INVESTIGATE PLOW BLADE OPTIMIZATION

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16. Abstract

The main technique for removing accumulated snow from roadways is through the use of snow plows and snow plow blades (blades), or cutting edges. The blade is bolted to the snow plow, and it is the component of the plowing system that makes contact with the roadway surface. Multiple blades are currently on the market that may last longer than the standard ODOT steel blades, which encouraged ODOT to pursue further research to compare the cost-effectiveness of using the specialty blades compared to the costs for using ODOT's current flame-hardened steel blade (standard blade) and procedures for replacing these standard blades. As with any new equipment, a thorough assessment of the various specialty blades is needed in order to determine which, if any, are prudent to implement. The blades tested during this study included standard flame hardened steel in various configurations, carbide tipped, JOMA, PolarFlex, and BlockBuster XL Classic. During field research activities, data must be collected at multiple locations throughout the entire winter season, at any time of day, and for any length of time. The optimal way to collect such a large amount of data is through video recording. For this purpose, the research team acquired a digital video recorder (DVR) equipped with a global positioning system (GPS) and an infrared vision camera for each truck in the study. Blade measurements are taken periodically to track the wear of each blade. When analyzing the data from first year, the results indicated implementing the carbide and XL Classic blades will result in a cost savings. The remaining blades would cost more to utilize than the equivalent number of standard blades. The second year data results in a savings from the all blades test except the single stacked carbide tipped blade and the truck with a standard blade but no counterbalance. When reviewing two years of data an average savings of $778 per PolarFlex blade and $426 per XL Classic blade implemented in place of a standard blade.

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Prepared in cooperation with the Ohio Department of Transportation
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- Mr. Doug Riffle, ODOT District Five Fairfield County Transportation Administrator.
- Mr. Brian Olson, ODOT District Four Area Maintenance Engineering

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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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Blade – Plow Blade or Cutting Edge

Carbide - carbide-tipped steel blade

DOT – Department of Transportation

DVR – Digital video recorder

FHWA – Federal Highway Administration

ft – foot or feet

GPS – Global positioning system

in. – Inch

JOMA - JOMA™ 6000 blade

lb – Pound

LOS – Level of Service

mph – Miles per Hour

ODOT – Ohio Department of Transportation

PolarFlex – PolarFlex blade system

XL Classic - Winter® BlockBuster® XL Classic™ Carbide blade system

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 $86 million (ODOT, 2013). 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 goal of snow and ice control is to provide adequate level of service (LOS) to the motoring public, which is measured by regain time or the amount of time to recover after a snow event by increasing the vehicle speed to within 10 miles per hour (mph) of the speed limit.

The main technique for removing accumulated snow from roadways is through the use of snow plows and snow plow blades (blades), or cutting edges. The blade is bolted to the snow plow, and it is the component of the plowing system that makes contact with the roadway surface. Friction is created when the blade makes contact with the roadway, causing wear and eventually resulting in the need to replace the blade. The rate of deterioration is based on several factors including: the type of blade, type of roadway surface, plowing speed, and the operator's plowing habits. It is not uncommon for blades on plow trucks in Ohio to require replacement two or three times per winter season. Some areas in the state that receive higher snowfall amounts may replace blades as many as ten times per winter season, as seen in ODOT Lake County in the 2013–2014 winter season. These blade replacements add costs to the winter maintenance budget in the form of material and labor. Given the heavy weight of the plow blades (which may weigh 150 pounds (lb) or more for a six foot section), associated safety and efficiency issues may arise when the blades are replaced.

Multiple blades are currently on the market that may last longer than the standard ODOT steel blades, which encouraged ODOT to pursue further research to compare the cost-effectiveness of using the specialty blades compared to the costs for using ODOT's current flame-hardened steel blade (standard blade) and procedures for replacing these standard blades. As with any new equipment, a thorough assessment of the various specialty blades is needed in order to determine which, if any, are prudent to implement. The assessment should include the following metrics:

- A survey of current ODOT blade practices,
- Data obtained from the manufacturer and from other evaluations of each specialty blade reviewed in this evaluation,

- Data analysis on the cost-effectiveness of utilizing the specialty blades as compared to ODOT's current blades and the replacement process,
- In-field performance evaluation of each specialty blade in various annual snowfall amounts seen in Ohio, which includes a cost benefit analysis, maintenance, labor costs, and equipment purchase costs,
- Applicability assessment for replacing blades in a safe and efficient process, and
- Determining ideal conditions to implement the specialty blades.

Once data are collected and analyzed, a cost–benefit analysis is performed to determine the potential for wider implementation of the specialty blades in ODOT's maintenance procedures.

1.1 Purpose and Objectives

The research team proposes that three objectives must be met to ensure that project PS-2014-07 *"Investigate Plow Blade Optimization"* will be considered a success. These three objectives include:

- Objective One – Determine a usage strategy based on safe, efficient, and cost-effective methods for changing and purchasing plow blades,
- Objective Two – Recommend specialized blade changing equipment to assist and protect personnel, and
- Objective Three – Recommend plow blades based on condition types.

These objectives will provide ODOT with continuing knowledge of the different blades available and any cost savings associated with the utilization of each blade.

1.2 Benefits from this Research

Several benefits are expected from the outcome of this project. One important benefit is the information ODOT will gain regarding the quality of the available blades. This knowledge may be used in the decision making process for widespread incorporation of specialty blades and other new technologies into ODOT's winter maintenance fleet. Another benefit is the ability to test the new blade within multiple ODOT garages immediately.

1.3 Organization of this Report

This report is divided into eight chapters. Chapter 1 introduces the topic and includes a list of the research objectives. Chapter 2 presents the background information gathered prior to the start of data collection for this project, including surveys of ODOT districts and transportation agencies in other states.

Chapter 3 presents the project setting, including details about the ODOT garages participating in the evaluation and the different blade systems tested. Chapter 4 presents the research methodology employed to collect the appropriate data for use in the analysis. Chapter 5 summarizes the results and provides a cost analysis from the data collection and analysis in year one. Chapter 6 presents the results and provides a cost analysis from the data collection and analysis in year two. Chapter 7 reviews the blade changing process. Chapter 8 develops the implementation plan for the specialty blades within ODOT's fleet.

