTNs are chained to guard rail posts or sign posts in the median, which allowed them to collect data from vehicles moving in both eastbound and westbound directions. By placing the BTNs in the median, the interval length and number of intervals for both directions of travel are the same. This allows the team to collect more comprehensive speed estimations for vehicles moving in both directions.

### *3.2.2 Winter 2013 to 2014 Bluetooth Nodes Deployment*

In the second winter season (winter 2013–2014), the BTNs remained on I-76; however, the locations are moved in order to collect speed data from roadway segments to the east and west of SR-44. The BTN locations for the second winter season are presented in Figure 3.4.

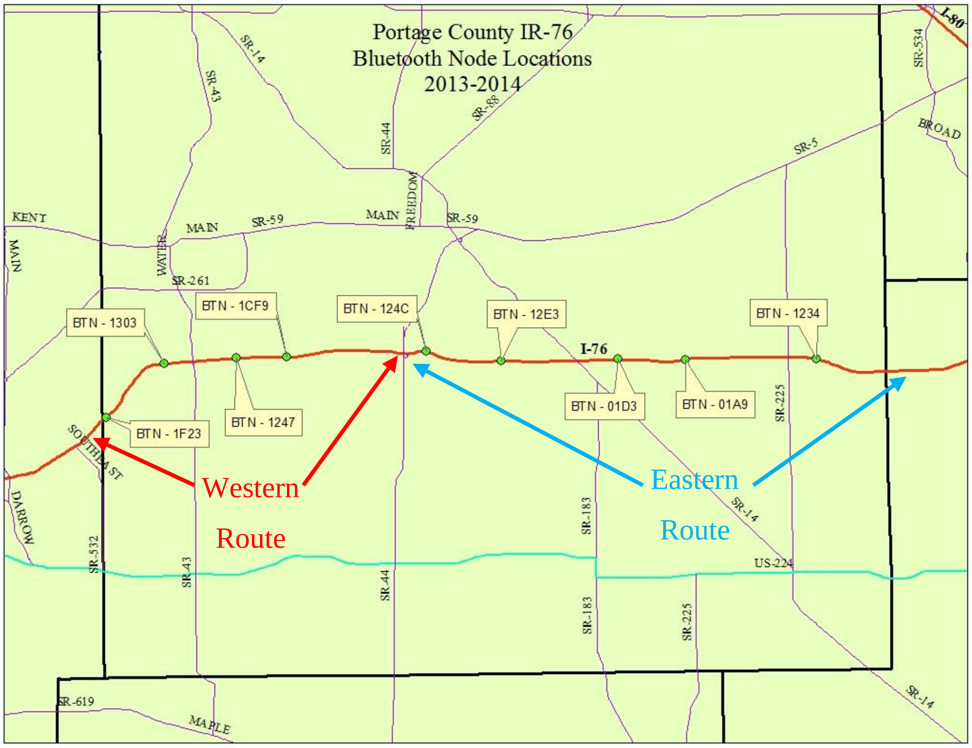



Figure 3.4: Location of Bluetooth Nodes for Winter 2013–2014.

The BTNs are placed using SR-44 as the center divider, with four nodes on the western side and five nodes on the eastern side, as shown in Figure 3.4. As with the previous deployment, the nodes are placed in the center median so that speeds of vehicles traveling both in the eastbound and westbound directions may be determined. To compare the effectiveness of the TowPlow to the standard truck, the two trucks are given routes that would experience similar amounts of snowfall. The two routes given to the trucks are I-76 west of SR-44 and I-76 east of SR-44, as presented in Figure 3.4. This division of roadway segments on I-76 into east and west routes created two treatment routes:

- Option One – The TowPlow treats the east side all day, and the wing plow treats the west side all day, or

- Option Two – The TowPlow treats the east side during the morning shift and the west side during the night shift, while the wing plow treats the west side during the morning shift and the east side during the night shift.

This deployment strategy allowed the team to collect Bluetooth data for traffic speeds for each truck individually and to determine the LOS provided by each truck.

## 3.3 Snow Plow Truck Data Collection

To determine how the TowPlows are utilized during various winter events, several key categories of data are collected from the trucks:

- Time and mileage the TowPlow is deployed,
- Time and mileage the TowPlow is used for salting only,
- Time and mileage the TowPlow is used for plowing,
- Time and mileage the TowPlow is used in a particular lane,
- Mileage and fuel used while plowing the routes, and
- Speed of the plow truck.

These data are collected from all three TowPlows and are used to determine how the TowPlows are utilized and to compare differences in how each county utilizes the TowPlow unit within its fleet. The BTN data, speed of the trucks, and fuel data may be used to compare the Portage County TowPlow to the standard truck. The following subsections provide additional information on the data collected and the methods used to collect the data. Subsection 3.3.1 presents the data collection method for the three TowPlows, and Subsection 3.3.2 presents the data collection method for the standard ODOT truck equipped with a wing plow, which runs on I-76 in conjunction with Portage County's TowPlow unit.

### *3.3.1 Data Collected from the TowPlow*

The data recorded by the TowPlow is obtained by video cameras attached to the truck in four separate locations, along with a GPS unit and a digital video recorder (DVR) inside the truck. Maintenance workers at Ashtabula and Portage Counties attached cameras to the back of the TowPlow, both the right and left sides of the truck facing the TowPlow and the lane to the left, and inside the cab facing out toward the front plow. The camera positions are presented in Figure 3.5.

Left Camera

Back Camera

Right Camera

Front Camera

Figure 3.5: Cameras Positioned on the TowPlow and Truck.

The camera on the passenger door records the TowPlow lane position, plow position, and what type of treatment the TowPlow is conducting. The data are collected from the cameras and recorded onto a DVR inside the truck, as shown in Figure 3.6. The DVR's hard drive component is switched out regularly to permit downloading of the video footage for future analysis.

Figure 3.6: DVR Mounted in Truck to Record Video Footage of TowPlow.

The camera feeds may be viewed by an operator within the cab via a monitor mounted inside the truck. The camera feeds provide the operator with additional points of view, therefore increasing visibility and safety for the operator. A sample of the video feeds and the data provided are presented in Figure 3.7 below.


Figure 3.7: Sample of Video Feed and Data Recorded by the DVR.

The video provides data on the location of the TowPlow, the type of treatment the TowPlow is performing, whether or not the front plow is deployed, and which lane the TowPlow is treating.

To provide additional help to ODOT's TowPlow operators, LaserLine® GL3000PMC Wing Plow Guidance Lasers (Laserline Mfg., Inc., Redmond, Oregon) are mounted to all three TowPlows. The lasers are designed to assist with positioning the TowPlow or wing plow when it is fully deployed. The laser projects a green dot in front of the truck to allow the operator to see the right edge of path where the TowPlow's end will be reaching. The laser is typically mounted on the outside of the truck, above the passenger-side door, as shown in Figure 3.8.

Figure 3.8: LaserLine® GL3000PMC Wing Plow Guidance Laser Mounted to TowPlow.

The laser projects ahead of the truck, showing the path of the TowPlow and helps the operator to determine if the blade will strike any upcoming objects. The laser may be attached in two ways. The laser may either be attached to the truck at a fixed angle so as to show the future position of the blade that is fully extended — or it may be attached directly to the end of the TowPlow, showing the operator the future position of the blade at any angle.  Portage County mounted its laser to the truck at a fixed angle, while the lasers used by Ashtabula and Mahoning counties are mounted to the TowPlow and move out as the TowPlow is deployed from behind the truck.

### *3.3.2 Data Collected from the Standard ODOT Wing Plow*

The data from the standard truck is collected using a different process than that used for collecting data from the TowPlow. At the beginning of the winter 2013–2014 season, the research team installed GPS-AVL equipment on a Portage County standard truck in order to record the necessary data. Figure 3.9 presents a modem used to receive and send data for the GPS-AVL system.

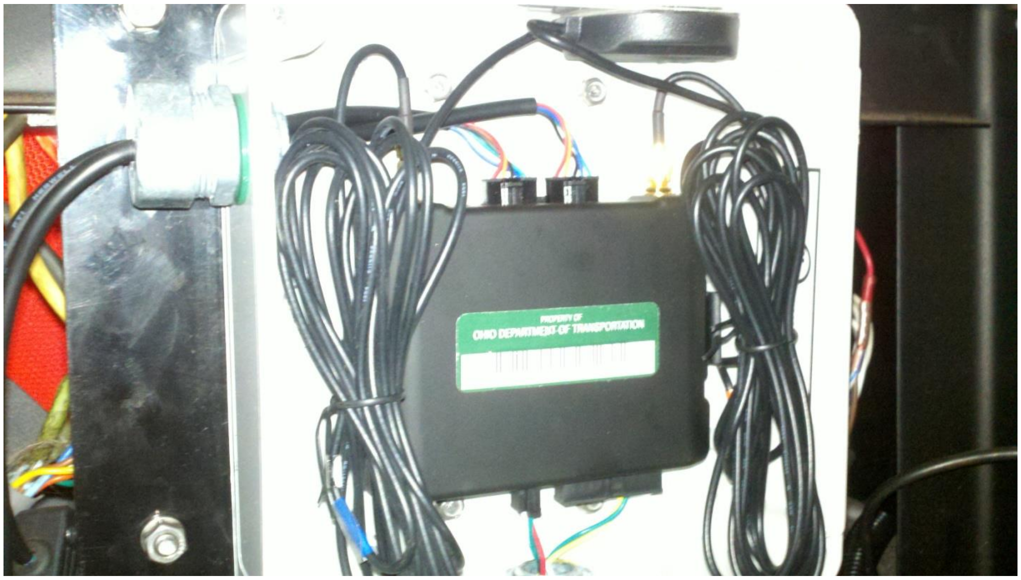



Figure 3.9: GPS-AVL Modem installed in an ODOT Standard Truck.

The GPS-AVL equipment records the truck's GPS coordinates, spreader rates, plow position, speed, and the time interval for maintaining each segment of the route. All the data recorded by the GPS-AVL system are compared to the driver's Maintenance and Repair (M&R) 661 form. A blank ODOT M&R 661 form is shown in Figure 3.10.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Date | | Shift | to | County | | End Mileage | |
| Operator | | Truck # | | Fuel Used | | Begin Mileage | |
| | | | | | | Total Mileage | |

**Road Condition and Operation Report**

| Time On | Time Off | Route # | Location From: | Location To: | Road Conditions # (use key below) | Treatment # (use key below) | Materials Used: Salt | Calcium | Brine | Abrasives | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 | | | | | |
| | | | | | | | Total Tons | Total Gallons | Total Gallons | Total Tons | Page 1 Totals |

**Road Condition Key:**
1= clear 5= icy
2= snow covered 6= icy in spots
3= snow covered in spots 7= slush covered
4= drifted 8= blocked

**Road Treatment Key:**
1= plowing & applying chemicals/abrasives
2= applying chemicals/abrasives only
3= plowing only
4= plowing back, center & turn lanes
5= roadway patrol only

*Page 1*

Figure 3.10: Blank ODOT M&R 661 Form.

The M&R 661 forms includes the start and end time for each treated roadway, location of the treated roadway, road condition, type of treatment used, and the treatment materials applied to the roadway. The GPS-AVL system, along with sensors, collect the same data as are recorded on the M&R 661 forms and sends the data to a server, which may be accessed by both the research team and ODOT. The M&R 661 forms are filled out periodically by the plow truck operators; however, because the operators tend to be focused on the maintenance of the roadway, the form may lack sufficient detail for the purposes of this study. Consequently, the research team primarily relied on the GPS-AVL system and BTN data to facilitate comparisons of the standard truck to the TowPlow.

## 3.4 Data Fusion

The weather, speed, and utilization of the TowPlow and standard truck are all affected by one another, and this interaction is captured through a process called data fusion. Figure 3.11 presents the interaction between the three major categories of data collected over the 2013–2014 winter season.

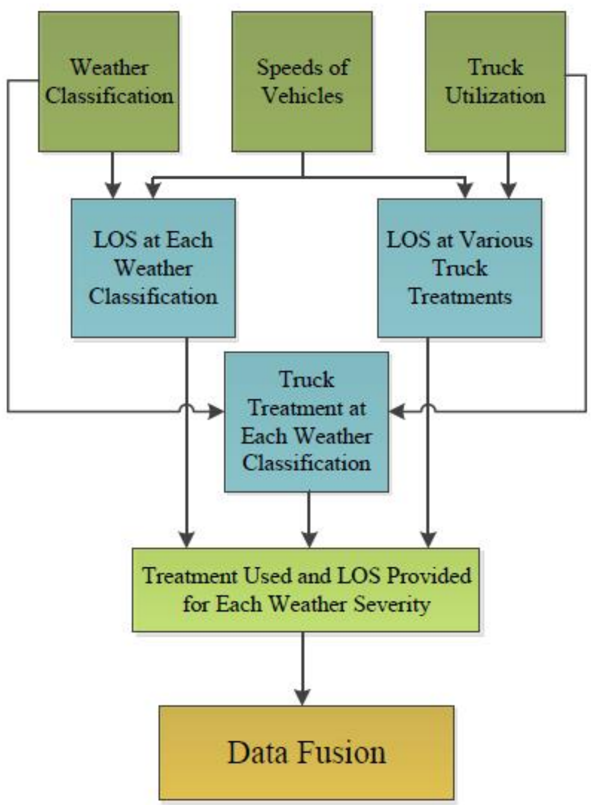



Figure 3.11: Flow Chart showing Data Interaction.

The LOS, based on the speed of vehicles at each storm classification, is analyzed to determine how weather is affecting the roadways maintained by ODOT. Figure 3.12 presents vehicle speeds collected from a segment of I-76 in Portage County on February 5, 2014, as an example to demonstrate how weather severity may affect the vehicle speeds on a road segment.

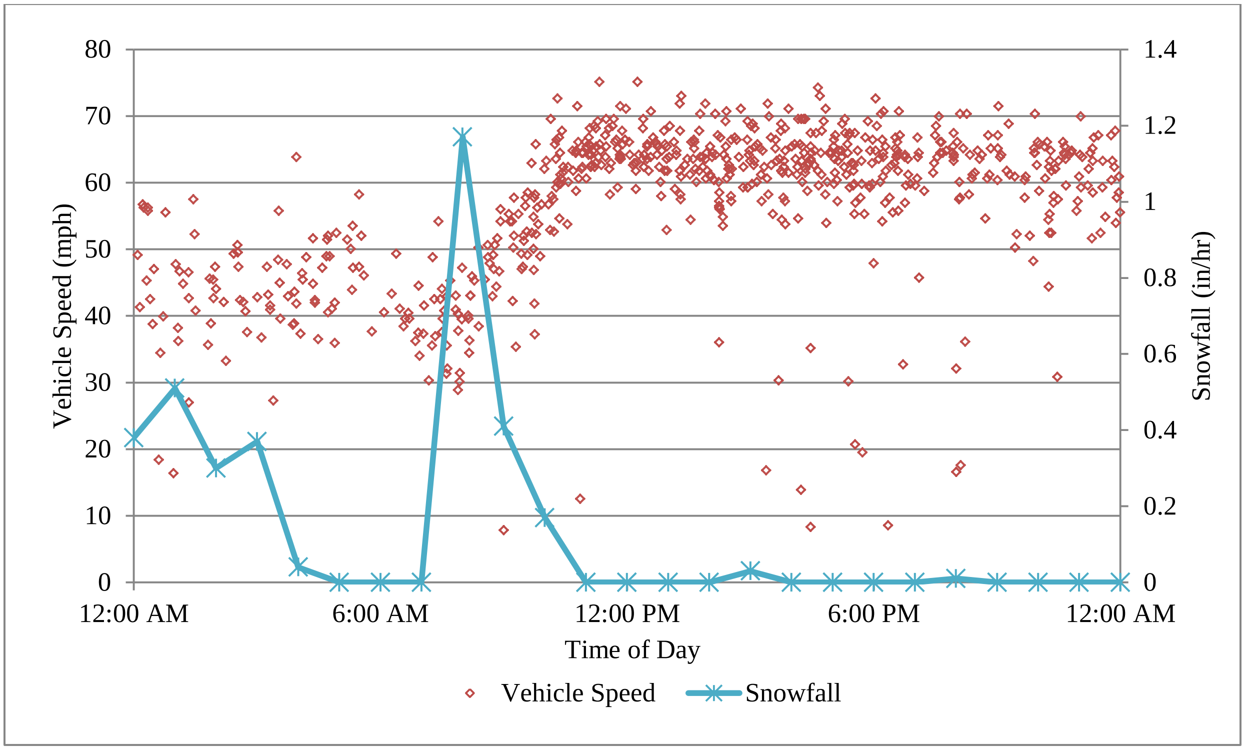



Figure 3.12: Vehicle Speeds Collected on a Segment of I-76 in Portage County on February 5, 2014.

From Figure 3.12, it may be seen that the vehicle speeds are reduced while snowfall increases from midnight through noon. After noon, the vehicle speeds begin to travel at baseline speeds, as the snowfall is minimal at that time.

Determining the LOS while considering the type of treatment the TowPlow is applying to the route is important in evaluating the TowPlow and its effectiveness. When the TowPlow is deployed in the right lane of a two-lane segment, the traveling vehicles are not able to pass the TowPlow and therefore must travel at the same speed as the TowPlow. The TowPlow's treatment type and usage is dependent on the storm severity. These three components are all contingent upon one another; therefore, all three components must be analyzed together in order to determine the effectiveness of the TowPlow as compared to the standard truck.

# CHAPTER IV TOWPLOW FIELD EVALUATION SUMMARY

In this study the research team evaluated the use and implementation of three Viking-Cives TowPlows that are located in Ashtabula, Mahoning and Portage counties. There are four main findings within this chapter:

- TowPlow deployment,
- Treatment applied from the TowPlow,
- Location of the TowPlow with respect to the lane configuration, and
- Snow event observed over the 2013–2014 winter season in each country.

This chapter is divided into two sections: first are the definitions used while collecting data, and second are the results of the data collected from the TowPlows. Figure 4.1 shows the general trend of the data collected and then presented within this chapter.

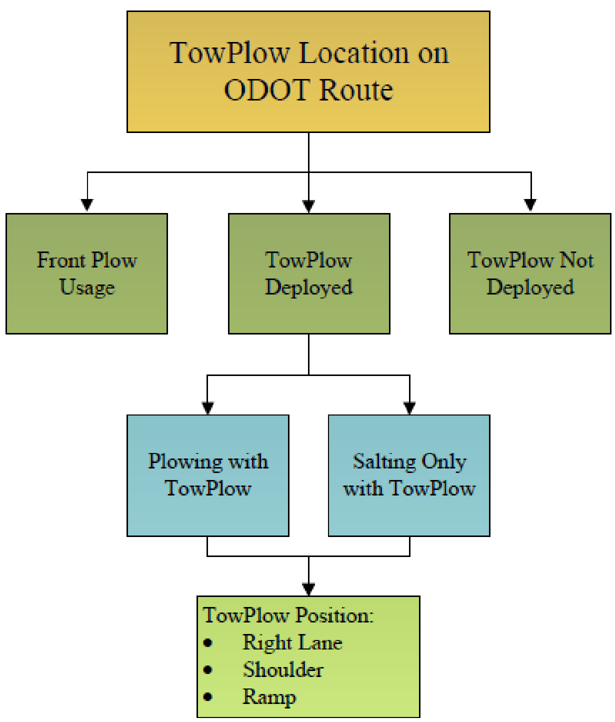



Figure 4.1: Information Documented from Video Footage of the TowPlow.