CHAPTER II BACKGROUND

This chapter provides information about the background information including the literature review and survey results for the project. This chapter is divided into two sections:

- Section One – Literature review, and
- Section Two – In-state survey.

2.1 Literature Review

The research team contacted eight state departments of transportation (DOTs) that experience weather conditions similar to the conditions that ODOT faces. These agencies are contacted to increase knowledge of different blades as well as the blade changing equipment used by these agencies. Based on the conversations with the state DOTs, the findings are categorized into four subject areas:

- Subsection One – Plow blade types,
- Subsection Two – Plow blade evaluations,
- Subsection Three – Plow blade usage, and
- Subsection Four – Plow blade changing techniques.

These subsections provide an overall knowledge of practices used in other states that employ plow blades.

2.1.1 State DOT Plow Blade Types

The first subject area provides information pertaining to the type of plow blades that the various states use for the different plowing applications, as well as the length of the blades and the types of blades used are presented in Table 2.1.

Table 2.1: Plow Blade Types for Various Applications.

State	Application	Blade Type	Section Length
Colorado	Front Plow	Carbide Insert	3 foot to 6 foot
	Wing Plow	Carbide Insert	3 foot to 6 foot
Maine	Front Plow	JOMA	3 foot, 4 foot
	Wing Plow	Carbide Insert	8 foot (Single Blade)
Michigan	Front Plow	Carbide Insert	3 foot
	Wing Plow	Carbide Insert	3 foot
	Underbody Plow	Carbide Insert	3 foot
Nebraska	Front Plow	Carbide Insert	3 foot, 4 foot
	Wing Plow	Carbide Insert	3 foot, 4 foot
New Hampshire	Front Plow	JOMA	3 foot, 4 foot
	Wing Plow	Carbide Insert	8 foot (Single Blade)
North Dakota	Front Plow	Tungsten Carbide	3 foot, 4 foot
	Wing Plow	Tungsten Carbide	3 foot, 4 foot
	Underbody Plow	Tungsten Carbide	3 foot, 4 foot
Ohio	Front Plow	Steel, Carbide Insert	5 foot, 6 foot
Pennsylvania	Front Plow	JOMA	3 foot, 4 foot
	Wing Plow	JOMA	3 foot, 4 foot
	Tow Plow	JOMA	3 foot, 4 foot

Note: All state agencies contacted said they use the same blade type regardless of pavement condition and plowing speed; several indicated this is because they plow at relatively the same speed regardless of roadway class. These agencies are in states that have similar weather to Ohio and that responded when contacted. Survey taken in spring 2013.

The most common types of blades currently deployed by the responding states are carbide insert blades and JOMA blades. JOMA blades consist of carbide inserts in steel sections which are encased in rubber. Polar Flex blades consist of carbide tipped steel blades mounted using a flexible rubber element (Mastel, 2011), and have been evaluated by several states as discussed in the following section. For the different plow types (front, wing, and underbody), most states use the same type of blade for each plow. However, New Hampshire and Maine indicated that they use different blade types for each plow application. Due to blade weight and easier installation, most states use blade section lengths of only three or four feet, as compared to the longer five- or six-foot sections used by ODOT. Using shorter section lengths may result in fewer injuries to maintenance workers, based on the reduced weight lifted during the changing process.

2.1.2 State DOT Plow Blade Evaluations

Along with the plow blades commonly used in the various states, many evaluations have been conducted of other plow blade types to determine the feasibility of implementation. The results of several studies may be found in Colson (2010), Mastel (2011), and CTC and Associates (2010). The types of blades evaluated by several states and the corresponding findings are presented in Table 2.2.

Table 2.2: State DOT Plow Blade Evaluations.

State	Blades Tested	Results
Colorado	A few districts are evaluating JOMA blades.	Recently began evaluation; at this time, it is unclear if the blades are cost-effective.
Maine	Studied JOMA, Kuper, and Polar Flex blades.	JOMA are observed to be the best in terms of reduced wear, which means the blades significantly outlasted standard blades.
Michigan	Tested a hardened steel blade (could not recall name).	Blade cost is $320 per section and did not last long enough to be considered as cost-effective.
Nebraska	Have recently started testing JOMA blades.	Blades were operational for 3 to 4 times more miles than standard carbide.
New Hampshire	Studied JOMA, Kuper, and Polar Flex blades.	JOMA are the best in terms of reduced wear, which means the blades significantly outlasted standard blades.
North Dakota	Studied JOMA, Polar Flex, and stacked carbide blade systems.	JOMA and Polar Flex blades last 3 to 4 times longer; stacked carbide blades showed no improvement based on the frequency of blade changes.

Note: Survey taken in spring 2013.

Some of the key findings from the discussions about plow blade evaluations with the various states include:

- JOMA and PolarFlex blades are the most commonly evaluated,
- Most states report increased life spans for JOMA and PolarFlex blades compared to their standard blades,
- The stacked carbide blade system shows no improvement to standard blades in terms of the frequency of blade changes, and

- The hardened steel blades tested by the Michigan DOT did not outlast the standard blades long enough to justify the higher price.

Since the purchase prices for the blades vary for each state, the benefit-to-cost analysis of the blades will not be consistent, indicating a possible need for further investigation by the research team.

2.1.3 State DOT Plow Blade Usage

This section focuses on the life span and the purchase costs of blades for the various state DOTs; both of these factors are of high importance to ODOT and accordingly, this study. The number of blade changes and the cost of the blades for the state DOTs are presented in Table 2.3.

Table 2.3: Frequency of Changes and Costs of Plow Blades.

State	**Blade Type**	**Life Span**	**Cost**
Colorado	Carbide Insert	3 to 5 changes per season	3 foot: $146 6 foot: $292 Heat treated steel: $49 – $158
Maine	JOMA	2 or 3 changes per season	3 foot: $623.93 4 foot: $831.91
	Carbide Insert	2 or 3 changes per season	NA
Michigan	Carbide Insert	90 to 500 hours, budget 2 or 3 changes per season	3 foot: $175
Nebraska	Carbide Insert	0 to 6 changes per season	3 foot: $130 4 foot: $174 Steel covering: $35 – $45
New Hampshire	JOMA	2 or 3 changes per season	3 foot: $623.93 4 foot: $831.91
	Carbide Insert	2 or 3 changes per season	NA
North Dakota	Tungsten Carbide	2 to 4 changes per season	Full Plow: $525.20
Pennsylvania	JOMA	5 to 10 times longer than carbide blades	3 foot: $602.93 4 foot: $803.20

Note: "NA" denotes that a price was not provided for a certain blade type. Survey taken in spring 2013.