## 4.1 TowPlow Data Collecting Definitions

Figure 4.2 shown below illustrates the deployment options available to the TowPlow. It should be noted that the research team considers the TowPlow to be deployed if the plow itself occupies any portion of the second lane or shoulder whether or not the TowPlow is deployed to the maximum angle of 30 degrees.


Figure 4.2A: TowPlow Deployed


Figure 4.2B: TowPlow not Deployed.
(Truck and TowPlow figures modified from Viking-Cives Website)

Figure 4.2: TowPlow Deployed vs. Not Deployed.

Figure 4.3, below, shows the lane configuration of the TowPlow. In all cases, the named lane is based on the location of the TowPlow itself – not the truck pulling the plow. In the case of lane deployment, the TowPlow may occupy the right lane in slightly different ways, as illustrated in Figures 4.3B and 4.3C. However, the research team is not able to differentiate between the scenarios presented in Figures 4.3B and 4.3C.

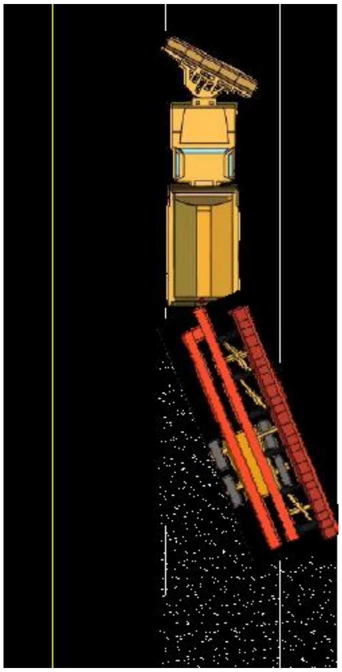


Figure 4.3A: Shoulder Deployment

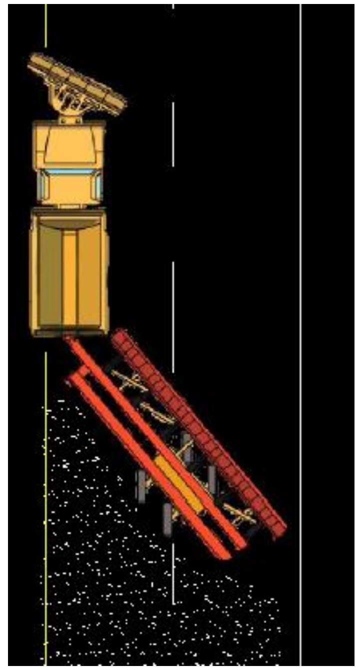


Figure 4.3B: Right Lane Deployment

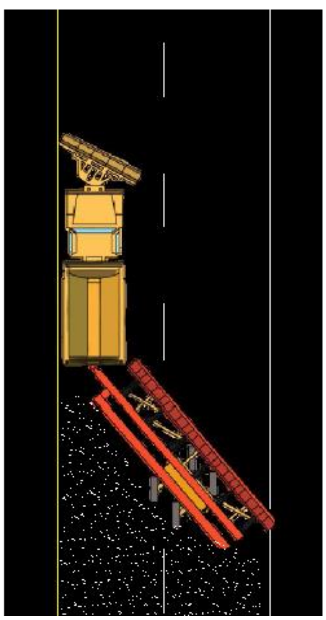


Figure 4.3C: Right Lane Deployment

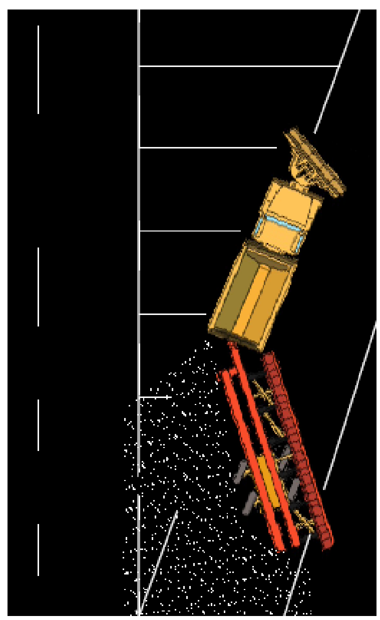


Figure 4.3D: Ramp Deployment

(Truck and TowPlow figures modified from Viking-Cives Website)
Figure 4.3: TowPlow Lane Configurations.

The salt application using the TowPlow is based on two data sources. In the first case, the research team assumed the TowPlow is salting if the TowPlow is deployed and the blade is in the up position while reviewing the TowPlow video footage. The second source is using the M&R 661 forms to verify salt application.

Another data component required for the analysis is the collection of weather data. The weather data are based on reports provided by NOAA. In this portion of the study the research team used five weather severities. The five weather categories, as mentioned in Chapter 3, are:

- No Snowfall – Appling anti-icing liquid before a storm or when there is a chance for a storm,
- Trace Snowfall – Less than 0.10 inches of total accumulation and with peak snowfall rates less than 0.10 inches per hour,
- Light Snowfall – Between 0.10 and two inches of total accumulation and with peak snowfall rates between 0.10 and 0.25 inches per hour,
- Moderate Snowfall – Between two and six inches of total accumulation and with peak snowfall rates between 0.25 and 0.75 inches per hour, and
- Heavy Snowfall – Greater than six inches of total accumulation and with peak snowfall rates greater than 0.75 inches per hour.

In addition to the five weather categories, the research team also needed to clarify what constitutes a weather event. One of the most common ways to do this is to define the event based on an arbitrary time interval such as per day, or midnight to noon. In this study, the research team decided to evaluate an event based on hours of snowfall. The start time of an event is defined as the first occurrence of snowfall and the end time is considered one hour after the final hour of consecutive snowfall, so long as there are two or more hours after the end time that are without snowfall. Simply stated, if only one hour after no snowfall is recorded, the event is considered to be continuous until two or more consecutive hours occur with no snowfall. Using this definition, events may span multiple days or multiple events may occur in the same day. Figure 4.4 presents an example showing the process for defining a winter event with snowfall on the same day.

| Date | Snowfall (in) |
|---|---|
| 12/16/2013 7:00 | 0.00 |
| 12/16/2013 8:00 | 0.27 |
| 12/16/2013 9:00 | 0.00 |
| 12/16/2013 10:00 | 0.00 |
| 12/16/2013 11:00 | 0.00 |
| 12/16/2013 12:00 | 0.00 |
| 12/16/2013 13:00 | 0.00 |
| 12/16/2013 14:00 | 0.00 |
| 12/16/2013 15:00 | 0.00 |
| 12/16/2013 16:00 | 0.00 |
| 12/16/2013 17:00 | 0.00 |
| 12/16/2013 18:00 | 0.00 |
| 12/16/2013 19:00 | 0.00 |
| 12/16/2013 20:00 | 0.01 |
| 12/16/2013 21:00 | 0.02 |
| 12/16/2013 22:00 | 0.03 |
| 12/16/2013 23:00 | 0.02 |
| 12/17/2013 0:00 | 0.03 |
| 12/17/2013 1:00 | 0.20 |
| 12/17/2013 2:00 | 0.07 |
| 12/17/2013 3:00 | 0.08 |
| 12/17/2013 4:00 | 0.16 |
| 12/17/2013 5:00 | 0.14 |
| 12/17/2013 6:00 | 0.02 |
| 12/17/2013 7:00 | 0.00 |
| 12/17/2013 8:00 | 0.00 |

Note: The snowfall value indicates the snowfall that occurred from hour prior.
Figure 4.4: Defining Events – Example of Two Events Occurring on Same Day.

## 4.2 2013–2014 Winter Season Utilization Results

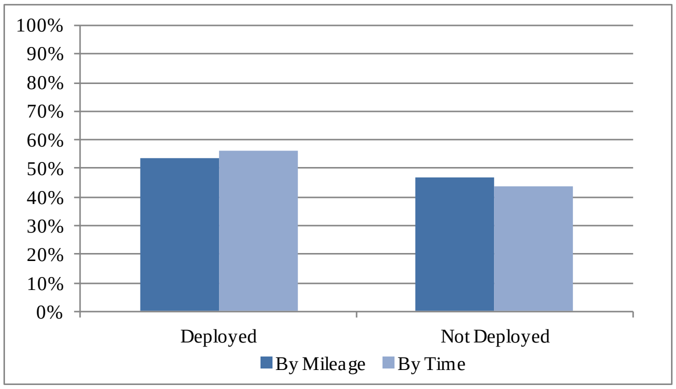
The results of the utilization analysis for the three TowPlows during the 2013–2014 winter season are presented in Figures 4.5 through 4.8. In each of these figures, the bar charts on the left side provide the percentage that the TowPlows are used, which are calculated either by miles traveled or time. The tables on the right side summarize the values shown in the chart.

Figure 4.5 shows the TowPlow status of the TowPlow. Figure 4.5A presents the average use for all the TowPlows, while Figures 4.5B, 4.5C and 4.5D are the results for the individual counties. The general findings show that Ashtabula and Mahoning counties deploy the TowPlow on average approximately 30 to 35% more frequently than Portage County. This difference is based on how the individual counties implement their TowPlows. It should be noted that this is not a reflection on Portage County's maintenance practices, since the research team requested Portage County to place the TowPlow on a designated route in order to capture LOS data of the TowPlow. Therefore, the Portage County TowPlow would be assigned to maintain its route during minimal snowfall similar to any other standard ODOT truck, while the other two counties are able choose when and where to utilize the TowPlow.

Figure 4.6 summarizes the amount of time the TowPlow is being used for treatment of routes while in the field. In this figure, the TowPlow is deployed for treating its route. When the plow blade is down, the TowPlow is assumed to be "plowing", when the blade is not down, the research team assumes that the TowPlow is "only salting". Not surprisingly the majority of the time, greater than 80%, the TowPlow is plowing. The remaining time, the operator is using the TowPlow to aid in spreading salt across multiple lanes. Similar to the previous figures, the results for Portage County are slightly different from those for the other counties because of the strict requirement for the TowPlow to remain on I-76.

Figure 4.7 summarizes the lane deployment of the TowPlow for plowing and/or salting. As stated previously, the lane description is based on the location of the TowPlow, not the location of the truck towing the TowPlow. The general results show the right lane has the highest rate of use, followed by the shoulder and, finally, the highway ramps. One note of interest is the lane use for the TowPlow in Mahoning County. Mahoning County almost exclusively uses its TowPlow for clearing the right lane and very infrequently uses the TowPlow to clear shoulders or ramps.

Figure 4.8 provides a summary of the winter events versus the weather classification. From a research perspective, it is fortunate that the winter season had many events. During this study period, a total of 60 events are recorded throughout the three counties. It should be noted that an event may have occurred in all three counties on the same day, and the event is counted separately in each county. There are five events when no snowfall occurred; this may be due to a forecast that predicted snowfall but none occurred, or it may be due to a routine patrol to ensure that routes are clear of drift snow and ice. Eight events are classified as trace snowfall; for these events, the NOAA data collected included snowfall amounts that are quantified to the nearest 0.01 inch. For many of the trace events, little to no treatment is applied to the routes; however, the operators may have chosen to apply salt as a precaution, especially in low temperatures. During the study period, there are 27 light snowfall events, 15 moderate snowfall events, and five heavy snowfall events.

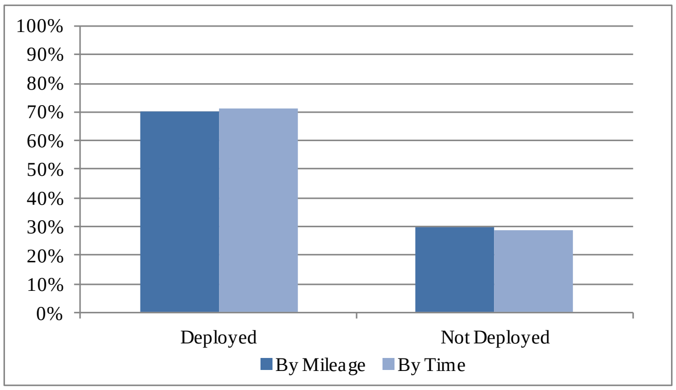



Number of Events: 60

Overall TowPlow Status:

| Event Type | Average (%) |
|---|---|
| Deployed Mileage | 53 |
| Deployed Time | 56 |
| Not Deployed Mileage | 47 |
| Not Deployed Time | 44 |

Figure 4.5A: TowPlow Status while Truck is on Route for All Three TowPlows.

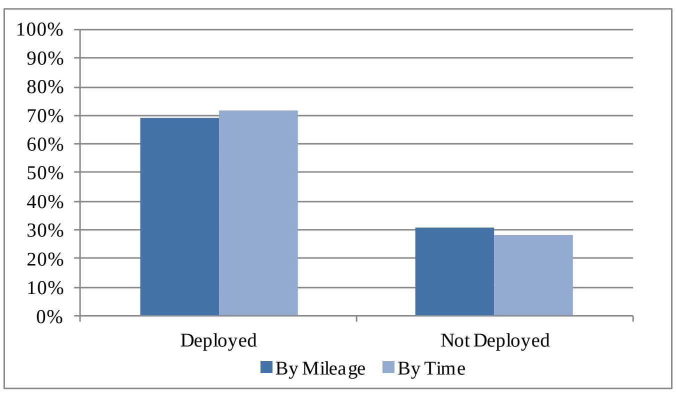



Number of Events: 17

Ashtabula TowPlow Status:

| Event Type | Average (%) |
|---|---|
| Deployed Mileage | 70 |
| Deployed Time | 71 |
| Not Deployed Mileage | 30 |
| Not Deployed Time | 29 |

Figure 4.5B: TowPlow Status while Truck is on Route for Ashtabula County.

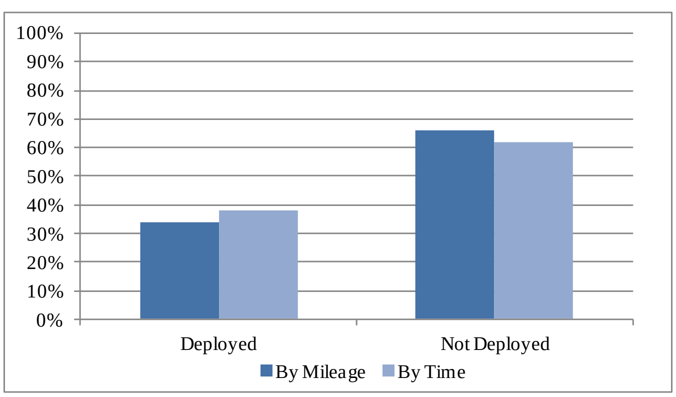



Number of Events: 12

Mahoning TowPlow Status:

| Event Type | Average (%) |
|---|---|
| Deployed Mileage | 69 |
| Deployed Time | 72 |
| Not Deployed Mileage | 31 |
| Not Deployed Time | 28 |

Figure 4.5C: TowPlow Status while Truck is on Route for Mahoning County.



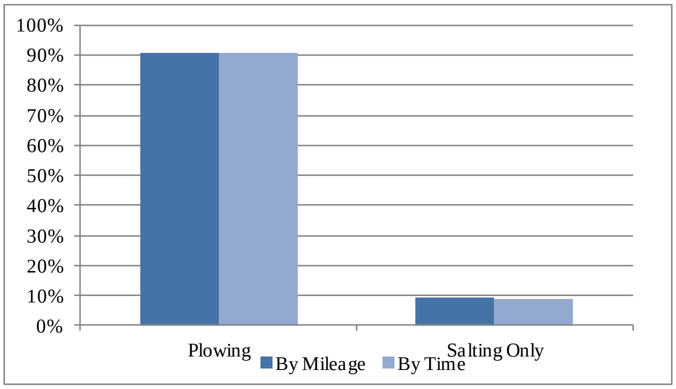

Number of Events: 31

Portage TowPlow Status:

| Event Type | Average (%) |
|---|---|
| Deployed Mileage | 34 |
| Deployed Time | 38 |
| Not Deployed Mileage | 66 |
| Not Deployed Time | 62 |

Figure 4.5D: TowPlow Status while Truck is on Route for Portage County.

Figure 4.5: TowPlow Status while Truck is on Route for 2013–2014 Winter Season.

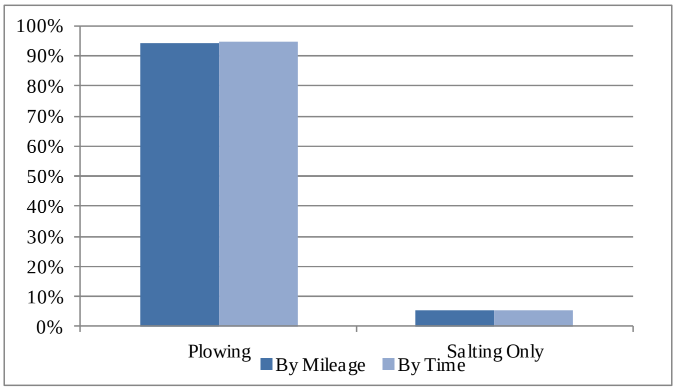



Number of Events: 60

Overall TowPlow Treatment

| Event Type | Average (%) |
|---|---|
| Plowing Mileage | 91 |
| Plowing Time | 91 |
| Salting Mileage | 9 |
| Salting Time | 9 |

Figure 4.6A: TowPlow Treatment when Deployed for All Three Counties.

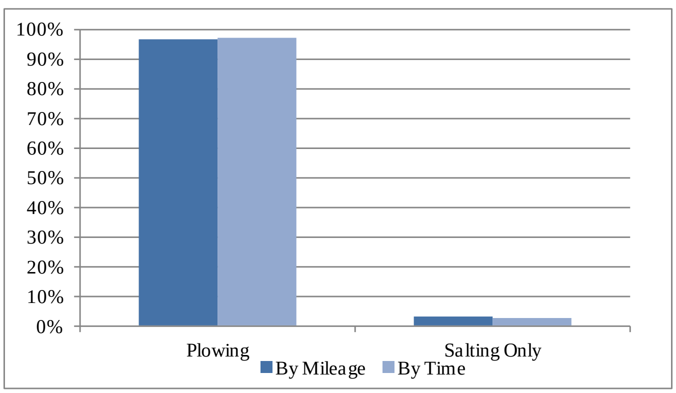



Number of Events: 17

Ashtabula TowPlow Treatment

| Event Type | Average (%) |
|---|---|
| Plowing Mileage | 95 |
| Plowing Time | 95 |
| Salting Mileage | 5 |
| Salting Time | 5 |

Figure 4.6B: TowPlow Treatment when Deployed for Ashtabula County.

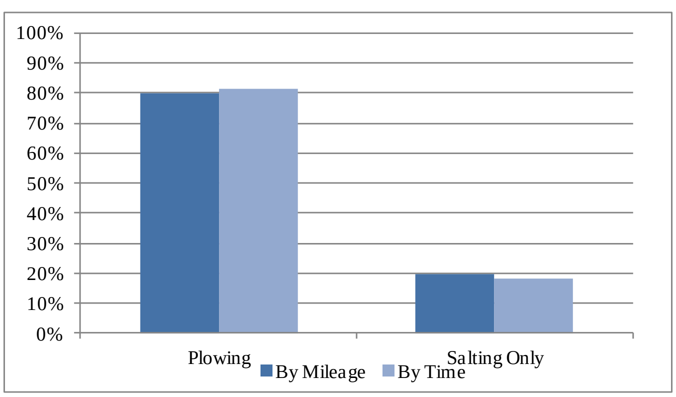



Number of Events: 12

Mahoning TowPlow Treatment

| Event Type | Average (%) |
|---|---|
| Plowing Mileage | 97 |
| Plowing Time | 97 |
| Salting Mileage | 3 |
| Salting Time | 3 |

Figure 4.6C: TowPlow Treatment when Deployed for Mahoning County.



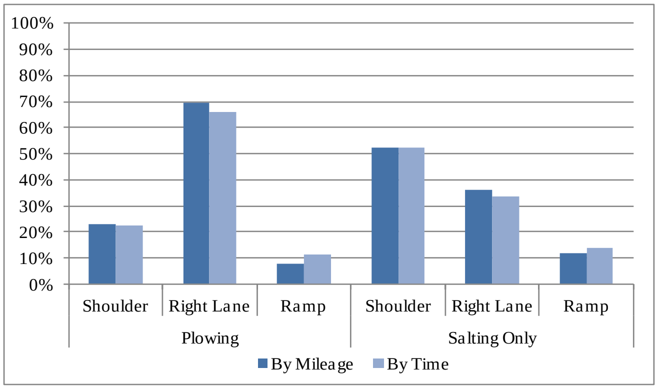

Number of Events: 31

Portage TowPlow Treatment

| Event Type | Average (%) |
|---|---|
| Plowing Mileage | 80 |
| Plowing Time | 82 |
| Salting Mileage | 22 |
| Salting Time | 18 |

Figure 4.6D: TowPlow Treatment when Deployed for Portage County.

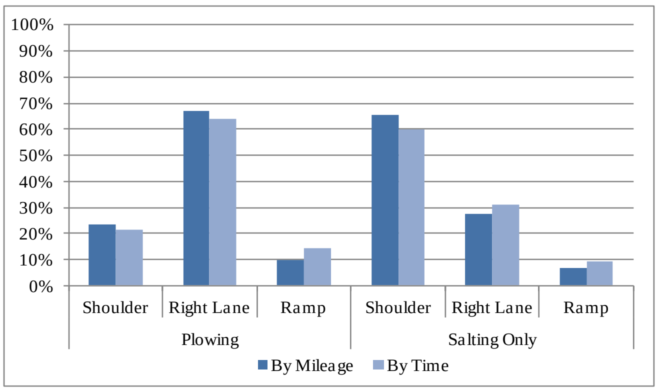
Figure 4.6: TowPlow Treatment Type when Deployed on Route for 2013–2014 Winter Season.




Number of Events: 60
Overall Average TowPlow Lane Configuration:

| Event Type | Shoulder (%) | Right Lane (%) | Ramp (%) |
|---|---|---|---|
| Plowing Mileage | 23 | 69 | 8 |
| Plowing Time | 23 | 66 | 12 |
| Salting Mileage | 52 | 36 | 12 |
| Salting Time | 53 | 33 | 14 |

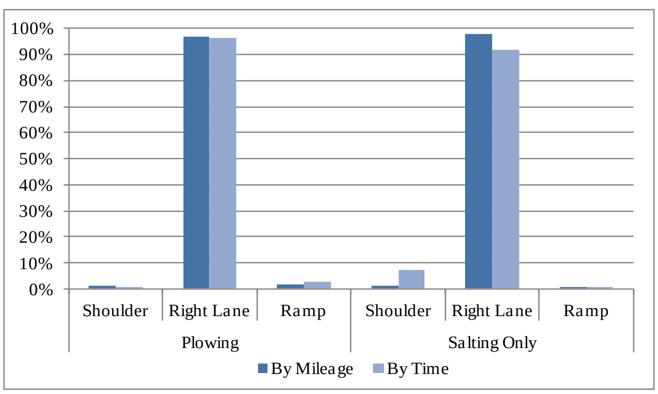
Note 4.7A: Lane Configuration of TowPlow when Deployed for All Three Counties.




Number of Events: 17
Ashtabula Average TowPlow Lane Configuration:

| Event Type | Shoulder (%) | Right Lane (%) | Ramp (%) |
|---|---|---|---|
| Plowing Mileage | 23 | 67 | 10 |
| Plowing Time | 22 | 64 | 14 |
| Salting Mileage | 66 | 28 | 7 |
| Salting Time | 60 | 31 | 9 |

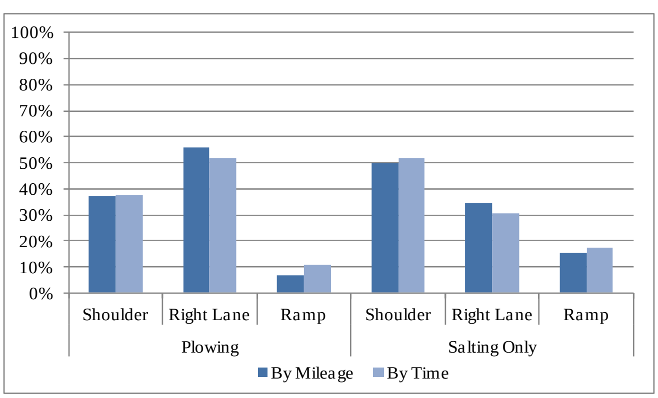
Note 4.7B: Lane Configuration of TowPlow when Deployed for Ashtabula County.




Number of Events: 12
Mahoning Average TowPlow Lane Configuration:

| Event Type | Shoulder (%) | Right Lane (%) | Ramp (%) |
|---|---|---|---|
| Plowing Mileage | 1 | 97 | 2 |
| Plowing Time | 1 | 96 | 3 |
| Salting Mileage | 1 | 98 | 1 |
| Salting Time | 7 | 92 | 1 |

Note 4.7C: Lane Configuration of TowPlow when Deployed for Mahoning County.

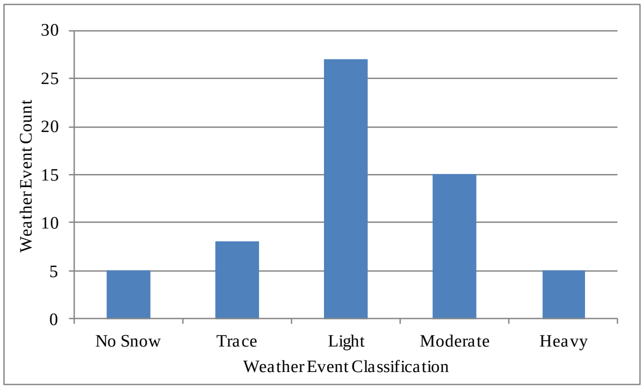



Number of Events: 31
Portage Average TowPlow Lane Configuration:

| Event Type | Shoulder (%) | Right Lane (%) | Ramp (%) |
|---|---|---|---|
| Plowing Mileage | 37 | 56 | 7 |
| Plowing Time | 37 | 52 | 11 |
| Salting Mileage | 50 | 35 | 15 |
| Salting Time | 52 | 30 | 18 |

Note 4.7D: Lane Configuration of TowPlow when Deployed for Portage County.

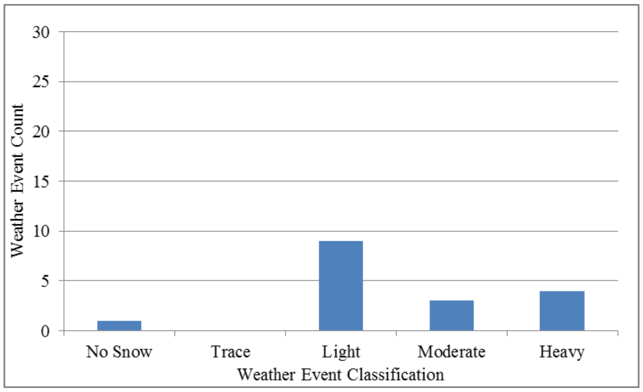
Figure 4.7: Lane Configuration of TowPlow when Deployed on Route in 2013–2014 Winter Season.




Number of Events: 60
All Three Counties Events:

| Event Type | Number of Events |
|---|---|
| No Snow | 5 |
| Trace | 8 |
| Light | 27 |
| Moderate | 15 |
| Heavy | 5 |

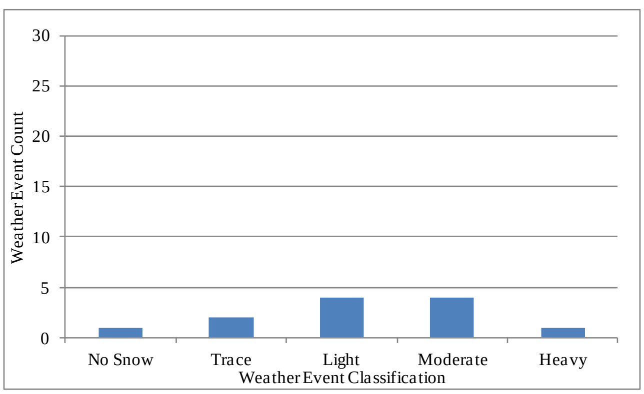
Figure 4.8A: All Three Counties Event Weather Classifications.




Number of Events: 17
Ashtabula Events:

| Event Type | Number of Events |
|---|---|
| No Snow | 1 |
| Trace | 0 |
| Light | 9 |
| Moderate | 3 |
| Heavy | 4 |

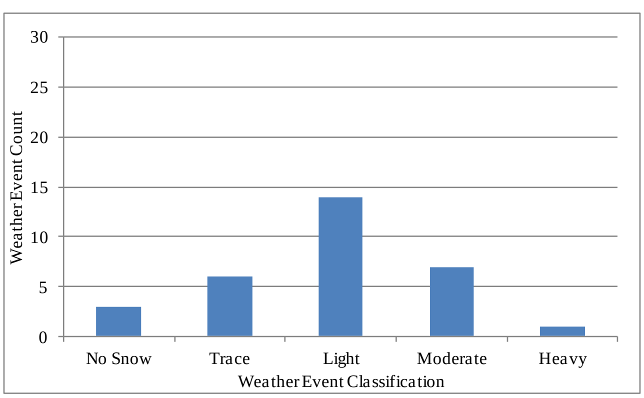
Figure 4.8B: Ashtabula County Event Weather Classifications.




Number of Events: 12
Mahoning Events:

| Event Type | Number of Events |
|---|---|
| No Snow | 1 |
| Trace | 2 |
| Light | 4 |
| Moderate | 4 |
| Heavy | 1 |

Figure 4.8C: Mahoning County Event Weather Classifications.




Number of Events: 31
Portage Events:

| Event Type | Number of Events |
|---|---|
| No Snow | 3 |
| Trace | 6 |
| Light | 14 |
| Moderate | 7 |
| Heavy | 1 |

Figure 4.8D: Portage County Event Weather Classifications.

Figure 4.8: Weather Event Classification for the 2013–2014 Winter Season.

Table 4.1 summarizes all the data collected for each TowPlow throughout the winter season of 2013–2014. The time on route and total miles traveled are provided along with the percentages of each. The “Event Total” in the first row indicates that total time and miles the TowPlows are on route. The sum of “TowPlow Not Deployed” and “TowPlow Deployed” is equal to the “Event Total”.

Table 4.1: Summary of TowPlow Utilization for 2013–2014 Winter Season.

| | | Total | | | | Ashtabla | | | | Mahoning | | | | Portage | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Time | Mileage | By Time | By Miles | Time | Mileage | By Time | By Miles | Time | Mileage | By Time | By Miles | Time | Mileage | By Time | By Miles |
| Event Total: | | 415:47:12 | 12655 | - | - | 179:58:55 | 5221 | 43% | 41% | 48:17:25 | 1622 | 12% | 13% | 187:30:52 | 5812 | 45% | 46% |
| TowPlow not Deployed: | | 181:25:03 | 5880 | 44% | 46% | 52:03:04 | 1555 | 29% | 30% | 13:38:19 | 495 | 28% | 31% | 115:43:40 | 3830 | 62% | 66% |
| TowPlow Deployed: | | 234:22:09 | 6778 | 56% | 54% | 127:55:51 | 3667 | 71% | 70% | 34:39:06 | 1126 | 72% | 69% | 71:47:12 | 1985 | 38% | 34% |
| TowPlow Salting Only: | | 21:05:55 | 629 | 9% | 9% | 6:53:41 | 202 | 5% | 5% | 0:58:37 | 34 | 3% | 3% | 13:13:37 | 394 | 18% | 20% |
| TowPlow's Position | Shoulder | 11:05:15 | 362 | 53% | 58% | 4:08:22 | 132 | 60% | 66% | 0:04:22 | 34 | 7% | 100% | 6:52:31 | 196 | 52% | 50% |
| | Right lane | 7:03:06 | 194 | 33% | 31% | 2:07:34 | 56 | 31% | 28% | 0:53:47 | 0 | 92% | 1% | 4:01:45 | 138 | 30% | 35% |
| | Ramp | 2:57:34 | 74 | 14% | 12% | 0:37:45 | 13 | 9% | 7% | 0:00:28 | 0 | 1% | 1% | 2:19:21 | 61 | 18% | 15% |
| TowPlow Plowing: | | 213:16:14 | 6143 | 91% | 91% | 121:02:10 | 3465 | 95% | 95% | 33:40:29 | 1087 | 97% | 97% | 58:33:35 | 1591 | 82% | 80% |
| TowPlow's Position | Shoulder | 48:35:14 | 4029 | 23% | 66% | 26:19:44 | 3425 | 22% | 99% | 0:19:04 | 12 | 1% | 1% | 21:56:26 | 592 | 37% | 37% |
| | Right lane | 44:15:31 | 2279 | 21% | 37% | 5:27:18 | 338 | 5% | 10% | 8:27:48 | 1049 | 25% | 96% | 30:20:25 | 892 | 52% | 56% |
| | Ramp | 24:35:26 | 782 | 12% | 13% | 17:25:05 | 650 | 14% | 19% | 0:53:37 | 26 | 3% | 2% | 6:16:44 | 106 | 11% | 7% |

The sum of “TowPlow Salting Only” and “TowPlow Plowing” is equal to “TowPlow Deployed”. Within each treatment type, Table 4.1 also presents the time and miles where the TowPlow is deployed in each lane configuration. This data are presented in graphic form in other figures in this chapter. Evaluating the data presented in Table 4.1 allows the research team and ODOT to create an implementation plan for the TowPlows in each county.

# CHAPTER V VEHICLE DELAY

In order to determine the impacts of the TowPlow on the roadway motorists, the research team analyzed the delay created during winter maintenance activities. To accomplish this, the delay created by the TowPlow in various configurations is compared to the delay created by the standard plow truck.

## 5.1 Introduction

Winter weather conditions such as snowfall and wind may have detrimental impacts on roadway operations and the level of service provided to the motoring public. The pavement friction is reduced as a result of the cold temperatures, snowfall, and wind, causing motorists to reduce the speed of their vehicles. It is generally accepted that the majority of motorists will decrease their driving speed based on their perception of the roadway conditions. Several studies throughout the world have been conducted to determine the impacts of snowfall on vehicle speeds. It is found that in London, light snow increases travel times by 5.5% to 7.6% and heavy snow increases travel times by 7.4% to 11.4% (Tsapakis et al. 2012). A study conducted in Baltimore, Minneapolis, St. Paul, and Seattle determined that snow reduces speeds by 5% to 16% on average in each city evaluated (Hranac et al. 2006). On Interstate 84 (I-84) in Idaho, motorists are found to reduce their mean speeds by 11.9 miles per hour (mph) (Liang et al., 1998). A similar study conducted in Toronto found that motorists reduce their speeds by 1.9 mph during light snow events and by 23.6 to 31.1 mph during heavy snow events (Ibrahim et al., 1994).

Winter weather may have a wide range of impacts that are based on the geographical location and arrival time of the storm. Depending on the arrival and duration of a storm, motorists may alter their mode of transport, delay their trip, cancel their trip, or continue with their planned trip. Regardless of when and where a storm arrives, maintenance agencies must combat the storm to the best of their abilities. Agencies employ a variety of techniques to clear roadways of ice and snow in order to limit the speed decreases caused by the winter event. Some of the strategies commonly utilized include plowing, applying salt and other abrasives during storms, and pretreating roadways before a storm arrives. Recently, many agencies, such as state departments of transportation (DOTs), have been evaluating the use of specialty winter maintenance equipment within their fleets. Some of the specialty equipment includes tow behind trailers that swing out and plow a second travel lane or shoulder, as well as salt hoppers that are capable of spreading de-icing materials over multiple lanes. A number of studies have been conducted to determine the advantages of winter maintenance equipment and materials. Other studies have been conducted to determine the benefits and disadvantages of many anti-icing and de-icing materials (Shi et al. 2013, Fischel 2001). Additionally, many studies have evaluated TowPlow blades to determine which are the most efficient at removing snow and which are the most cost-effective to implement (Mastel 2010, Braun Intertec Corporation 2010, CTC and Associates LLC 2010, Colson 2010, Colson 2009).

In this study, BTN are utilized to collect speed data to facilitate comparisons between the resulting speeds and delays produced by specialty winter maintenance equipment with those for a standard plow truck. BTN are a relatively new type of equipment used to record speeds of motorists along a roadway. BTN may be used for calculating vehicle speeds because of their ability to detect the MAC address of an enabled device, and a particular MAC address may be matched on multiple nodes that are separated by a known distance. Not every motorist has a Bluetooth enabled device, and resulting studies have found Bluetooth penetration rates ranging from three percent to ten percent (Brennan et al. 2010, Hainen et al. 2010, Asudegi 2009). Despite the small sample size, overall trends may be captured from available devices, including travel times that may easily allow delay determinations (Hainen et al. 2010, Schneider et al. 2012, Martchouk et al. 2011, Wasson et al. 2008).

One aspect of specialty equipment that is not formally documented is the impact on resulting travel speeds and the associated delay. It is reasonable to assume that different types of winter maintenance equipment will have varying impacts on level of service. It is prudent to determine the impacts of specialty equipment on vehicle speeds and vehicle delay in comparison to a standard plow truck used by the agency evaluating the new equipment.