The frequency of blade changes range from zero to six per season, with most states expecting two or three changes per season, which is consistent with current ODOT practice according to the in-state survey presented in the next section. The cost of the blades varies based on blade type, with the JOMA blades costing around four times as much as the carbide blades. States indicated the main factors affecting how quickly the blades wear are the type of roadway and the operator's plowing style. This may support the need to use different plow blades based on pavement type.

2.1.4 State DOT Plow Blade Changing Techniques

Most of the commonly used plow blades are heavy and create pinch points when changing, which creates concern for the safety of maintenance workers. The changing techniques used by various state DOTs are presented in Table 2.4.

Table 2.4: State DOT Plow Blade Changing Techniques.

State	Changing Techniques
Colorado	Lift the truck and use two or more workers to change blades by hand.
Maine	Put the truck on lift; two or more people use hand and impact wrenches to change the blades. The blades are lifted into place by hand.
Michigan	Lift the truck 5 feet up on a hoist; use two operators to change the blades. Use impact wrenches and lift blades by hand.
Nebraska	Lift the truck and use two or three people to change blades. Cut off bolts and replace each time. Lift blades by hand.
New Hampshire	Put truck on a lift; two or more people use hand and impact wrenches to change the blades. The blades are lifted into place by hand.
North Dakota	Takes two employees 30 minutes total to change blades. A lifting system was developed to raise plow blades without having to lift them in place by hand.
Ohio	One garage uses two employees to lift and change the blades by hand, taking a total of one hour. Another garage chains the blades to the plow so that employees do not need to lift the blades by hand.
Pennsylvania	Blades are changed by hand using two or more workers. Workers follow mounting specifications to limit blade wear.

Note: Survey taken in spring 2013.

Most state agencies reported placing the truck on a lift and using two or three employees to change the plow blades. The employees will lift the blades by hand and use wrenches to bolt the blades in place. North Dakota indicated they developed a lifting system in house, in order to eliminate the need for employees to lift the blades by hand. While the same number of employees will most likely be required to change plow blades regardless of the section length, the likelihood of an injury occurring may be reduced by using shorter sections. However, no state agencies reported using commercial blade changing equipment for this purpose.

2.2 In-State Survey

The research team surveyed ODOT garages in each county in Ohio to determine the current usage of plow blades, the methods used for changing plow blades, and the equipment used to assist in changing plow blades. Accordingly, this section is divided into four subsections:

- Subsection One – Survey introduction,
- Subsection Two – Equipment,
- Subsection Three – Road surface, and
- Subsection Four – Summary of survey results.

These four sections will provide sufficient background information about the formulation of the survey, the collection of the survey information and the results of the survey.

2.2.1 Survey Introduction

The survey is developed with the intention of gathering information about ODOT's current blade usage. The research team also collected information regarding the typical plow application, additional plow equipment, plow blade configuration, plow blade changing techniques, safety concerns and road information for each county. In order to evaluate the plow blades successfully, the research team must establish the base conditions to compare with the new blades. The base conditions include a standard blade and equipment such as counterbalances, plow shoes or plow guards. The survey used in the evaluation is presented in Figure 2.1.

District ___________ County_____________________
Name____________________ Date _______________

1.) What plowing systems are used in your county? (please check all that apply)
  ○ Front ○ Wing ○ Underbody ○ Tow plow

2.) How many lane-miles do you maintain? ________

3.) Do you pre-wet your salt?
  ○ Yes ○ No

4.) How many hours before a storm do you anti-ice?
____

5.) Do you use any kind of tripping mechanism?
  ○ Yes ○ No

6.) Do you use carbide inserts?
  ○ Yes ○ No

7.) Do you use plow shoes?
  ○ Yes ○ No

8.) Do you use plow guards?
  ○ Yes ○ No

9.) Do your plow systems have counter-balances on them?
  ○ Yes ○ No

10.) If yes, how often are they adjusted? _________________

11.) What kind of counter-balance are used?
  ○ Spring ○ Hydraulic

12.) Do you use full length plow blades?
  ○ Yes ○ No

13.) Do you use partial length plow blades?
  ○ Yes ○ No

14.) Do you use a cover plow blade to cover the joint?
  ○ Yes ○ No

15.) What types of materials are the plow blades in your county? (please check all that apply)
  ○ Polymer ○ Rubber ○ Steel ○ Other________

16.) What kind of road surface types are in your county? (please check all that apply)
  ○ Concrete ○ Asphalt ○ Chipseal

17.) Do you use different plow blades for different types of road surfaces?
  ○ Yes ○ No

18.) Do you use different plow blades in different weather conditions?
  ○ Yes ○ No

19.) Do you notice a difference in life span with different types of plow blades?
  ○ Yes ○ No

20.) If yes, please explain._____________________________
____
____

21.) What are the lengths (in feet) of plow blades used in your county? ______________________________________

22.) What manufactures of plow blades do you use? (please list all) ____
____

23.) How many times a season do you change plow blades?
____

24.) How many people are needed to change plow blades?
____

25.) On average, how long does it take to change blades on one plowing system? ____________________________

26.) Where does plow blade changing occur within your county? (please check all that apply)
  ○ County Garage ○ Outposts

27.) Which direction is the head of the bolts on the plow blades?
  ○ Facing the Front ○ Facing the back

28.) Do you have any safety protocol for changing plow blades?
  ○ Yes ○ No

29.) If yes, please explain._____________________________
____
____

30.) Do you have a training program for changing plow blades?
  ○ Yes ○ No

31.) If yes, please explain._____________________________
____
____

32.) On average, how many injuries do you experience from changing plow blades in a season?___________________

33.) What tools and equipment do you use to change plow blades?____
____

34.) What are your biggest safety concerns when changing plow blades? ___________________________________
____
____

35.) Are there any plow blades that you would like to have considered for evaluation?_________________________
____

Figure 2.1: In-State Survey.