## 5.2 Methodology

The data collection methodology used in this study is divided into three sections. First is the use of Bluetooth technology to gather the vehicle speed data. Second is the data collection process for the two types of winter maintenance equipment. The third is the fusion of the speed data segments and the winter maintenance equipment data.

### *5.2.1 Speed Data Collection Using Bluetooth Technology*

The BTN, introduced in Chapter 3, are deployed to calculate the speeds of passing motorists. The general principle of the Bluetooth system used to capture vehicle speeds is to place one node at location *X* and another node at location *Y* along a road, with a known distance *Z* between the two nodes. Once the nodes are deployed and the distance is known, it is possible to calculate the space mean speed of passing motorists. The nodes consist of a Bluetooth antenna to detect an active Bluetooth signal in passing vehicles, a computer board to maintain time synchronization and send data to a server, and batteries to power the device. Multiple nodes are placed along the roadway to record the timestamp and MAC address when an active Bluetooth device passes. The raw data is sent in real-time to a server for processing, which includes grouping multiple recordings of a single MAC address on an individual node, and matching the unique MAC addresses on multiple nodes. The distance between each node is known so that when a MAC address is recorded on multiple nodes, the speed may be calculated by dividing the distance by the time difference. Additional information about the intricacies of the Bluetooth node development and deployment may be found in other works (Schneider et al. 2012, Pasolini et al. 2002, Ahmed et al. 2008, Barceló et al. 2009, Haghani et al. 2010, Quayle et al. 2010, Kim et al. 2011). For this study, data are collected continuously from December 2013 until April 2014. This duration allowed the research team to not only track delay created by winter storms, but also to capture reoccurring congestion or other traffic patterns that may bias the data.

### *5.2.2 Winter Maintenance Equipment Data Collection*

This study compares the speeds resulting from the winter maintenance activities of a tow behind plow capable of plowing a second lane and a standard plow truck with a front plow, wing plow, and salt spreader. These will be referred to as the TowPlow and standard truck, respectively. The following paragraph describes the data collection process for both types of equipment.

The TowPlow is utilized in the 24-mile study zone on I-76 during the 2013–2014 winter season. This study zone is divided by State Route 44 (SR-44) so that the truck with the TowPlow maintains both directions of travel on the west side of the county, while the standard truck maintains both directions of travel on the east side. Additionally, there are events in which the trucks changed directions in order to eliminate biases in speeds due to road geometry, interchange density, or environmental factors, which will be accounted for in the data. The two trucks maintained different sections of the highway to eliminate cross contamination or the possibility that the maintenance activities of both trucks influence the speed data. A video system that includes four cameras and a digital video recorder is incorporated to collect data from the TowPlow. From the video footage, the researchers are able to record the plow status of the front plow and the tow behind plow, as well as to determine whether the hopper is applying de-icing material, the location of the truck (latitude and longitude), and the speed of the truck. The standard truck used in conjunction with the TowPlow is equipped with a GPS/AVL system to collect data automatically. The GPS/AVL system records the plow status, material application status, material application rate, and location. The standard truck is utilized during 22 snowfall events that occurred during the analysis period.

### *5.2.3 Data Fusion*

To evaluate the impact of the type of winter maintenance equipment on vehicle speeds, the Bluetooth speed data must be combined with the winter maintenance equipment data. The exact location of each BTN is known a priori, and segments are predefined to pair each node with the two adjacent nodes on either side in order to calculate a speed. Since the location of each truck is recorded, the data may be analyzed to determine each pass of the winter maintenance equipment through a given BTN segment.

For this study, the speeds are analyzed in three ways. First the entry time, plow status, treatment status, and exit time when a plow truck travels through an individual node segment are recorded. This resulted in each node segment having a unique start and end time, with each node starting at time t=0. When the truck passes the last node segment it will start at t=0, while the previous node segment will be at t=i, which is equal to the time it took the truck to travel between the two node segments. This will continue back to the node where the truck began treating, with each node segment having a unique start time and time duration. To determine the effects of the winter maintenance equipment, the research team queried the speeds for each segment beginning at the entry time until 20 minutes after the exit time for each of the segments identified. Second, the entry time, plow status, treatment status, and exit time are recorded when the plow truck exits the highway. At this point, t=0 is set for all the node segments the truck has recently treated. This analysis results in several node segments having the same start and end times, since the speeds are recorded in all recently treated segments for a period of 30 minutes once the truck exits the highway. Third, the time intervals when the standard truck is treating while the TowPlow is not treating are considered. The times for the standard truck are analyzed as in the first scenario, while the times on the other segment are analyzed from t=0 until the last time recorded for the standard truck. Figure 5.1 is developed to help describe this process and shows the first and second scenarios on the top and bottom, respectively.

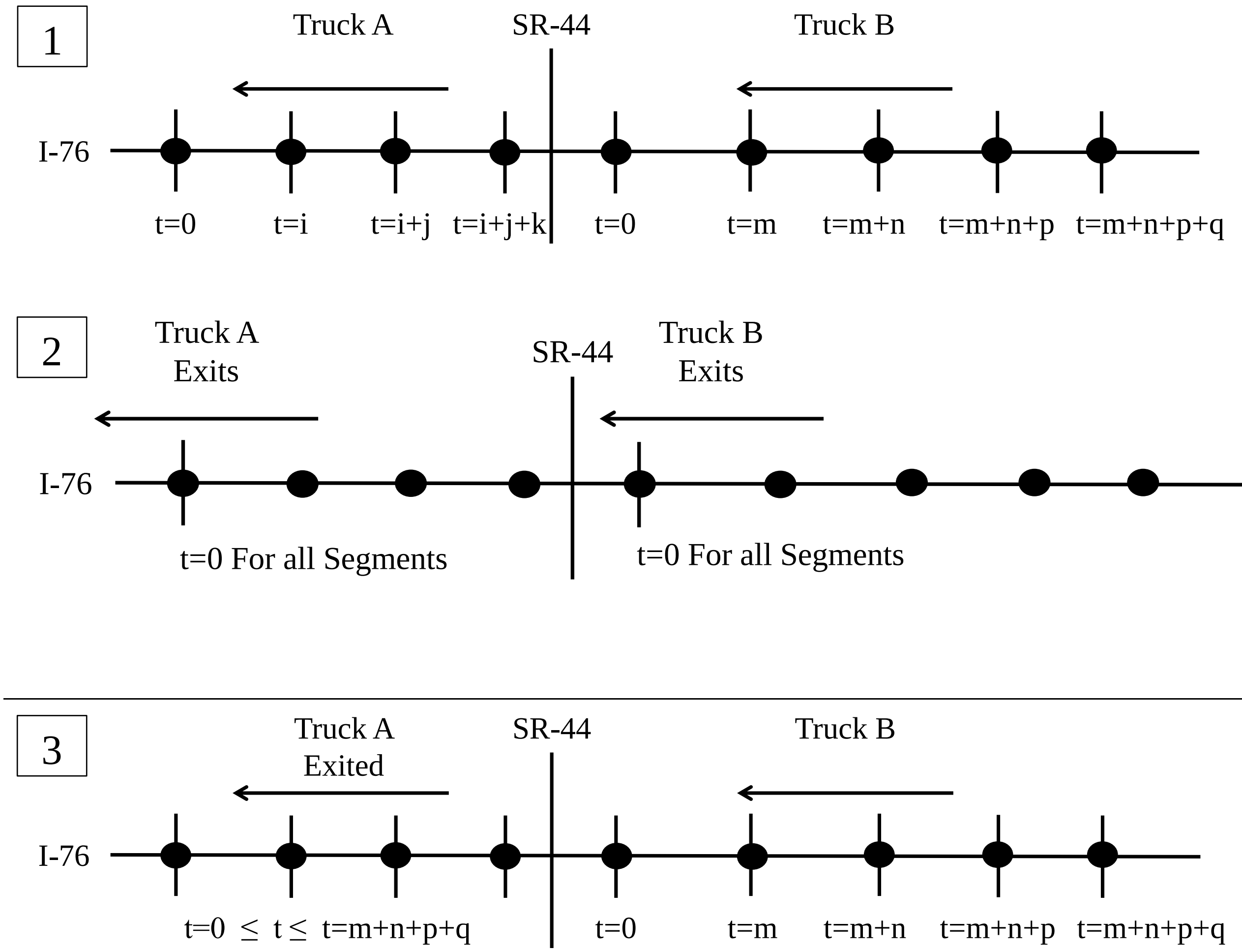



Figure 5.1: Description of Different Speed Data Collection Strategies.

In the first scenario, speeds are analyzed beginning each time a truck passes through the node segment. For the second scenario, speeds are analyzed using the same times for all segments recently treated, beginning at the time when the truck exits the highway. For the third scenario, speeds in the segment maintained by the standard truck are analyzed as in scenario one, while the same time frame is used for the other segment not currently being maintained.

In addition to the speed data, the hourly snowfall, the previous four hours' snowfall, and the total snowfall for the day are incorporated into the dataset. The snowfall data are gathered through the use of a NOAA weather station. The speeds and accompanying delay are analyzed based on different storm severities, which are determined using the previous four-hour snowfall. The storms are classified into three categories based on the previous four-hour snowfall: light for snowfall less than 0.5 inches, moderate for snowfall equal to or greater than 0.5 inches but less than one inch, and heavy for snowfall equal to or greater than one inch. Storm severity is often calculated using total snowfall for an event. However, since the speeds and delays are based on current and recent weather, future weather cannot be used in this determination. Although other researchers have developed storm severity classifications (Nixon et al. 2005), the classification system described herein is utilized based on the locality of the data and the temporal duration of the snowfall data.

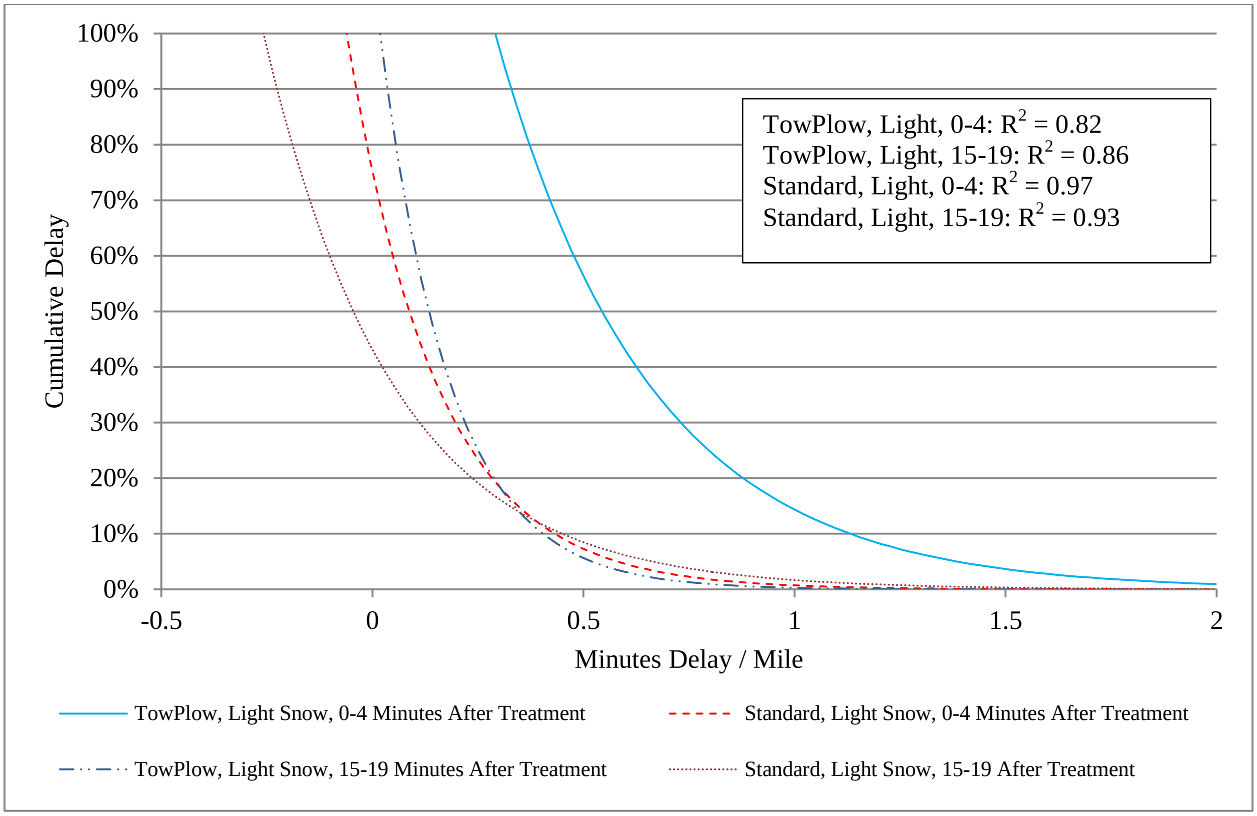
Delay is calculated from the vehicle speeds by comparing the expected travel time to the actual travel time. The expected travel time may be determined in minutes by multiplying the distance between the two nodes by the quotient of 60 minutes per hour and the speed limit. Similarly, the actual travel time may be found by replacing the speed limit with the actual vehicle speed. The BTN are placed in the field from December 2013 to April 2014 to capture baseline speeds under ideal weather conditions as well as speeds during winter events. The average speeds during weekday peak hours with normal weather are analyzed to determine if the expected travel time should be lower than the speed limit due to congestion, and the results indicated that using the speed limit is appropriate for the west side of SR-44, while 66 mph is appropriate for the east side of SR-44. As stated previously, the speed limit is 65 mph west of SR-44 and 70 mph east of SR-44. These 65 mph and 66 mph values are used as the baseline conditions from which delay is calculated, and the trucks maintain sections on both sides to eliminate any bias that may arise in the data from the different speed limits. Since each node segment is not of uniform length, the delay per mile is calculated to normalize for the varied lengths.

## 5.3 Analysis and Discussion

This research aims to quantify the impacts that various types of winter maintenance equipment have on vehicle speeds and the accompanying delays. To accomplish this, a TowPlow is assigned to maintain sections of a roadway in conjunction with a standard plow truck while the vehicle speeds and maintenance activities are recorded. Accordingly, the analysis and discussion is considered separately for the two types of delay: 1) the delay resulting after the winter maintenance equipment has recently passed through each segment and 2) the delay resulting after the winter maintenance equipment has exited the highway. In each case, an exponential decay curve is fit to the data with the accompanying coefficient of determination (R-squared value).

### *5.3.1 Delay in Individual Node Segments*

The first set of results analyzed is the delay occurring in each node segment after the truck passes through while treating the roadway. The times when the delays per mile occur are grouped into five-minute intervals for each weather category and treatment type. The cumulative delay per mile occurring during normal utilizations are compared, including the TowPlow (treating both lanes of the highway simultaneously) and the standard truck (treating one lane at a time), as shown in Figure 5.2.



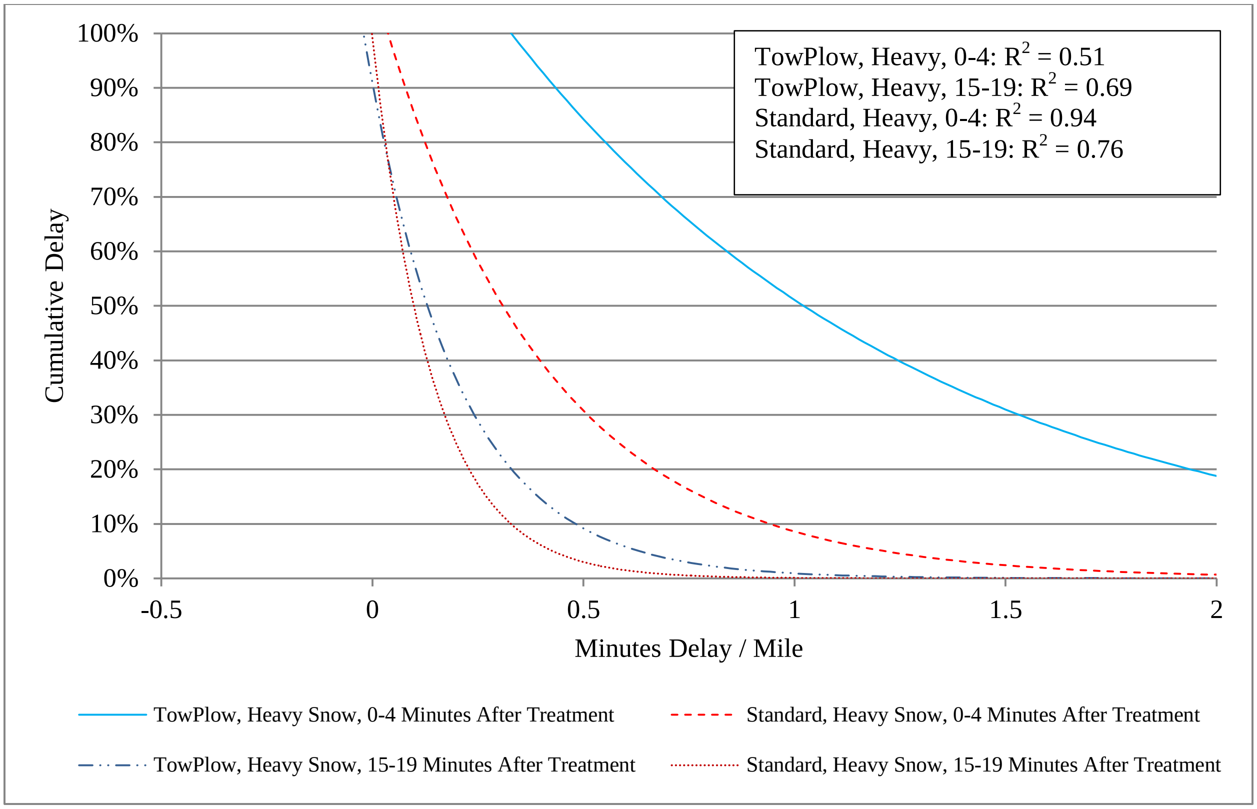
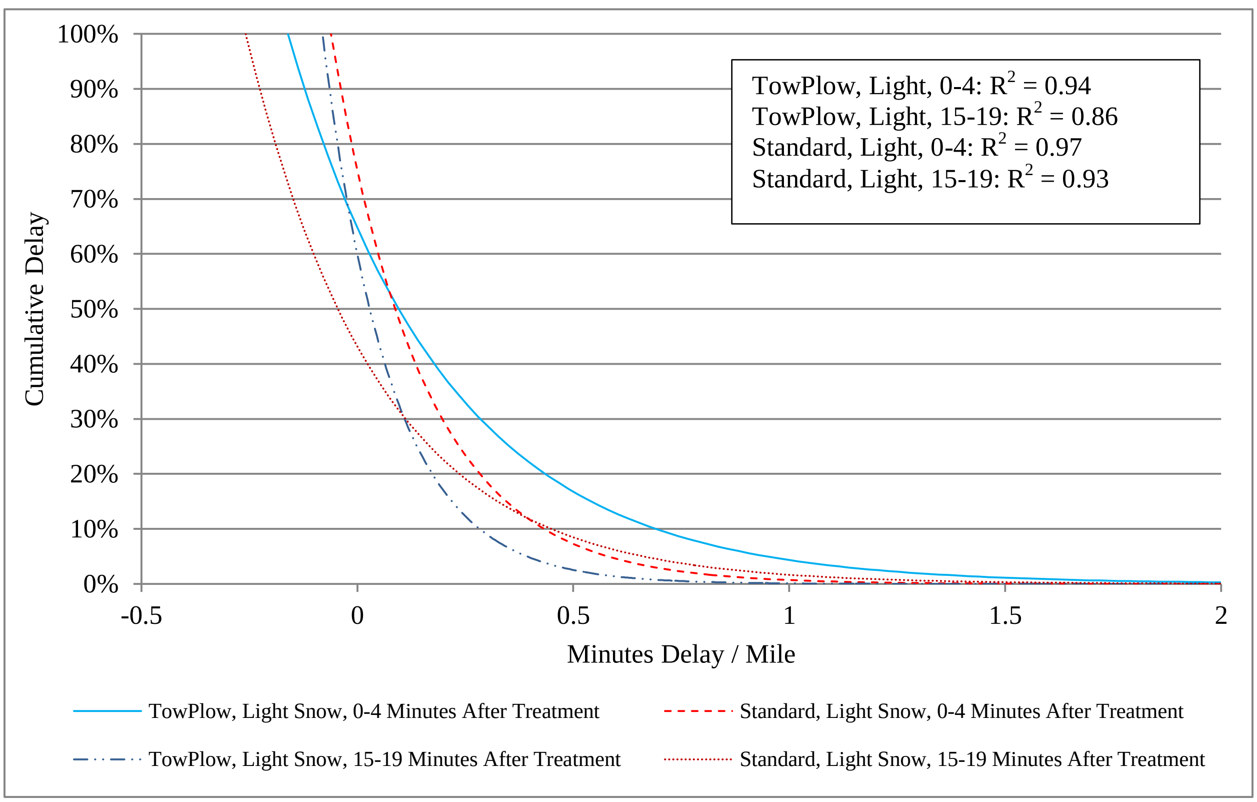



Figure 5.2: Cumulative Delay per Mile for TowPlow Maintaining Two Lanes and Standard Truck during Light and Heavy Snowfall.