These 35 questions provide the researchers with information pertinent to the successful evaluation of plow blade usage in the state of Ohio. Information collected from the survey includes which blades are being used, road surface types, truck equipment and safety issues related to plow blade changing.

Additional information from the surveys will help the researchers determine appropriate plow blade changing strategies as well as identify counties in Ohio where the evaluation of plow blades should be conducted.

To gather responses to the survey, the researchers elected to call each county garage manager. Attempts are made to ensure the surveys are completed by a county manager. When that is not possible, an assistant manager or mechanic is surveyed.

The flow of the information discovery phase of the project is shown in Figure 2.2 below.

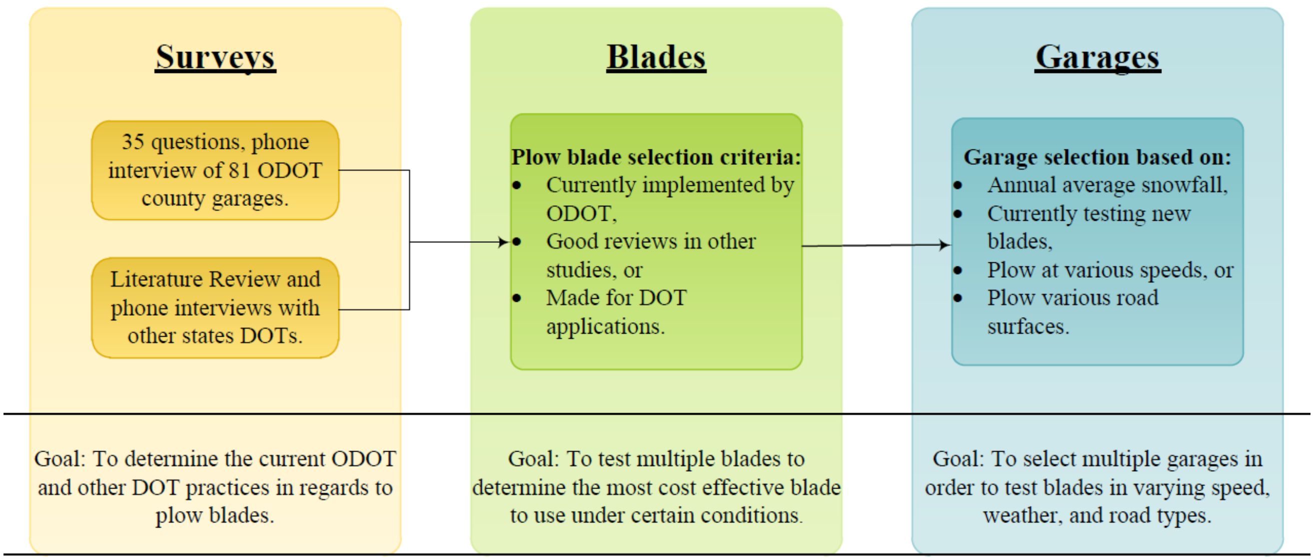


Figure 2.2: Project Flow Diagram

The in-state and out-of-state DOT surveys will be analyzed to determine which plow blades will be tested. The in-state surveys will then be utilized to determine which garages will be used for the testing of the plow blades. Garages will be selected that provide different factors such as weather conditions, road surface types and plowing speeds.

The research team contacted individuals in all 88 counties in Ohio. The breakdown of respondents and their respective title are shown in Table 2.5.

Table 2.5: Survey Respondents.

District	Number of Counties	Number of Counties Surveyed	Percentage Complete	Correspondence		
				Transportation Administrator	Mechanic	Transportation Manager
1	8	8	100%	5	2	1
2	8	8	100%	1	2	5
3	8	8	100%	6	1	1
4	6	6	100%	0	1	5
5	7	7	100%	5	2	0
6	8	4	50%	1	0	3
7	9	8	89%	6	1	1
8	7	6	86%	5	1	0
9	8	7	88%	5	0	2
10	9	9	100%	1	3	5
11	7	7	100%	7	0	0
12	3	3	100%	3	0	0
Total:	88	81		45	13	23
Percentage				55.6%	16.0%	28.4%

Note: Survey taken in fall 2013.

All 88 counties are contacted, and responses are received from 81 of the counties, resulting in a 92% response rate. Of the total responses, the majority of the people surveyed are county managers (55.6%) and assistant managers (28.4%). Some mechanics are surveyed in counties where several unsuccessful attempts are made to contact the county and assistant managers.

2.2.2 Equipment

The majority of the questions in the survey focused on equipment usage in order to investigate the effects of the employed equipment on plow blade wear. The length of the blades used in each district, which is shown in Figure 2.3, is of paramount importance to the researchers.