The delay per mile shown corresponds to the delay of each individual vehicle on the roadway. The time intervals of zero to four minutes after the truck treated the node segment are compared to the time intervals of 15 to 19 minutes after treatment occurred. The delay per mile is shown for the TowPlow and the standard truck for light and heavy snowfall at zero to four minutes and 15 to 19 minutes after the truck passes through the node segments. From the first figure, it is found that the TowPlow has higher delay per mile than the standard truck during light and heavy snow. This occurs as a result of the TowPlow treating both lanes, which restricts traffic to traveling behind the truck and plow. While restricting traffic to traveling behind the TowPlow does result in increased vehicle delays, this may be viewed as a benefit by eliminating the possibility for a vehicle to travel at excessive speed in an untreated lane. Essentially, the TowPlow may limit vehicles by making them travel at slower speeds until both travel lanes are cleared.

When comparing the delay per mile from the TowPlow zero to four minutes after treating during light and heavy snow, much greater delay is apparent during heavy snowfall. One possible cause for this result is that the TowPlow may be traveling more slowly and causing greater queues, which is not the case since the TowPlow treated at an average speed of 32 mph and 29 mph during light and heavy snowfall, respectively, which would result in a difference of 0.2 minutes per mile in delay. This difference is only applicable when comparing the same time interval of the TowPlow during light and heavy snowfall. The larger delay during heavy snowfall is likely caused by motorists recognizing the hazardous conditions and reducing their speeds accordingly, a supposition which is further reinforced by a similar pattern found for traffic in segments maintained by the standard truck. During light snowfall, the TowPlow has a higher delay per mile during each time interval; during heavier snowfall, the delay per mile in the segments maintained by the TowPlow approaches that of the standard truck. Since the TowPlow maintains both lanes of traffic at once, the larger initial delay dissipates and approaches that of the standard truck over time. Since the TowPlow is maintaining both lanes, a similar delay per mile is expected to occur if two plow trucks are gang plowing.

The second configuration in which to analyze the delay per mile is a situation where the TowPlow treats the right lane and the shoulder while the standard truck maintains one traffic lane. Figure 5.3 shows the cumulative delay per mile for the TowPlow maintaining one lane and the shoulder and the standard truck maintaining one lane during light and heavy snowfall, during time intervals zero to four and 15 to 19 minutes following treatment.



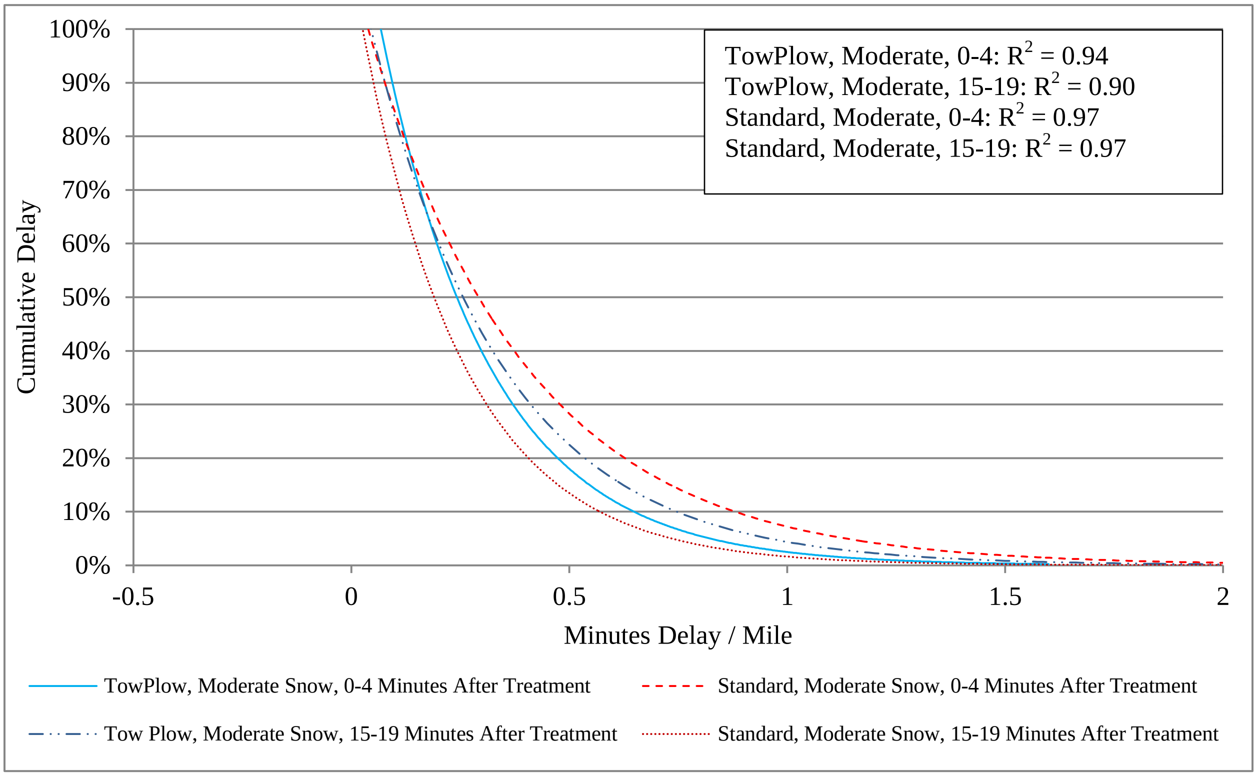
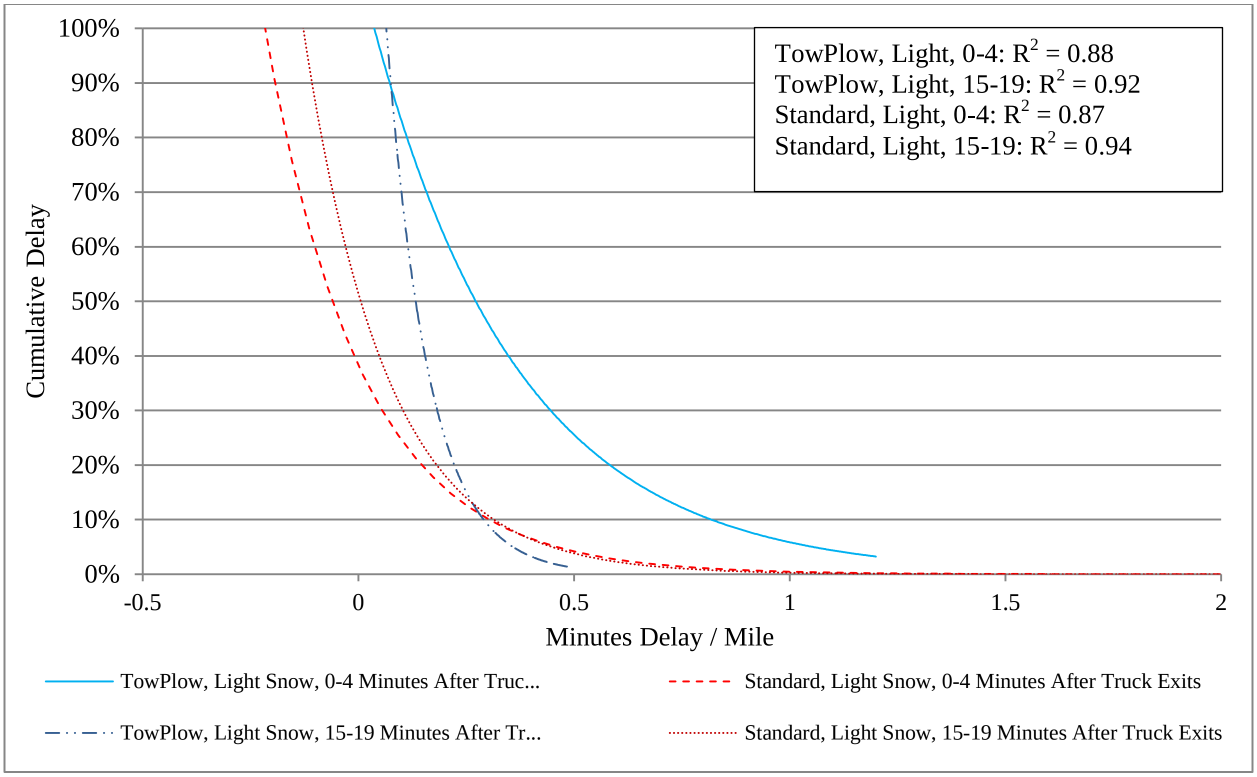



Figure 5.3: Cumulative Delay per Mile for TowPlow Maintaining One Lane and Shoulder and Standard Truck during Light and Heavy Snowfall.

During light snowfall, the delay per mile for the TowPlow maintaining one lane and the shoulder is very similar to that of standard truck, since both trucks are maintaining a single lane in this configuration. When comparing the delay per mile during heavy snowfall, the values are very similar when comparing the first time interval to the second for each of the trucks. Having similar delay per mile immediately after the trucks treat and 15 to 19 minutes following treatment indicates that no significant queues developed behind either of the trucks.

### *5.3.2 Delay when Trucks Exit the Roadway*

Since the TowPlow may block both travel lanes while treating and cause queues to develop, the cumulative delay per mile is analyzed in all segments after the trucks have exited the highway. Figure 5.4 shows the cumulative delay per mile in segments maintained by the TowPlow treating two lanes and the standard truck treating one lane after the trucks have exited the highway.



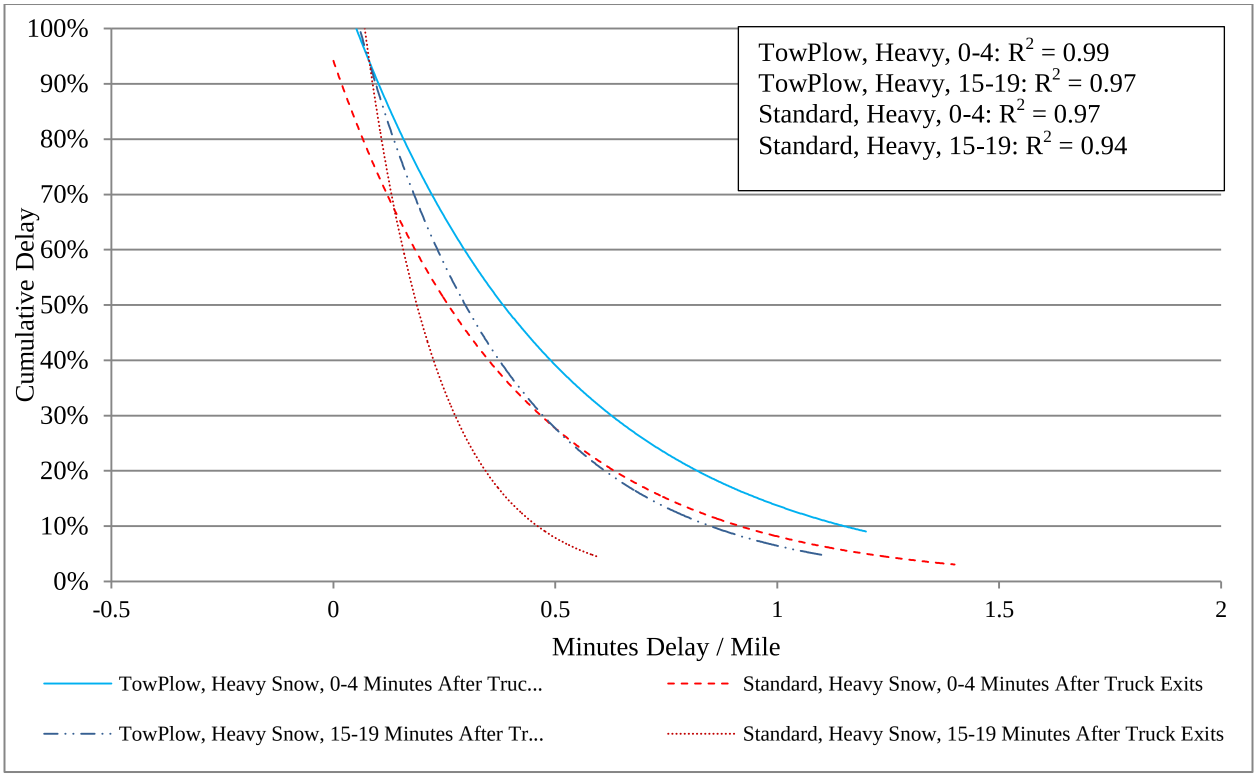
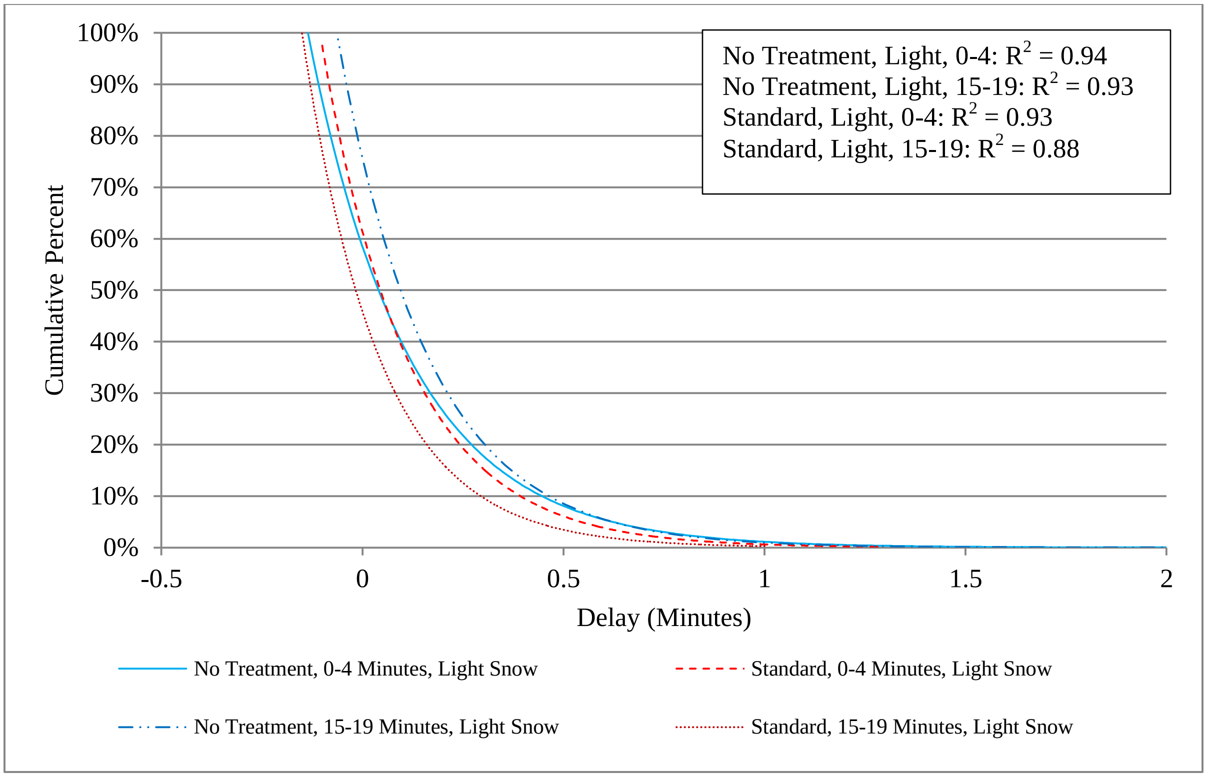




Figure 5.4: Cumulative Delay per Mile for TowPlow Maintaining Two Lanes and Standard Truck during Light and Heavy Snowfall after the Trucks have Exited the Highway.

During light snowfall, the delay per mile is higher for the TowPlow than for the standard truck, which is caused by the queues that build up when the equipment blocks both lanes of travel. When comparing the delay per mile caused by the TowPlow during light and heavy snowfall, the values are similar. However, the delay per mile caused by the standard truck is much greater during heavy snowfall than light snowfall and reaches similar values as the TowPlow; this trend results from motorists decreasing their speeds when only one lane of the roadway has been cleared by the standard truck. This finding indicates that although the TowPlow creates larger delays than the standard truck, it is more effective during heavier snowfall, since it is able to clear two travel lanes in a single pass. The initial delay may be seen by comparing the delay per mile in the zero to four minute interval in Figure 5.4 to the delay in the same time interval in Figure 5.2.