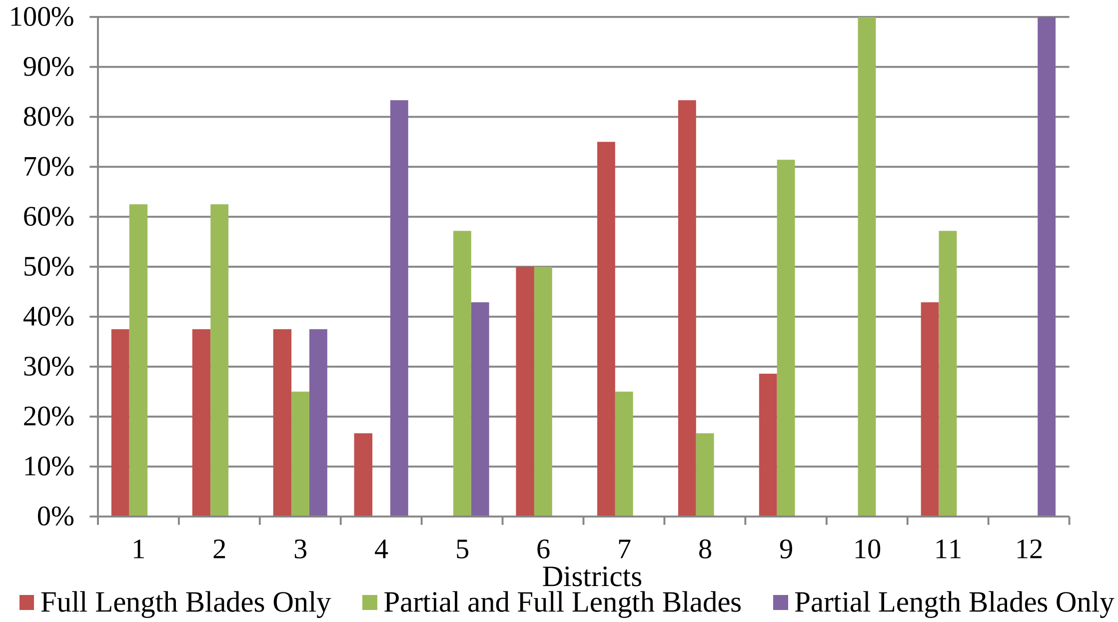


Figure 2.3: Blade Section Length used in Each District.

The survey results are aggregated by district, and the percentages reflect the portion of counties in the district that use a certain blade length. The results indicate that only District 12 is using partial length blades in all garages. In addition, many districts are using full-length blades, which are heavier and more difficult to work with than the shorter blades. To increase safety, one simple strategy may be to implement plow blades with shorter section lengths. The shorter sections of blades are lighter and easier to handle and are therefore expected to cause fewer injuries.

Other plow blade implementation strategies that may affect wear are the use of cover blades and the use of stacked plow blades. In the first strategy, a cover blade is used to cover the joint where two partial length blades meet. In the second strategy, two full-length blades are installed on the plow in order to decrease the wear on each blade by increasing the surface area in contact with the roadway. The percentage of counties in each district that use cover blades or stacked blades may be seen in Figure 2.4.

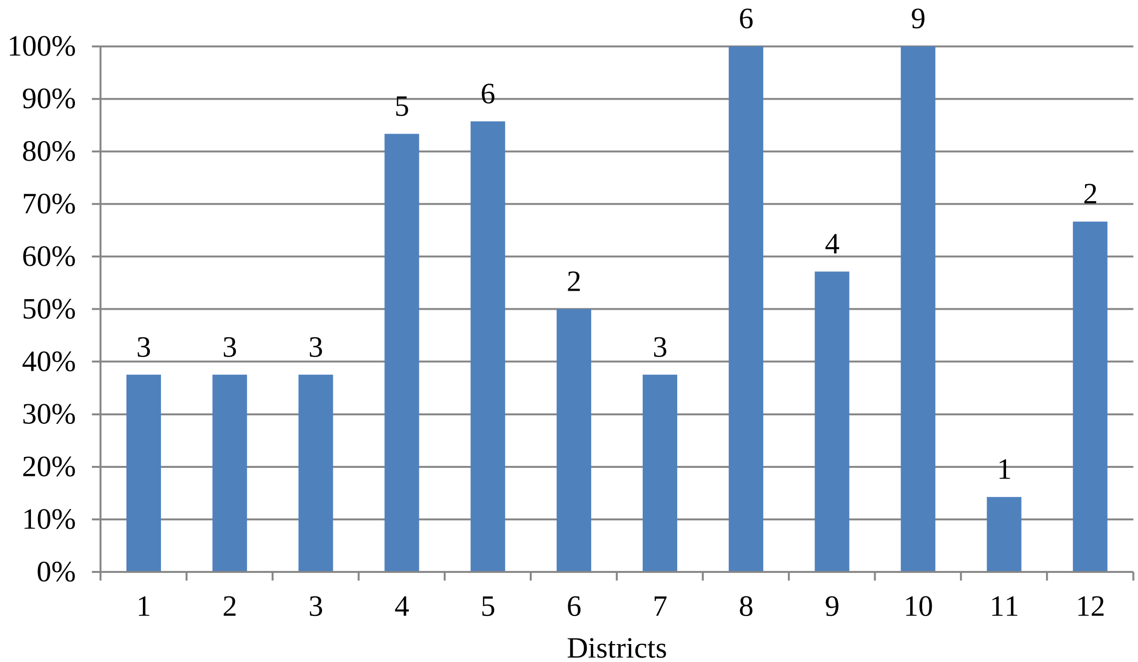


Figure 2.4: Usage of Cover Blades or Stacked Blades by District.

Figure 2.4 shows that all districts have some counties that use either stacked or cover blades. The percentage of counties using only stacked plow blades may be determined by isolating the garages that responded "yes" to the question regarding the use of full-length blades and that responded "yes" to the question regarding the use of cover or stacked blades. The breakdown of percentages may be seen in Figure 2.5.

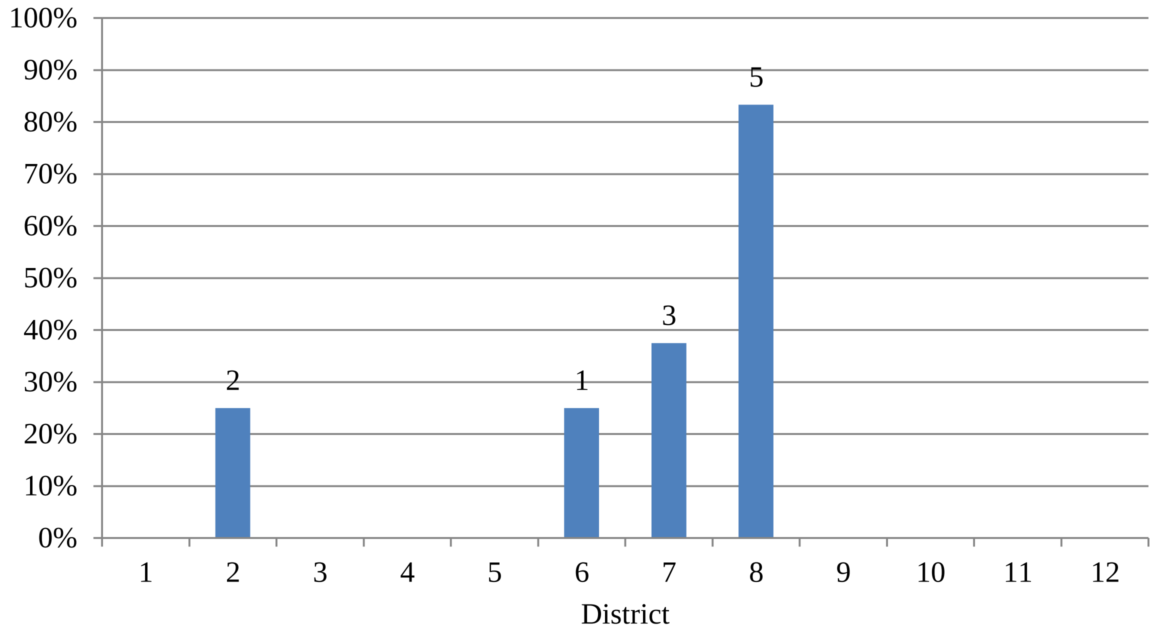


Figure 2.5: Percentage of Counties Using Stacked Blades in each District.

Only a small number of the counties in Ohio use stacked blades exclusively, while nearly half of the counties use either stacked blades or cover blades. The use of multiple blades may reduce the wear of plow blades by increasing the surface area contacting the roadway; if it is found that stacking blades significantly reduces blade wear, this strategy may need to be tested with the new specialty blades. The specialty blades are much more expensive than the standard ODOT plow blades, which may make it very difficult to see a cost benefit if the specialty blades are stacked.

Another aspect of the survey is to determine plow blade type usage in each county. Table 2.6 shows the percentage of counties in each district that are using each type of specialty blade.

Table 2.6: Percentage of Counties in each District Using Various Plow Blades.

District	Carbide	PolarFlex	Winter XL Classic	Rubber Blades
1	25%	0%	0%	0%
2	25%	0%	0%	0%
3	50%	0%	0%	0%
4	50%	0%	0%	33%
5	14%	0%	0%	57%
6	25%	0%	0%	0%
7	0%	0%	0%	0%
8	17%	0%	0%	0%
9	71%	0%	0%	0%
10	44%	0%	0%	0%
11	100%	0%	100%	14%
12	33%	33%	0%	0%

Note: All districts use steel blades. No district is currently using JOMA, polyurethane, or any other blade type.

Table 2.6 presents the percentage of counties within each district, many counties may utilize multiple blade types. All districts use a steel blade as their standard, and not many are currently using a specialty plow blade. Lake County in District 12 is using Polar Flex blades, and all counties in District 11 are testing the Winter XL Classic blades. Some counties do use rubber blades, but most are installed on underbody plows. During the survey, the researchers are informed that the rubber plow blades do not work well with high speed interstate applications; consequently, the rubber blades are not considered in this evaluation.

Another piece of equipment that may impact the wear of blades is a plow shoe. Plow shoes are placed on the bottom of the plow to help reduce the amount of force placed on the plow blade. The percentage of counties in each district reporting that they use plow shoes is shown in Figure 2.6.

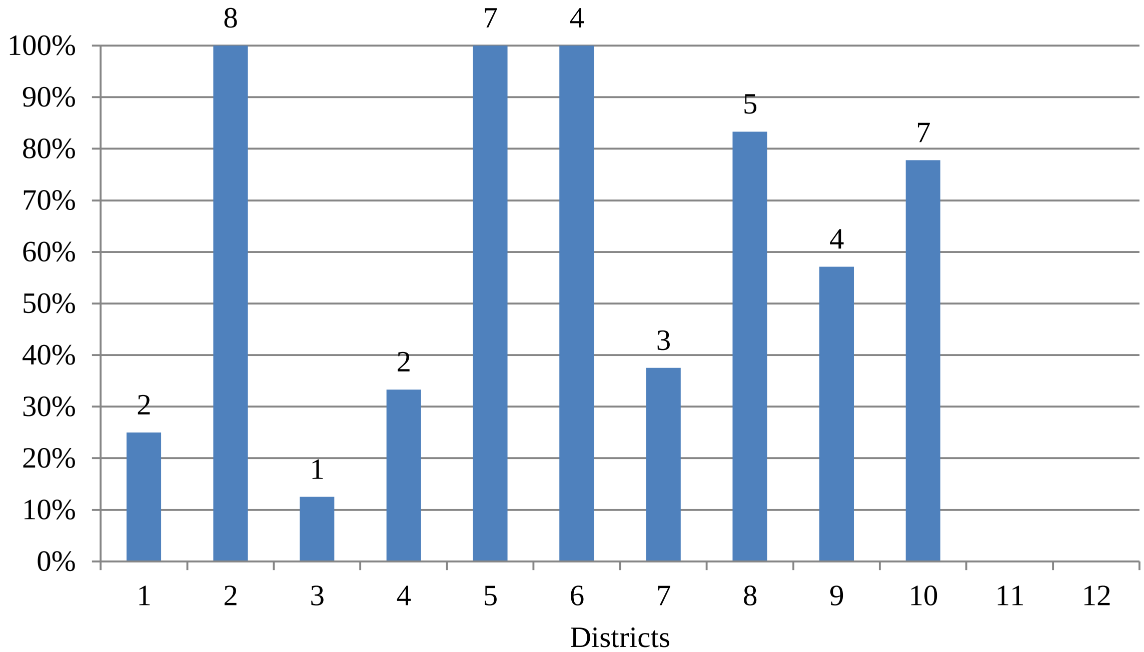


Figure 2.6: Percentage of Counties in each District using Plow Shoes.

None of the counties in Districts 11 and 12 reported using plow shoes, while the other districts reported varied usage. Several county garages indicated that they are currently using plow shoes but are phasing out the plow shoes and are no longer purchasing new plow shoes when the old ones fall off. Because a number of ODOT garages are phasing out the use of the plow shoes, the research team recommends that plow shoes are not used with the plow blades in this evaluation.

Plow guards are often used to help reduce the wear on plow blades. Plow guards are placed on the edge of the plow; they either wrap around the edge of the plow blade or have a straight section that stops at the edge of the plow blade. Figure 2.7 presents a plow blade with straight plow guards on each side.