## 5.4 Delay When Standard Truck is Treating without the TowPlow

There may be times when the standard truck is maintaining its route while the TowPlow is not required to do so as a result of being able to maintain two lanes in a single pass. It is important to analyze the delay caused solely by the standard truck’s maintenance activities. To accomplish this, the research team identified times when the standard truck is treating while the TowPlow had either finished maintaining its route or is simply patrolling the roadways. The same process used previously to analyze the delay is incorporated on this dataset. Figure 5.5 shows the cumulative delay per mile for the sections maintained by the standard truck and the sections that received no maintenance at the time when the standard truck is treating.



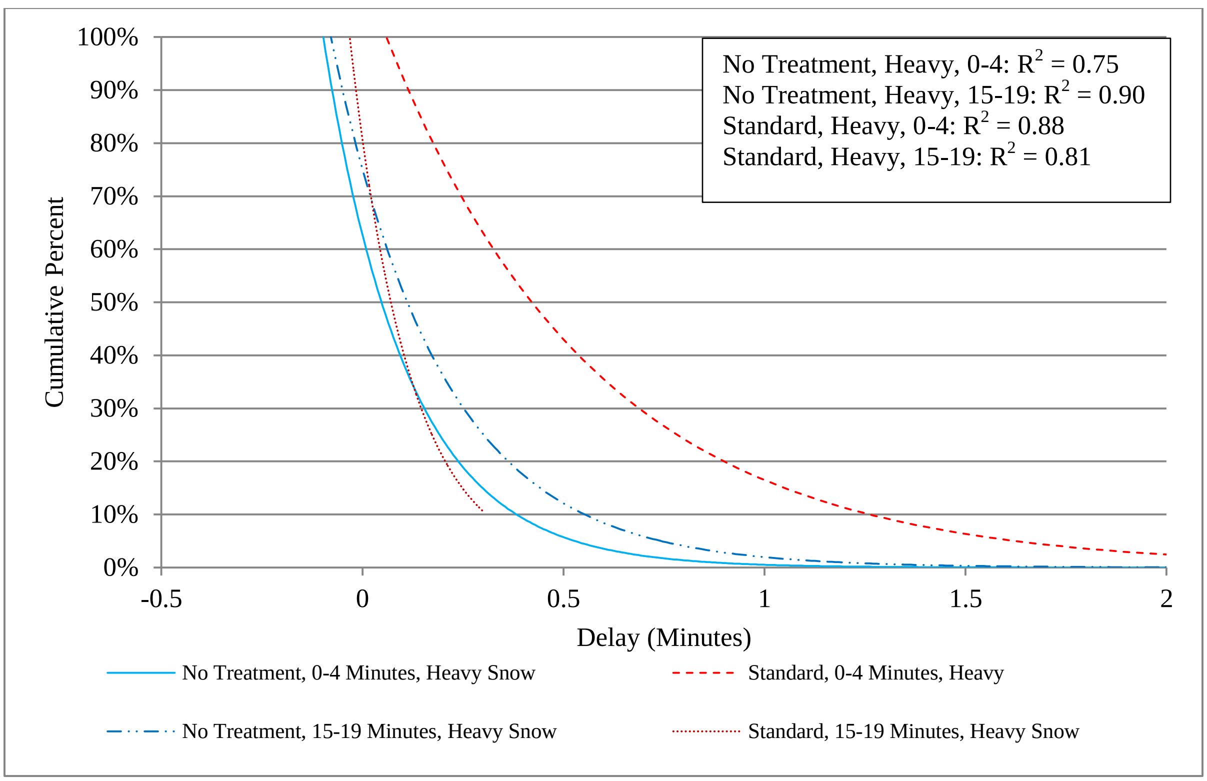




Figure 5.5: Cumulative Delay per Mile for Standard Truck and No Treatment during Light and Heavy Snowfall.

The delay per mile is found to be nearly identical during light snowfall for the standard truck and the section with no truck currently maintaining the roadway. When comparing the delay per mile during heavy snowfall, there is more delay in the segments maintained by the standard truck than in the segments with no truck maintaining the roadway. One thing that is important to note is that the section with no current treatment has more delay 15 to 19 minutes after treatment than it does zero to four minutes later. This is not surprising, since it has been longer since any performance of maintenance activity has occurred. The greatest difference in delays occurs in zero to four minutes after the standard truck has treated during heavy snowfall. The segments with no current treatment have far less delay than the section just maintained by the standard truck.

## 5.5 Number of Treatments Required

The TowPlow is capable of plowing and treating two lanes per pass, compared to the standard truck, which is only capable of plowing and treating a single lane per pass. As a result, it is expected that the TowPlow will have to maintain the roadway a fewer number of times. The number of passes made by the TowPlow and standard truck while treating and not treating are shown in Table 5.1.

Table 5.1: Number of Loops per Hour made While Treating for the TowPlow and Standard Truck.

| | | Number of Passes | Events | Passes per Event |
|---|---|---|---|---|
| TowPlow | Treating | 74 | 29 | 2.6 |
| | Not Treating | 80 | 29 | 2.8 |
| Standard Truck | Treating | 149 | 29 | 5.1 |
| | Not Treating | 65 | 29 | 2.2 |

A “pass” refers to each event where the winter maintenance equipment treated one direction of the roadway, and “treating” refers to plowing, salting, or plowing and salting in the same pass. The standard truck made more passes while treating than the TowPlow, at a nearly 2:1 rate. While the TowPlow may create larger delays than the standard truck, the TowPlow is not on the road as often as the standard truck.

## 5.6 Conclusion

This investigation evaluated the impacts of specialty winter maintenance equipment on vehicle delay by fusing Bluetooth speed data, weather data, and winter maintenance treatment data. A TowPlow capable of maintaining two lanes in a single pass is compared to a standard plow truck that plows and spreads material over one lane at a time. Each type of winter maintenance equipment is analyzed on the same four-lane interstate highway. The TowPlow maintains one section of roadway, while the standard truck maintains a different section to avoid cross contamination. The roadway has multiple BTN segments to capture the vehicle speeds while maintenance activities are occurring.

The cumulative delay per mile is determined for the standard truck and the TowPlow during light and heavy snowfall. The times when delay occurred are grouped into five-minute intervals for two different scenarios, including occasions when the winter maintenance equipment has just passed through a BTN segment and for all recently-treated segments after the maintenance equipment has exited the highway. The results indicated that the TowPlow created a larger delay than the standard truck when plowing two lanes simultaneously and a similar delay when plowing one lane and the shoulder. These delays are caused by the TowPlow maintaining two lanes simultaneously and restricting vehicles from passing the plow as a result. This may be considered as a benefit of the TowPlow, as it does not allow for vehicles to pass at excessive speeds in an untreated lane. Although some motorists may not appreciate the forced speed reduction, the TowPlow ensures that motorists will travel at safer speeds when following the deployed equipment. Additionally, the delay created by the TowPlow is larger at the time closest to the time the truck first treated the roadway, as a result of the initial queue building up behind the truck. These initial queues are indicated by delay per mile curves that are much further apart for the TowPlow and standard truck in Figure 5.2, found immediately after the trucks treated the road, and the similar delay values for each truck in Figure 5.4, found after the trucks exited the highway. However, when looking solely at heavy snowfall, the delay is similar for each type of equipment, indicating that the TowPlow is more effective during heavy snowfall.

The number of passes made while treating are compared for the TowPlow and the standard truck. The TowPlow creates larger delays than the standard truck, as a result of the TowPlow's capability for maintaining two lanes per pass, but it does not need to treat as often as the standard truck. Since the TowPlow is found to treat half as often as the standard truck, the impact of the delays are realized far less often on the roadway. These results are found for a TowPlow capable of plowing two lanes at once, but the results would be similar for gang plowing operations when multiple plows are used simultaneously.

# CHAPTER VI COST ANALYSIS

This chapter presents the annualized cost for operating the TowPlow and an ODOT standard truck in a typical winter season in Ashtabula, Mahoning, and Portage Counties. The data collected during this evaluation are used in determining the utilization of the TowPlow and the standard truck. The utilization of each truck is applied to an efficiency equation to determine how many standard trucks are needed to provide maintenance that is equal to one TowPlow. This chapter is divided into four sections:

- Section One – Introduction to Monte Carlo simulation, the statistical methodology used for the cost analysis,
- Section Two – Utilization rates for the standard truck and the TowPlow,
- Section Three – Determination of the equivalence of the TowPlow to the standard truck, and
- Section Four – Annualized costs for TowPlow and standard truck.

## 6.1 Introduction to Monte Carlo Simulation

Monte Carlo simulations are used to determine the annualized costs for both the TowPlow and the standard truck, as well as to determine the equivalence of the TowPlow to the standard truck. In Monte Carlo simulation, a set of functions is solved many times over while randomly changing the variables' values within the functions. Each variable is presented with an average and standard deviation of a normal distribution, which the simulation applies when the random variable is selected. The software Matlab, developed by MathWorks (Natick, Mass.), is used to run the Monte Carlo simulation and allows the simulation to be repeated the desired number of times. In this study, a Monte Carlo simulation is used to determine a distribution of the annualized costs for employing the evaluated equipment as part of a winter maintenance program and to determine the equivalence of the TowPlow to an ODOT standard truck.

## 6.2 Utilization Rate

The utilization rate for the TowPlow and the standard truck is important for performing an annualized cost comparison for the trucks. The utilization rate represents how much the equipment is used to maintain the roadways during a winter event. The utilization rate is calculated in two different ways for each truck. In the first method, an overall utilization rate is calculated for the entire winter season. In the second method, utilization rates are calculated for four storm severities: trace, light, moderate, and heavy.

The TowPlow is considered to be operating any time the TowPlow is deployed for treating and is positioned in any treatment configuration on the roadway (for example, salting the right lane or plowing the shoulder of the road). The utilization rate of the TowPlow is calculated using video data to determine the deployment rate of the TowPlow during the winter event as a percentage of the total time the TowPlow is on the route during the event. Equation 6.1 shows how the utilization rates are calculated for the TowPlow.

$$Utilization\ Rate\ for\ TowPlow\ (UR_{TowPlow}) = \frac{Time\ TowPlow\ is\ Deployed}{Total\ Time\ TowPlow\ is\ on\ Route\ During\ Event} \times 100$$

Equation 6.1

The calculation shown in Equation 6.1 is performed for each winter event. An average utilization rate with a standard deviation over the entire season is calculated to determine an overall utilization rate, and an average for each storm severity is calculated to determine the utilization rate in each storm severity. All three TowPlows evaluated during this study are used in the calculation of the utilization rates.

The standard truck is considered to be operational when the truck is salting or plowing during the winter event. Equation 6.2 shows how the utilization rates of the standard truck are calculated.

$$Utilization\ Rate\ for\ Standard\ Truck\ (UR_{Standard}) = \frac{Time\ Standard\ Truck\ is\ Treating}{Total\ Time\ Standard\ Truck\ is\ on\ Route\ During\ Event} \times 100$$

Equation 6.2

Similar to the TowPlow utilization rate, the utilization rate for the ODOT standard truck (a truck with a front plow and a mid-mounted wing plow attached) is calculated for each winter event. Averages of the overall utilization over the entire winter season and for each of the four storm severities are determined in a manner that is similar to that used for determining the utilization of the TowPlow. In this study, one ODOT standard truck, the truck that is employed for treating I-76 in the opposite segment to that of Portage County’s TowPlow, is used to determine the overall utilization rate. The standard truck is equipped with a GPS/AVL system for collecting data such as time, location, and type of treatment being performed on the roadway. The data collected from the GPS/AVL system, along with information from the M&R 661 forms, which are completed by the operators of the truck during the treatment of the assigned route, are used in determining the time the standard truck is treating the road and the total time the truck is on route during an event.

## 6.3 TowPlow to Standard Truck Equivalency

The TowPlow is able to treat two lanes in one pass, compared to the standard ODOT truck, which is able to treat only one lane per pass. Reviewing the data collected from the three TowPlows used by ODOT in the winter of 2013–2014, it is observed that the TowPlow is not always used during the entire event, and it may not be necessary to use the TowPlow during less severe storms. Consequently, the equivalence of the TowPlow to the standard trucks will not necessarily be a 2:1 ratio. In order to determine the true equivalence for this evaluation, it is necessary to employ Equation 6.3.

$$\begin{aligned} &Capacity_{TowPlow} \times Overall\ UR_{TowPlow} \times Efficiency_{TowPlow} \\ &\qquad = Capacity_{Standard} \times Overall\ UR_{Standard} \times Efficiency_{Standard} \times \theta \end{aligned}$$

Equation 6.3

Where,
$Capacity_{TowPlow}$ = number of lanes the TowPlow may treat in a single pass = 2 lanes,
$Capacity_{Standard}$ = number of lanes the standard truck may treat in a single pass = 1 lane,
Overall $UR_{TowPlow}$ = overall utilization rate of the TowPlow over the 2013–2014 winter season,
Overall $UR_{Standard}$ = overall utilization rate of the standard truck over the 2013–2014 winter season,
$Efficiency_{TowPlow}$ = efficiency of theTowPlow in treating the roadway,
$Efficiency_{Standard}$ = efficiency of the standard truck in treating roadway, and
θ = number of standard trucks needed to equal the abilities of a single TowPlow unit.

In this study, the overall utilization rate of the TowPlow is found to have an average of 54% with a standard deviation of 0.3. The standard truck is found to have an average of 65% with a standard deviation of 0.3. As discussed with ODOT in a preliminary project meeting, the efficiency variables are assumed to be equal to one another, since there is no definitive method for collecting this data in the field and the variables would therefore drop out of the equation. The new equation, which is expressed without efficiency and is rearranged to solve for θ, is presented in Equation 6.4.

$$\theta = \frac{2\ lane\ \times Overall\ UR_{TowPlow}}{1\ lane\ \times Overall\ UR_{Standard}}$$

Equation 6.4

Equation 6.4 along with the average and standard deviation of the overall utilization rates for both trucks, are placed in Monte Carlo simulation using MatLab for a hundred thousand iterations. For each iteration, the Monte Carlo simulation selects a random utilization rate in order to create a distribution of θ. Figure 6.1 presents the results of the Monte Carlo simulation.

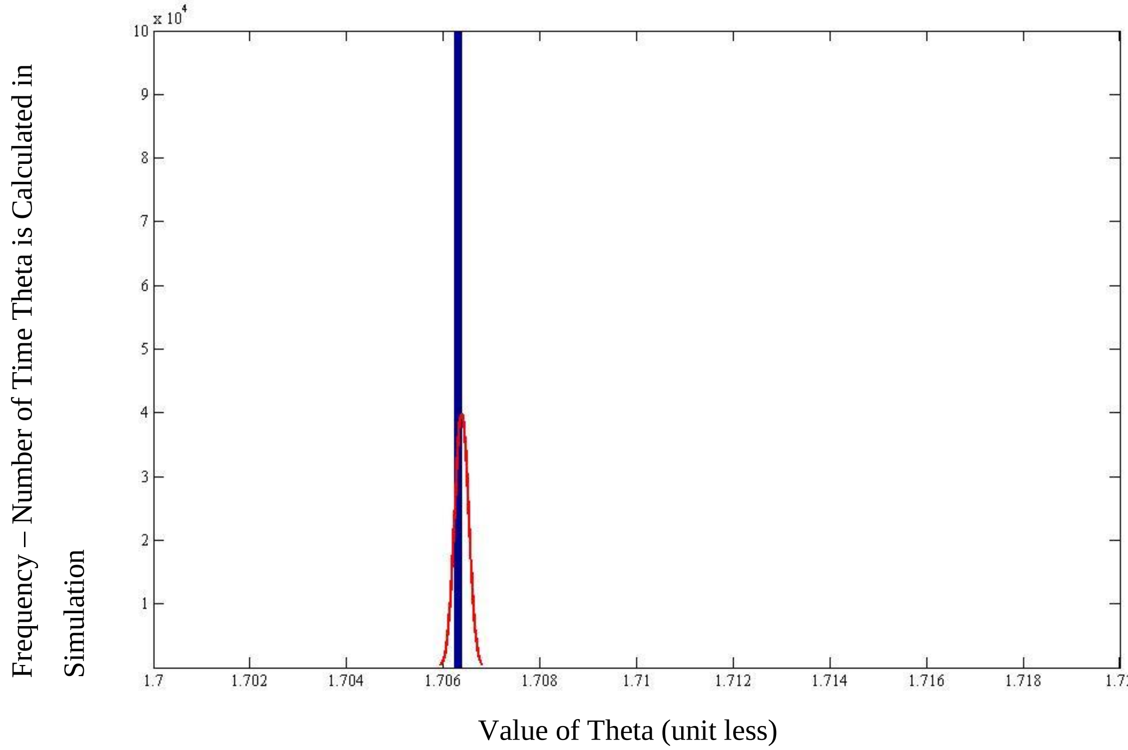



Figure 6.1: Distribution of Theta through Monte Carlo Simulation.

The y-axis of Figure 6.1 is the frequency, while the outcome of the simulation is the value on the x-axis. The simulation provides an average theta (θ) and a standard deviation. The resulting average of θ is determined to be 1.706 with a standard deviation of $1.418 \times 10^{-4}$. These values are applied to the annualized cost Monte Carlo simulation for a standard truck in order to determine the true comparison costs of operating the number of standard trucks that are equivalent to one TowPlow. Once θ is calculated, it is incorporated into the annualized standard truck cost to determine the true cost equivalency of the TowPlow as compared to the standard truck.

## 6.4 Annualized Cost for TowPlow and Standard Truck

There are several components to consider for the annualized cost of the TowPlow and Standard truck, which are presented in Figure 6.2.