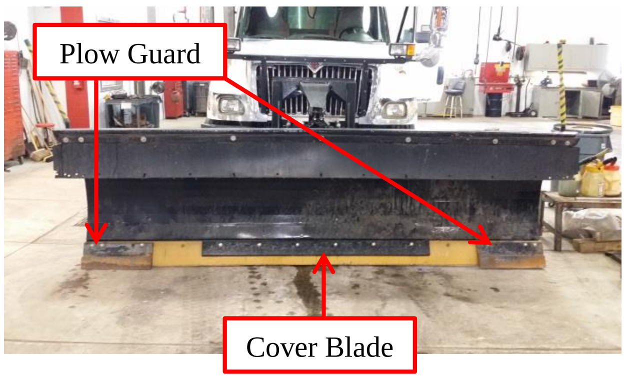


Figure 2.7: Plow Blade with Guards on Each Side and Cover Blade in Middle.

The percentage of counties using plow guards in each district is shown in Figure 2.8. Overall, plow guard usage is much higher than plow shoe usage. Several districts use plow guards in all counties, and all districts report that at least half of the counties are using plow guards. The lower usage of plow shoes is likely due to the fact that plow shoes are dislodged easily on uneven road surfaces.

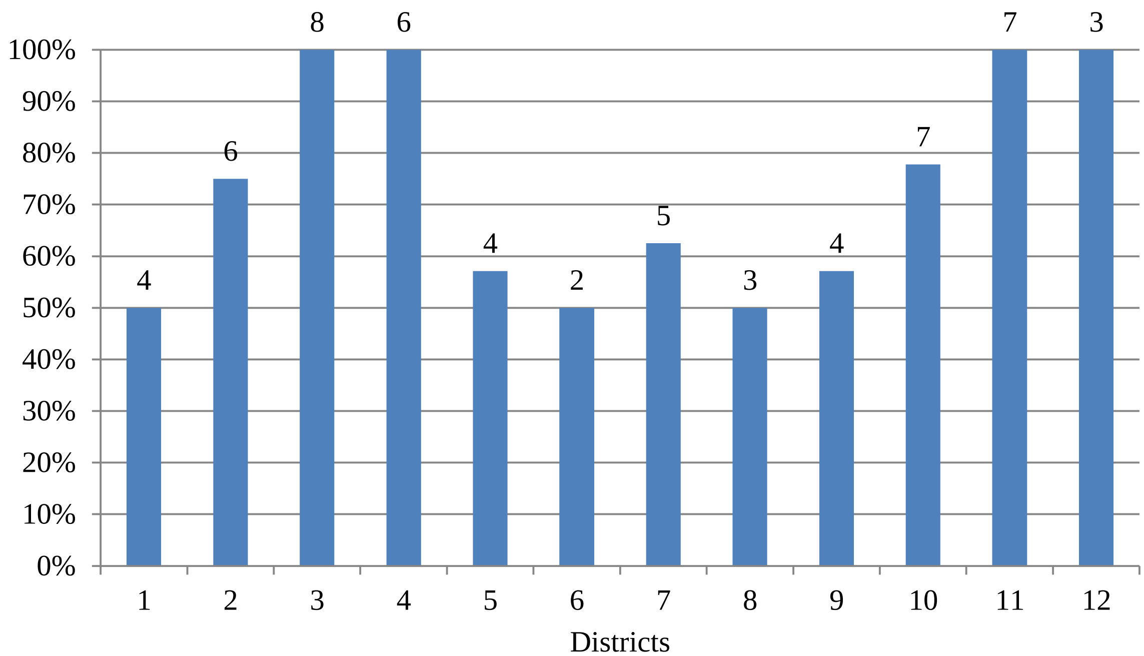


Figure 2.8: Percentage of Counties using Plow Guards in each District.

Another piece of equipment that may have major impacts on the wear of plow blades is a counterbalance. Figure 2.9 shows the percentage of counties in each district that use counterbalances.

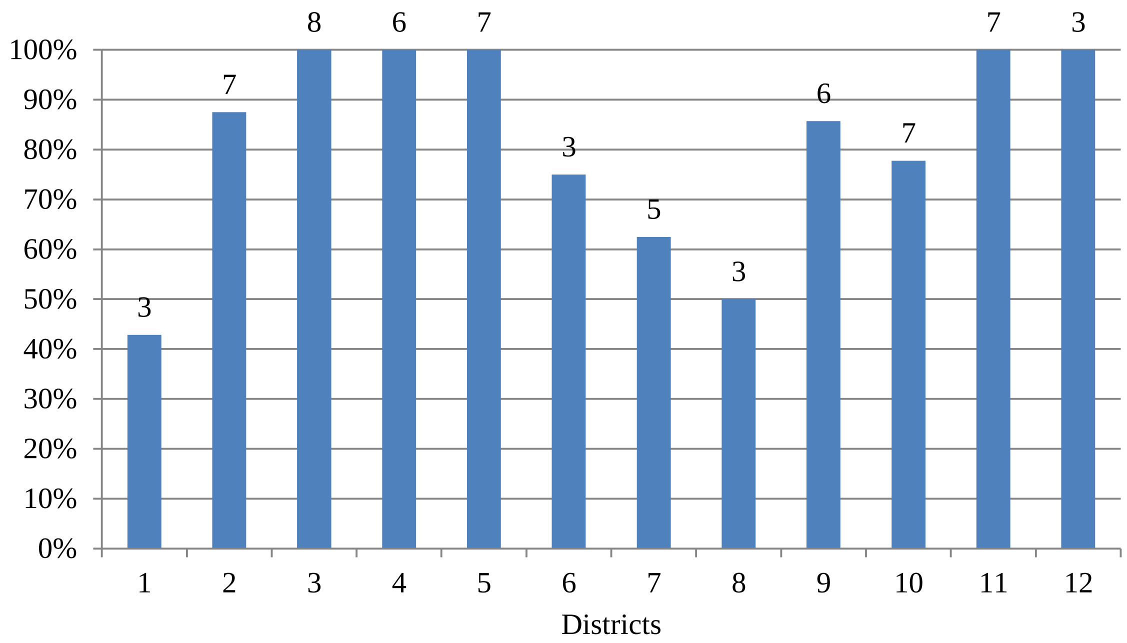


Figure 2.9: Percentage of Counties using Counterbalances in each District.