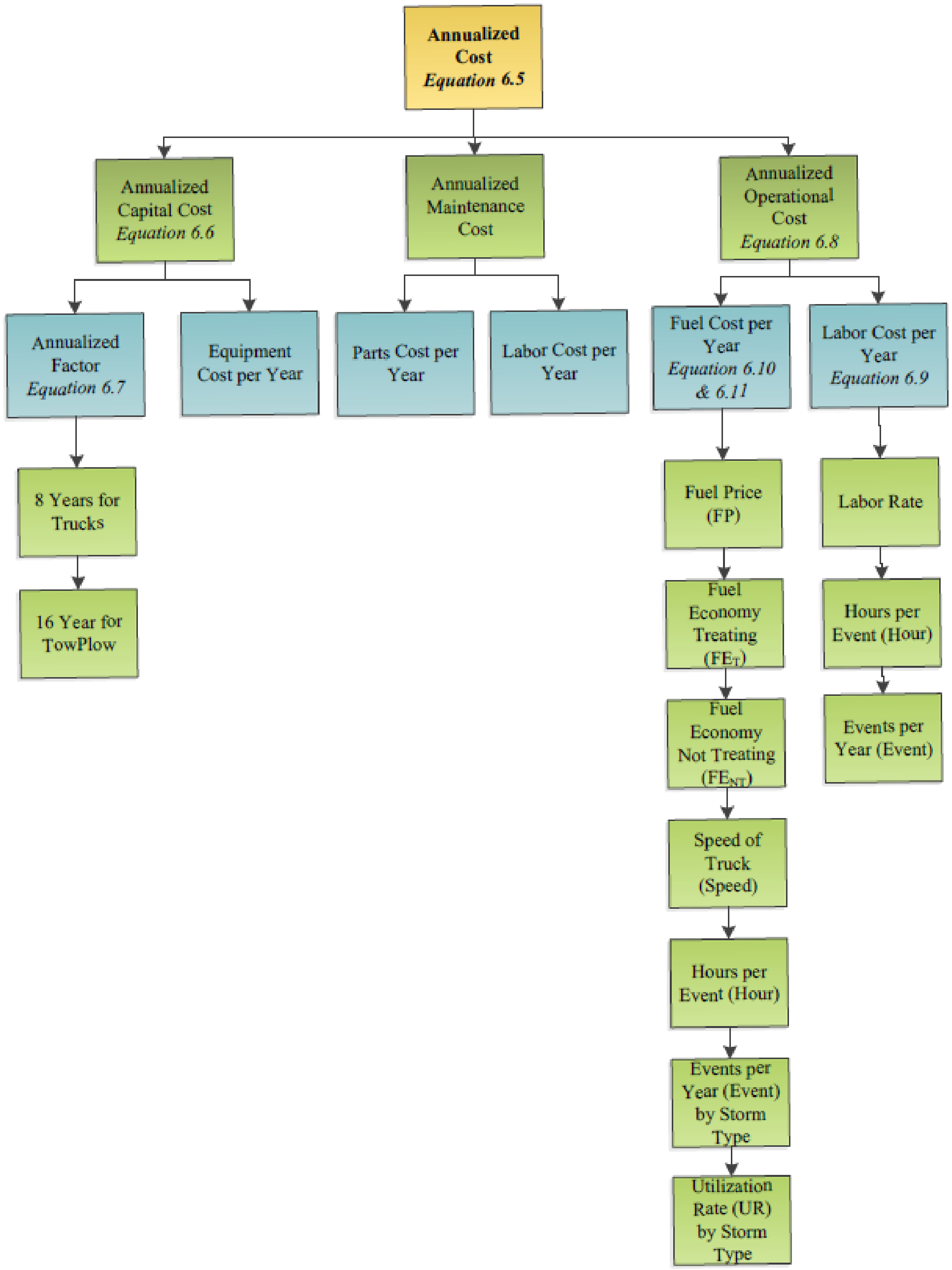



Figure 6.2: Variables to Calculate Annualized Cost of TowPlow and Standard Truck.

From Figure 6.2, it may be seen that three categories are considered in the annualized cost of equipment used for winter maintenance at ODOT: capital cost of the equipment, annualized with the expected life span of the equipment; the yearly maintenance cost to keep the equipment in service; and the costs for the operation of the equipment, which includes labor and fuel costs. The annualized cost is presented in Equation 6.5.

$$Yearly\ Cost = Annualized\ Capital\ Cost + Annualized\ Maintenance\ Cost + Annualized\ Operational\ Cost$$

Equation 6.5

As discussed with ODOT in preliminary meetings, there is little to no salvage value for winter maintenance equipment; therefore, salvage value is not considered in the annualized cost.

The annualized capital cost is determined using Equation 6.6, presented below.

$$Annualized\ Capital\ Cost = Capital\ Cost\ (\$) * Annualized\ Factor(yr^{-1})$$

Equation 6.6

Where,

$$Annualized\ Factor\ (\ yr^{-1}) = \frac{i}{(1+i)^n - 1} + i$$

Equation 6.7

In Equation 6.7, *i* represents the discount factor and *n* is the life expectancy of the equipment. The annualized factor, is known as a discount rate, is varied based on preliminary discussions with ODOT. The expected life of the standard truck and the truck pulling the TowPlow is eight years, in accordance with ODOT standard practices. ODOT expects the TowPlow attachment to last for two truck cycles; therefore, the life expectancy for the TowPlow is 16 years. The maintenance costs for all types of equipment are provided by ODOT.

The operational cost of the TowPlow and standard truck includes fuel costs as well as the labor costs associated with an operator, as represented in Equation 6.8.

$$\begin{aligned} &Annualized\ Operational\ Cost\ (\$/yr) \\ &\qquad = Fuel\ Cost\ per\ Winter\ Season(\$/yr) + Labor\ Cost\ per\ Winter\ Season\ (\$/yr) \end{aligned}$$

Equation 6.8

The labor cost per season is anticipated to be the same when comparing one TowPlow to one standard truck, since ODOT operates the trucks in shifts; however, the labor cost is increased when θ is applied to the equation, since multiple standard trucks are needed to match the capacity of the TowPlow. Equation 6.9 presents the labor cost calculation.

$$Labor\ Cost\ (\$/yr) = Labor\ Rate\ (\$/hr) \times Hour\ (hr/event) \times Total\ Event\ (events/yr)$$

Equation 6.9

In this study, the fuel cost difference is found to depend on the weather severity utilization rate (UR) and the fuel economy (FE) of each truck. Equation 6.10 is the total fuel cost per year, which is calculated by summing the fuel costs for each storm severity type.

$$\begin{aligned} Fuel\ Cost\ (\$/yr) &= Fuel\ Cost_{Trace}(\$/yr) + Fuel\ Cost_{Light}(\$/yr) + Fuel\ Cost_{Moderate}(\$/yr) \\ &+ Fuel\ Cost_{Heavy}(\$/yr) \end{aligned}$$

Equation 6.10

Where,

$$\begin{aligned} Fuel\ Cost_{Storm\ Type}\ (\$/yr) &= UR_{Storm\ Type}\left[\frac{FP\ (\$/gal)}{FE_T\ (mile/gal)} \times Speed\ (mile/hr) \times Hour\ (hr/event) \right. \\ &\left. \times Event_{Storm\ Type}\ (events/yr)\right] \\ &+ \left(1 - UR_{Storm\ Type}\right)\left[\frac{FP\ (\$/gal)}{FE_{NT}\ (mile/gal)} \times Speed\ (mile/hr) \times Hour\ (hr/event) \right. \\ &\left. \times Event_{Storm\ Type}\ (events/yr)\right] \end{aligned}$$

Equation 6.11

The fuel cost for the year is presented in Equation 6.10. Once the fuel cost for each of the four storm severity types is calculated using Equation 6.11, the total fuel cost is determined using Equation 6.10. Data used in these calculations, including labor costs for plow truck operators and diesel fuel costs, are provided by ODOT. Fuel economy data is obtained from information recorded on the ODOT M&R 661 forms completed by the truck operators.

### *6.4.1 Variables*

All the variables within the equations used for calculating the annualized costs are assigned an average and standard deviation, which the Monte Carlo simulation uses when selecting a random variable. Table 6.1 provides the average and standard deviation value for each variable, along with the source used to derive that particular variable.

Table 6.1: Values of Variables Used in Annualized Cost.

| Variable | Average | Standard Deviation | Source |
|---|---|---|---|
| Capital Cost TowPlow ($) | 101000 | 1000 | ODOT |
| Capital Cost of Truck Pulling TowPlow ($) | 200080 | 18067 | ODOT |
| Capital Cost Standard Truck (w/wing plow) | 168179 | 1000 | ODOT |
| Annualized Factor | 0.04 | 0.02 | ODOT |
| Fuel Price ($/gal) | 4 | 1 | ODOT |
| Fuel Economy (mile/gal) TowPlow Treating | 3.5 | 1.1 | M&R 661 |
| Fuel Economy (mile/gal) TowPlow Not Treating | 3.7 | 1.1 | M&R 661 |
| Fuel Economy (mile/gal) Standard Treating | 4.4 | 1.14 | M&R 661 |
| Fuel Economy (mile/gal) Standard Not Treating | 4.8 | 0.57 | M&R 661 |
| Speed of Truck (mph) | 31 | 9.5 | GPS/AVL and Video |
| Hours of Events (hr/event) | 8 | 2 | NOAA |
| Trace Events (event/yr) | 51 | 9 | NOAA |
| Light Events (event/yr) | 31.5 | 2 | NOAA |
| Moderate Events (event/yr) | 12 | 2.4 | NOAA |
| Heavy Events (event/yr) | 4.5 | 0.5 | NOAA |
| Utilization Rate TowPlow Trace Event | 0.17 | 0.3 | Video |
| Utilization Rate TowPlow Light Event | 0.45 | 0.3 | Video |
| Utilization Rate TowPlow Moderate Event | 0.72 | 0.3 | Video |
| Utilization Rate TowPlow Heavy Event | 0.91 | 0.3 | Video |
| Utilization Rate Standard Trace Event | 0.18 | 0.3 | GPS/AVL and M&R 661 |
| Utilization Rate Standard Light Event | 0.67 | 0.3 | GPS/AVL and M&R 661 |
| Utilization Rate Standard Moderate Event | 0.96 | 0.3 | GPS/AVL and M&R 661 |
| Utilization Rate Standard Heavy Event | 1 | 0.3 | GPS/AVL and M&R 661 |
| Labor Rate ($/hr) | 17.5 | 3 | ODOT |
| Maintenance Cost Truck and TowPlow ($/yr) | 9000 | 250 | ODOT |
| Maintenance Cost Standard ($/yr) | 8000 | 250 | ODOT |

Notes: Sources labeled "ODOT" are values provided by ODOT, "video" data is from the record TowPlow video data, "GPS/AVL" are values obtained from the GPS/AVL system equipped on a standard truck, the "M&R 661" are values obtained from standard ODOT M&R 661 forms completed by operators during events, and "NOAA" is data obtained from NOAA weather stations.

Information about the sources used to obtain these values are provided in the notes at the bottom of Table 6.1. The number of years to determine the discounted annualized capital cost of the equipment, which is calculated using Equation 6.7, is a set number that depends on the life expectancy of the equipment as discussed in Section 6.4, in the paragraph below Equation 6.7.

### *6.4.2 Results*

The first Monte Carlo simulation is run for the annualized cost to operate one TowPlow, using Equations 6.5 through 6.11. The simulation is repeated 500,000 times to determine an average annualized cost when randomly selecting values within the average and standard deviation of each TowPlow variable presented in Table 6.1. Figure 6.3 presents the distribution of the Monte Carlo simulation.

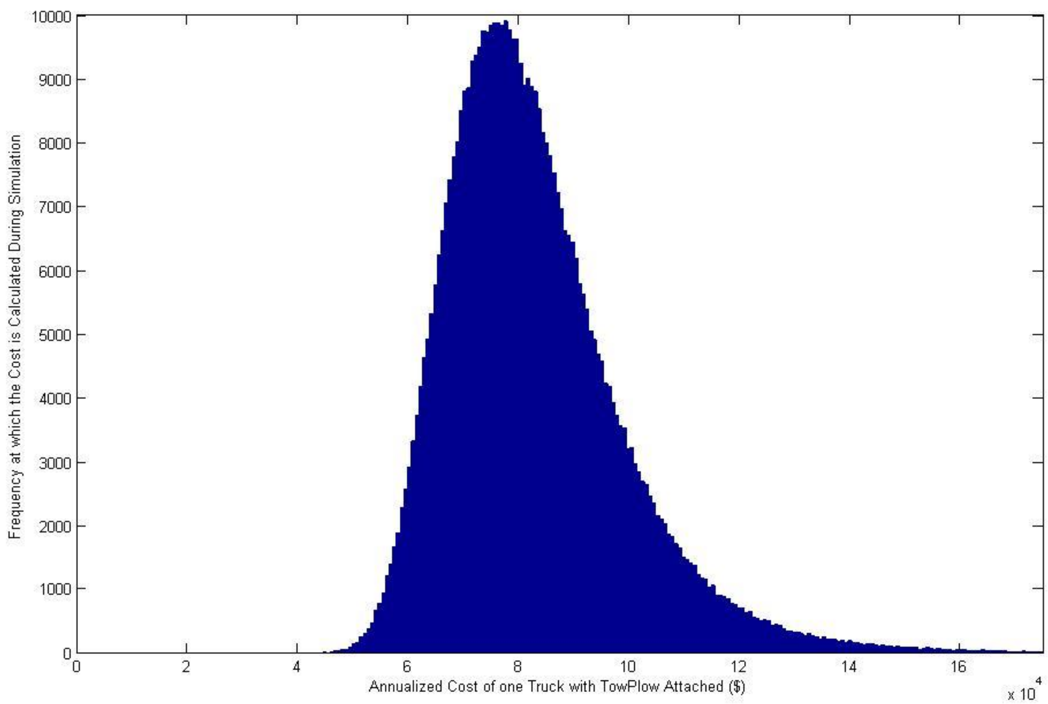



Figure 6.3: Distribution of the Annualized Cost of One TowPlow in Monte Carlo Simulation.

From the distribution shown in Figure 6.3, it is found that the TowPlow has an average annualized cost of $83,629. This cost includes an annualized capital cost for both the TowPlow and the truck pulling the TowPlow, the maintenance cost per year, the labor cost, and the fuel cost required to operate in an average winter season.

The cost to operate the standard truck, is a tandem axle truck with a mid-mounted wing plow, is calculated using Equations 6.5 through 6.11. Similar to the TowPlow cost, the simulation is repeated 500,000 times to find an average cost.  Figure 6.4 presents the cost to operate one standard truck.

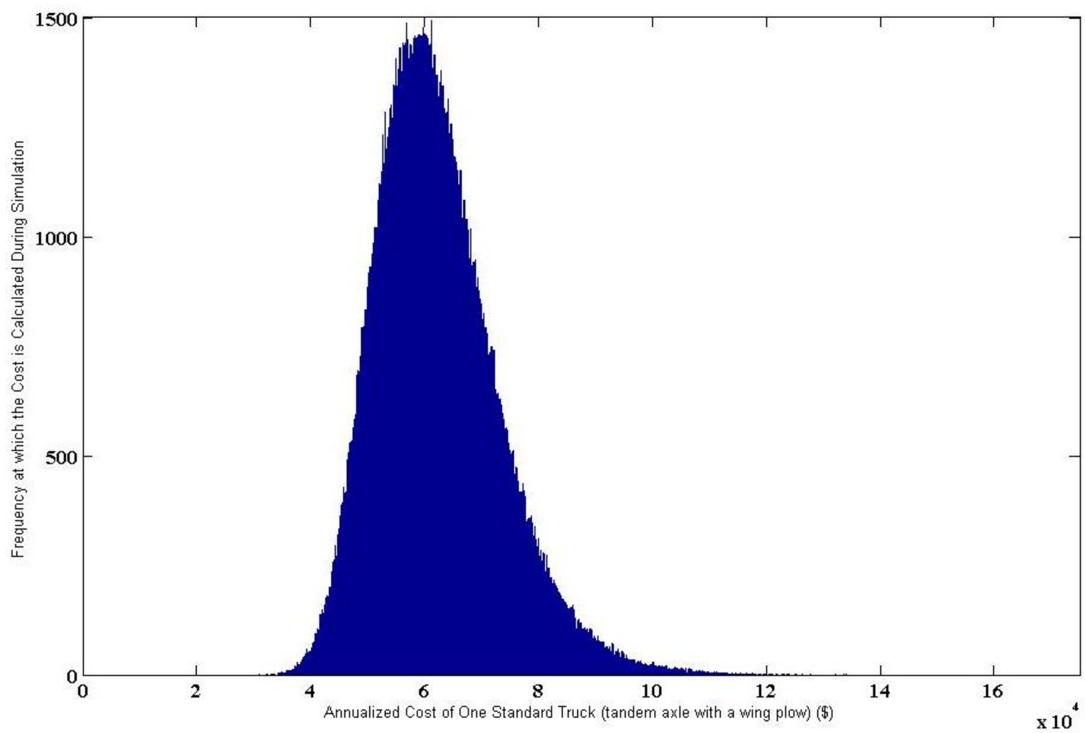



Figure 6.4: Distribution of the Annualized Cost of One Standard Truck in Monte Carlo Simulation.

The average annualized cost to operate one standard truck is $62,212.  Although this value is lower than that of the TowPlow, it is important to remember that one standard truck is not equivalent to one TowPlow, therefore, in order to determine a true comparison, θ is multiplied by Equation 6.5 for the standard truck as discussed in Section 6.3. Figure 6.5 presents the equivalent annualized cost for the standard truck.

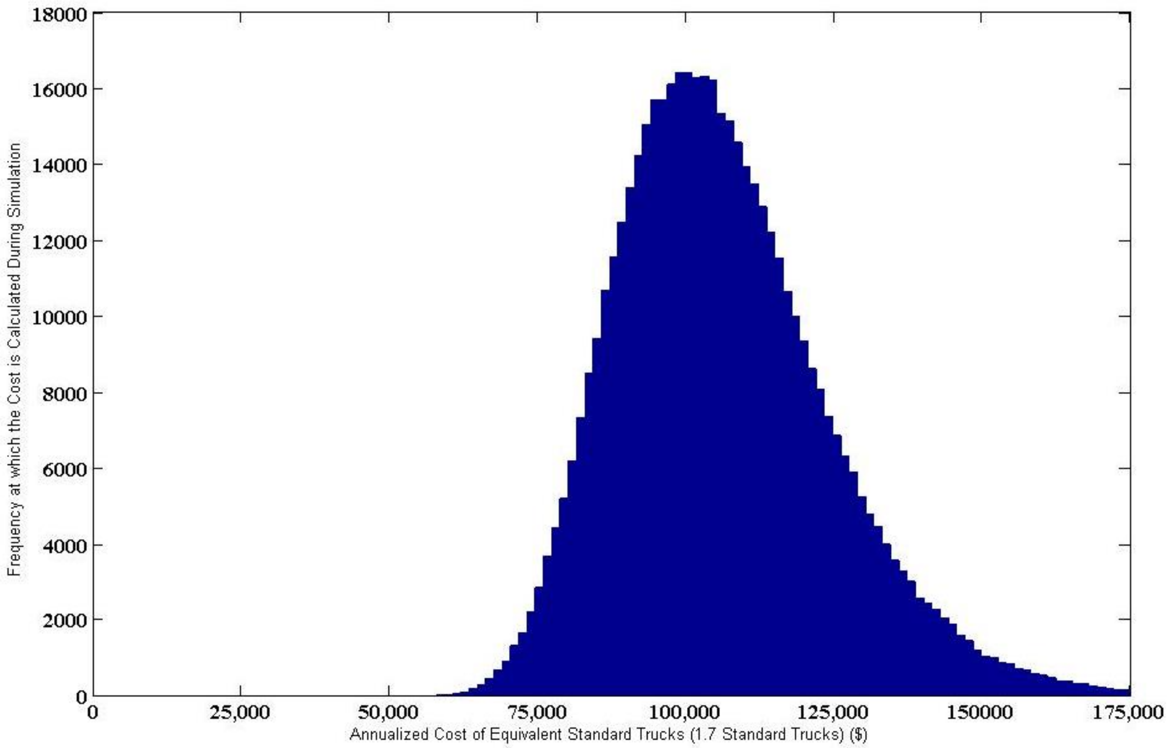



Figure 6.5: Distribution of the Annualized Cost of Theta (θ =1.7) Standard Trucks in Monte Carlo Simulation.

The average cost of the equivalent standard truck is $106,180. This value is greater than that of one TowPlow. This means that there is a cost saving associated with operating TowPlow verses the equivalent amount of standard trucks needed to match the TowPlow's ability. Table 6.2 presents a summary of the results.

Table 6.2: Annualized Cost Summary

| Equipment | Annualized Average Cost | Standard Deviation |
|---|---|---|
| TowPlow (includes truck towing TowPlow) | $83,629 | $12,568 |
| One Standard Truck (with a wing) | $62,212 | $10,865 |
| Equivalent Standard Trucks (1.7 – with wings) | $106,180 | $11,210 |

Note: 1.7 is the number of standard trucks needed to match one TowPlow (See Section 6.3, for details).

The TowPlow has an annual savings averaging $22,551 when comparing to the equivalent standard truck, based on the data collected during this evaluation.

# CHAPTER VII IMPLEMENTATION

This implementation plan is developed to aid with successfully implementing the results found within this report. Accordingly, this section is divided into eight sections.

- Section One – Recommendations for implementation of the TowPlow,
- Section Two – Steps needed to implement the findings from this study,
- Section Three – Suggested time frame for implementation,
- Section Four – Expected benefits from implementation,
- Section Five – Potential risks and obstacles to implementation,
- Section Six – Strategies to overcome potential risks and obstacles,
- Section Seven – Potential users and other organizations that may be affected, and
- Section Eight – Estimated cost of implementation.

## 7.1 Recommendations for Implementation

Currently, ODOT has TowPlows in active service in Ashtabula, Mahoning, and Portage counties. The TowPlow in Portage County was acquired through this research project, while the other two TowPlows were purchased prior to the beginning of this research. Based on the results of this research, the TowPlow is shown to have a lower annualized cost than the equivalent number of standard trucks in all counties evaluated. More information on the cost comparison and determination of the equivalent standard truck calculation may be found in Chapter 6. Based on these cost comparisons, the TowPlow is found to be more effective, financially speaking, in areas with a high frequency of plowable snowfall events. The value of the TowPlow increases as it is utilized more frequently, especially when it is placed on routes with multiple lanes in each direction. Table 7.1 presents some of the operational characteristics of the TowPlow. Table 7.1 was developed through a literature search and telephone interviews with maintenance personnel at other state DOTs that are currently using the TowPlow.

Table 7.1: Operational Characteristics of the TowPlow.

| | Roadway Functional Class where TowPlow Deployed | Speed of Truck When Plowing | Grade Changes | Traffic Impacts | Turn Around Location | Type of Spreader on Plow |
|---|---|---|---|---|---|---|
| **Massachusetts** [1] | Interstates (heavy traffic areas), use on ramps and bridges | *30–35 mph* | Mostly flat terrain; no issues with hills | None (always block shoulder to shoulder when plowing) | Use Interchanges | Salt spreader (truck and TowPlow spreaders on same controller and run together) |
| **Iowa** [1] | Multi-lane urban highways | *35–45 mph*, depends on weather | | Exit highway if traffic gets too backed up | Use Interchanges | Use brine tanks on TowPlow and salt spreader |
| **New Hampshire** [1] | Use on 1- and 2-lane highways in rural areas and 2- to 5-lane highways in urban areas | *20–25 mph* | Truck is *not powerful enough in mountainous areas* | | Use interchanges, operator backs TowPlow into a driveway, (like a trailer) | Use salt spreader (truck and TowPlow are on the same controller) |
| **Nebraska** [1] | Use on 4-lane divided urban highways | *35–45 mph* | | No complaints from public | Use the median more often than interchanges | Use salt spreader, use truck and TowPlow at same time |
| **Missouri** [1] | Use in urban and rural areas, on all roads except for 2-lane roads with unpaved shoulders; use mostly on divided highways | *45–50 mph* (slower in urban areas) | Lose speed on hills, use 460 hp trucks for mountainous areas | No more complaints than usual | Use interchanges | Some have brine and some have salt hopper |
| **Wisconsin** [1][2] | Used on state highways and interstates (testing on all roads in urban area) | *25–40 mph* | Maintaining speed on hills was an issue | | Worried about being able to cross medians | One TowPlow has a salt hopper, the other has a liquid brine tank |

Table 7.1: Operational Characteristics of the TowPlow (continued)

| | Roadway Functional Class where TowPlow Deployed | Speed of Truck When Plowing | Grade Changes | Traffic Impacts | Turn Around Location | Type of Spreader on Plow |
|---|---|---|---|---|---|---|
| **North Dakota** [2] | Used in urban and rural areas | | | | | Use brine tanks on TowPlow (control one at a time on TowPlow with retrofit truck) |
| **Maine** [2] | 4-lane highway with truck lanes | *15–25 mph* | When TowPlow is stopped on steep grades, the plow must back down the hill. | Used on 2-lane roads with no pull-off; this created traffic backups | *Stressed having turnarounds* at end of route and turnouts in middle of route | Use salt hopper, pre-wet with garden hose from liquid system on truck |

Note: (1) Indicates that information was obtained from conversations with personnel at the state DOT.
(2) Indicates that information was provided in a report produced by the state DOT.

Most state transportation agencies indicated that they utilized their TowPlow(s) on multilane highways, and some state DOTs indicated having issues in maintaining speed on hills. Additionally, several state DOTs indicated that traffic delays may result from utilizing the TowPlow. However, the Massachusetts Department of Transportation (MassDOT) indicated the delay created by the TowPlow is no different than delays for normal plowing operations, as MassDOT policy is to conduct gang plowing operations on multilane routes from shoulder to shoulder. The findings from Table 7.1 and this evaluation may aid in the decision to purchase a TowPlow and what types of routes the TowPlow is best suited to maintain.

## 7.2 Steps Needed to Implement Findings

Based on the cost analysis, the TowPlow is best implementable on multilane roads in areas receiving plowable snow regularly throughout the winter season. Prior to determining the need to implement TowPlow(s) within a fleet, it is important to determine the current capacity of the fleet and whether or not there is a need for one truck on a route or two. If there is a need to have multiple trucks on a route, it may be beneficial to consider specialty equipment such as the TowPlow. To implement the findings, ODOT will need to identify which garages and routes would benefit most from the addition of a TowPlow while balancing the delay results reported in Chapter 5. The TowPlow, while maintaining two lanes at once, is found to increase delay when compared to a standard truck plowing one lane. A delicate balance will need to be struck when deciding where to implement the TowPlow based on the ability to treat a route faster than a standard truck and the impacts on vehicle delay. Training will be required for operators to use the equipment while limiting the impacts on traffic. Figure 7.1 presents considerations when deciding to implement a TowPlow as part of a winter maintenance fleet.

| | Ideal TowPlow Environment | Less Ideal TowPlow Enviroment |
|---|---|---|
| Lane Configuration | Routes consist of multi-lane roadways which allow TowPlow to deployment throughout winter event. | Routes consist of primarily two lane roadways (1 lane in each direction) which would prohibit TowPlow deployment in winter event. |
| Traffic Impact *(Chapter 5)* | If TowPlow is deployed and blocking traffic, it is suitable for traffic to travel around 25-35 mph during winter event. | If TowPlow is deployed and blocking traffic, it is not suitable for traffic to travel around 25-35 mph during winter event. |
| Weather | Area receives high amounts of winter events in which plowing is necessary. | Area receives low amounts of winter events in which plowing is necessary. |
| Terrain *(New Hampshire Figure 7.1)* | Multi-lane routes are throughout flat or rolling terrain. | Multi-lane routes are throughout mountainous terrain. |
| Turnarounds | TowPlow has many places throughout route to turn around safely. | TowPlow does not have may turnarounds and may have issues turning around safely on multi-lane routes. |

Figure 7.1: Determining Ideal Areas to Implement a TowPlow.

When considering implementation of a TowPlow within a fleet, Figure 7.1 presents important factors to determine if and where to place a TowPlow. These factors are determined from data from this evaluation as well as through literature searches and surveys. The amount of horsepower required to pull the TowPlow varies based on the grade of the routes to be maintained and how often the truck stops and restarts. Through a literature search and telephone conversations with other state DOTs, the suggested power capacity for the truck used in conjunction with the TowPlow ranged from 300 to 460 horsepower.

## 7.3 Suggested Time Frame for Implementation

Currently, ODOT garages in Ashtabula, Mahoning, and Portage counties are implementing TowPlows within their winter maintenance operations. Once a need for the TowPlow is realized and the routes on which to use it are identified, a TowPlow may be implemented as soon as it is acquired. However, consideration should be given to the fact that ODOT's typical standard truck may not be sufficient for pulling the TowPlow in hilly areas. Trucks with increased horsepower and hydraulics are necessary to utilize the TowPlow, especially in areas where grades are more prevalent. While a truck with more horsepower has a higher purchase cost than the typical ODOT plow truck, this fact is included in the cost analysis. Acquiring the TowPlow, and potentially a new truck to tow the TowPlow, may be best during the off season to allow operators to be trained on the new equipment. Purchasing the TowPlow during the off season may also allow the mangers to change current snow routes to account for the added capacity of the TowPlow knowing that one TowPlow is observed to be equivalent to 1.71 standard trucks as seen in this evaluation. Additional modifications may be necessary to increase the safety of the TowPlow, such as installation of additional lighting, a camera/monitor system, and/or a guidance laser. However, additional time to incorporate modification is determined by the owner of the TowPlow; if needed, the TowPlow may be implemented into a winter fleet immediately.

## 7.4 Expected Benefits from Implementation

Once the TowPlow is implemented, it allows for routes with multiple lanes to be cleared more quickly than when a single standard truck is utilized. Although the TowPlow and truck utilized with it have a higher total cost than a standard truck and hopper, the TowPlow is found to be equivalent to 1.71 standard trucks. Based on this comparison, the cost of operating the TowPlow is less than what is required for a standard truck to maintain the same section of roadway. Accordingly, a financial savings would be realized when implementing the TowPlow. Table 7.2 presents the potential savings based on frequency and classification of storm events received in a season. The primary assumption of this table is that routes currently require two or more Standard trucks to maintain the expected LOS on the routes. The cost data presented in Chapter 6 are used in Table 7.2 and the numbers of events in each weather classification are changed to simulate the potential cost savings.

Table 7.2: Potential Annual Cost Savings for TowPlow.

| | 0 to 25 Events per Season | 26 to 50 Events per Season | 51 to 75 Events per Season | 76 to 100 Events per Season |
|---|---|---|---|---|
| Primarily Trace and Light Events *(Some Moderate, No Heavy)* | \$4,100 to \$12,000 | \$13,100 to \$17,400 | \$17,900 to \$20,800 | \$20,800 to \$24,100 |
| Primarily Light and Moderate *(Some Trace, Some Heavy)* | \$4,100 to \$12,800 | \$13,800 to \$17,500 | \$18,500 to \$21,400 | \$21,200 to \$25,800 |
| Primarily Moderate and Heavy *(Some Light, Some Trace)* | \$4,100 to \$12,900 | \$14,300 to \$17,500 | \$20,000 to \$29,000 | \$22,500 to \$29,200 |

Note: The primary assumption of this table is that routes currently require two or more Standard trucks to maintain the expected LOS on the routes.
One TowPlow compared to Equivalent (1.71) Standard ODOT Trucks.
Used same simulation as Chapter 6, only modifying number of events in each weather classification.
Weather classification is listed in Section 3.1 of this report.
Standard deviation of events is set as 1, unless 0 events, then set to 0.
Rounded to nearest hundreds place.
Simulation repeated 100,000 times, five random weather distributions for each category presented above.

As mentioned in the note of Table 7.2, these savings are based on one TowPlow compared to 1.71 Standard trucks. When no winter events occur, maintenance is not required, which results in a cost savings due to the fact that the annualized cost of one TowPlow and truck is less than 1.71 Standard trucks. However, this does not mean that all routes or garages require a TowPlow to maintain the expected LOS on a route. Implementing a TowPlow within a fleet should only be considered when there are current routes in which multiple Standard trucks are required to maintain regularly throughout a winter season. Table 7.3 presents the capital cost comparison of the TowPlow and Standard truck.

Table 7.3: Annual Capital Cost Comparison.

| TowPlow Quantity | Standard Truck Quantity | TowPlow Cost | Standard Cost | Cost Difference |
|---|---|---|---|---|
| 1 | 1.71 | $38,700 | $42,800 | $4,100 |
| 2 | 3 | $77,200 | $75,000 | ($2,200) |
| 7 | 12 | $269,600 | $300,200 | $30,600 |

Note: The primary assumption of this table is that routes currently require two or more Standard trucks to maintain the expected LOS on the routes. No maintenance cost is included, and all events are set to zero, therefore the capital cost is the only factor. The discount rate is varied as in Chapter 6. Life of the truck pulling the TowPlow and Standard is eight years, while the TowPlow itself is expected to be 16 years. RED indicates higher annual cost for the TowPlow than the Standard truck. GREEN indicates lower annual cost for TowPlow than Standard truck.

As presented in Table 7.3, the annual capital cost of the TowPlow and truck to pull it is less than the equivalent 1.71 standard trucks; however, it is not possible to purchase a fraction of a truck. The ratio of two TowPlows to three Standard trucks shows the Standard truck costs less, since this ratio reduces the equivalence to 1.5 Standard trucks to one TowPlow. However, using the observed 1.71 trucks ratio to find the nearest whole numbers is determined to be 7 TowPlows to 12 Standard trucks, in which the TowPlow's annualized capital cost is less than the equivalent annualized cost of the Standard trucks.

Though there is potential savings associated with the TowPlow in areas with less snow amounts, there may be other equipment more appropriate for these areas. Locations which receive fewer snow events in which plowing is required may consider other equipment. A winter maintenance fleet should be designed to handle the regular, expected amount of snowfall while maintaining the proper LOS the public expects to see and not the rare events an area may encounter. During the occasional events where plowing is required in these areas, an increased cycle time per truck within a smaller fleet may be more reasonable than having specialty equipment used only during these rare occurrences where the amount of snowfall is great enough to utilize the specialty equipment to its full capabilities. It is important to note, that if maintenance is needed on the truck used to tow the TowPlow during an event, the fleet loses the capacity of the TowPlow as well as the truck.

The factors with a positive correlation cause an increase in the utilization rate when they are increased. These factors include the snowfall intensity, number of lanes, and number of routes maintained. Moreover, each county garage included in the study utilized the TowPlow differently: Ashtabula and Mahoning counties used the TowPlow as a supplementary vehicle and sent it where it was most needed, while Portage County assigned the truck to a specific route. As a result, the utilization rate of the TowPlow was higher in Ashtabula and Mahoning counties than it was in Portage County.

## 7.5 Potential Risks and Obstacles to Implementation

Based on the information collected during this study, three potential risks and obstacles to implementation of the TowPlow have been identified. First and foremost, the capital cost associated with purchasing a TowPlow and new truck to pull the system is a significant hurdle associated with the implementation. The average cost of the truck and TowPlow purchased for the three trucks and TowPlows units is $301,080. In addition, increased delay is expected when the TowPlow is deployed. However, the associated traffic delay presents a minor impact, as similar delay would be realized from gang plowing operations. A third potential obstacle is the lack of familiarity with the TowPlow system on the part of the traveling public. Through the literature search and surveys of other state DOTs, incidents involving motorists and a TowPlow are found to be rare. In one incident, a motorist attempted to pass the TowPlow on the shoulder while the operator was turning into a highway turnaround, and the motorist slid off the shoulder and left the roadway. While this was no fault on the part of the DOT, it still presents a dynamic where a motorist may have been unfamiliar with the TowPlow and did not know how to safely interact with it on the roadway.

## 7.6 Strategies to Overcome Potential Risks and Obstacles

Strategies may be employed to overcome potential risks and obstacles associated with the implementation of the TowPlow. One obstacle for the TowPlow is motorists' lack of familiarity with the system. To overcome this, ODOT could post informational videos and articles on its website to educate the public about how to appropriately interact with the system. Additionally, ODOT could contact local news agencies in areas where a TowPlow may be deployed to aid in familiarizing the public with the system. Training of TowPlow operators by ODOT is also essential. In addition to the general training of operators in the use of the TowPlow, ODOT could provide supplemental training to give operators an idea of what to expect as queues build up behind them and to make them aware that the traveling public may be unfamiliar with the TowPlow system.

## 7.7 Impact on Potential Users and Other Organizations

In addition to ODOT, this research project may be of interest to potential roadway users and other organizations. The results of this research may be useful to state DOTs and local roadway maintenance agencies that are considering the incorporation of a TowPlow or multiple TowPlows into their maintenance fleets. As previously stated, one of the most affected groups will be the motorists on the roadways maintained by the TowPlow. Some motorists may be impacted by experiencing a longer delay when traveling behind the TowPlow, while others may experience the benefits of having the roadway cleared more quickly.

The local climatic conditions and roadway configurations in the area maintained by a transportation agency will be important considerations in the decision to incorporate a TowPlow, as two of the main factors affecting the implementation of the TowPlow are the amount of snowfall received and the number of lanes on each route. Table 7.4 shows a qualitative breakdown of situations in which the TowPlow is most useful.

Table 7.4: TowPlow Utilization Scenarios.

| Snowfall | 2 Lane | 2 Lane w/ Shoulder | 4 Lanes or More |
|---|---|---|---|
| Trace | No | Some | Some |
| Light | No | Some | Yes |
| Moderate | No | Yes | Yes |
| Heavy | No | Yes | Yes |

Since the TowPlow is capable of plowing a second travel lane in a single pass, there is no added advantage in utilizing a TowPlow on a two-lane roadway. However, if a two-lane roadway has wide shoulders, there may be an advantage in using the TowPlow in moderate and heavy snowfall when plowing is needed. There is some advantage to using the TowPlow on two-lane roads with shoulders in trace and light snowfall, but the small amounts of snowfall may not require plowing. The TowPlow is most useful for clearing roadways with four or more lanes and ramps during light, moderate, and heavy snowfall. Through this evaluation, ODOT expresses the advantage when treating on/off ramps since ODOT maintained highway ramps are typically wider than normal lanes.

## 7.8 Estimated Cost of Implementation

There will be no additional cost for ODOT to implement the TowPlows in Ashtabula, Mahoning, and Portage counties, as TowPlows have already been purchased for use in these areas. The cost to implement a TowPlow in other locations will be dependent upon the purchase price for the TowPlow system and for a truck with more horsepower than the trucks currently used by ODOT. In this study, it is determined that it would cost ODOT $83,629 to operate the TowPlow and $106,180 to operate the equivalent standard trucks on the same route – this results in a cost savings of $22,551 by using the TowPlow based on its increased maintenance capabilities when compared to a standard truck. From Equation 6.3, the number of standard trucks required to equal the treatment capabilities of one TowPlow is found to be 1.71. It is important to note that this ratio may vary based on weather event data and difference in capital cost to acquire equipment. As previously mentioned, the ODOT standard truck in the cost calculations is a tandem axle dump truck with a wing plow.

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