From the survey, it is found that most counties are using counterbalances. All districts have at least half of the counties using counterbalances except for District 1. The type of counterbalance used in each county is also determined and is shown in Figure 2.10.

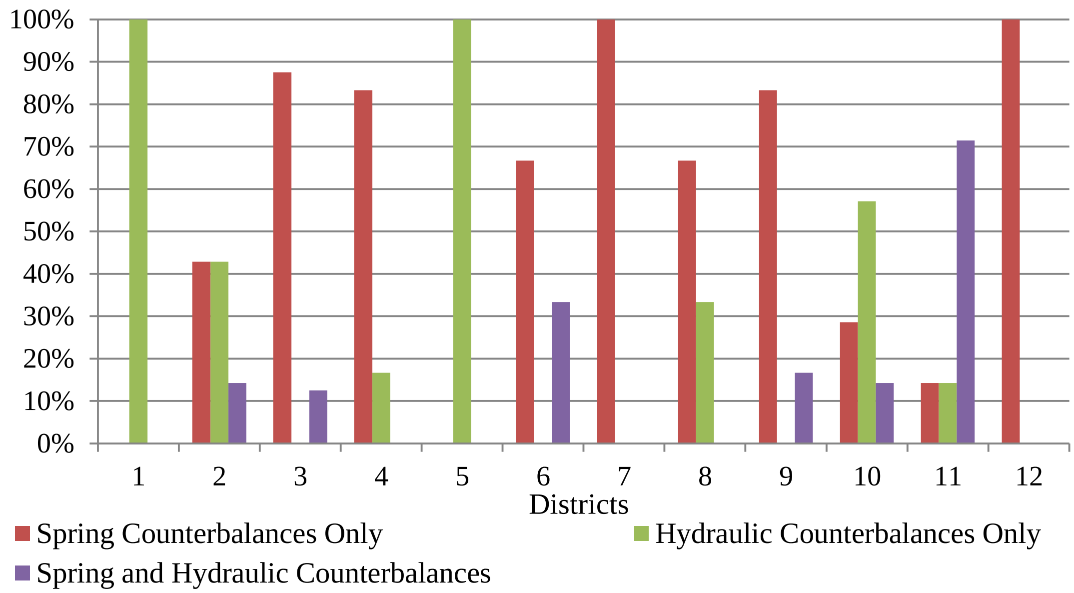


Figure 2.10: Percentage of each Type of Counterbalance used in each District.

Figure 2.10 shows a breakdown of what type of counterbalances are used in which districts. Districts 1 and 5 only use hydraulic counterbalances, while District 12 uses exclusively spring counterbalances. The remaining districts use both spring and hydraulic counterbalances. The research team matched counterbalance types for each set of the same blade, to ensure that the counterbalances are a controlled variable. All the test trucks with spring counterbalance are calibrated at the beginning of the season.

2.2.3 Road Surface

The type of road surface may play a pivotal role in determining which blades will have the best wear rate. Certain blades may be better suited for asphalt, concrete or chip seal surfaces. Figure 2.11 shows the breakdown of road surface types in each district.

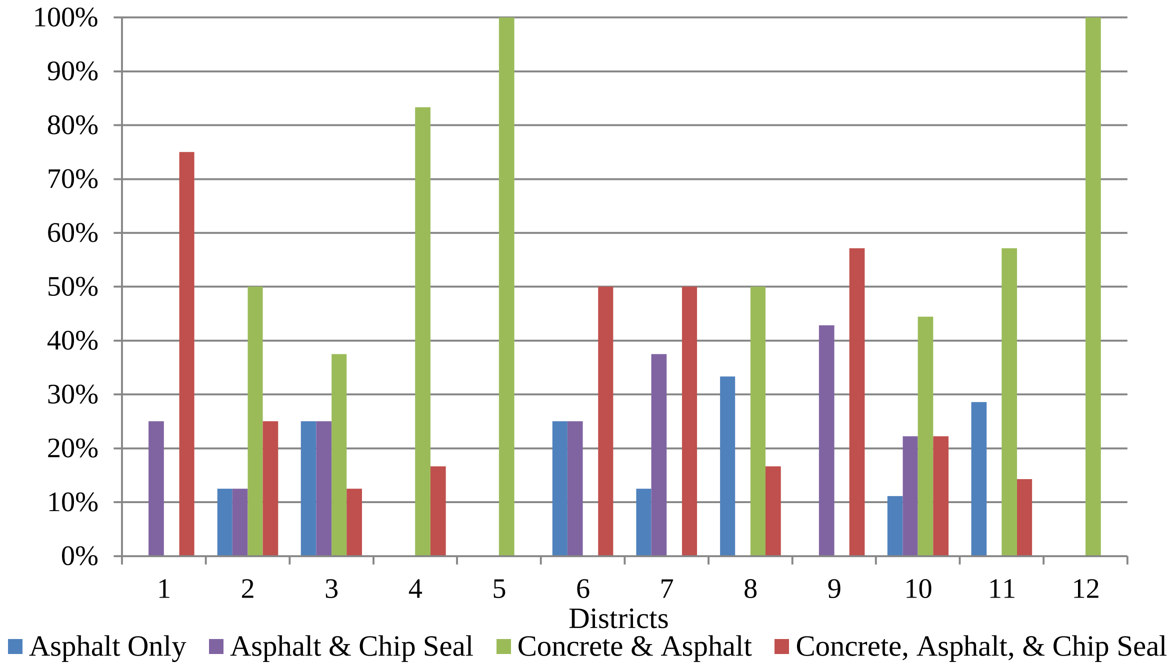


Figure 2.11: Road Surface Types in each District.

The majority of the counties have some combination of asphalt and concrete, with minimal chip seal. From Figure 2.11, it is difficult to determine the length of chip seal roads within each county, but 38 counties reported having at least some chip seal roads. When evaluating the plow blades, the researchers will test the blades on different road surface types to determine any differences in the amount of wear.

2.2.4 Summary of Survey Results

As previously stated, the survey consisted of 35 questions, and individual results are not presented for each question. Table 2.7 shows a summary of the survey results based on the responses received from 81 of the 88 county garages. The count listed in the table represents the number of counties in agreement with the statement. The percent represents the percentage of responding counties in agreement with the statement.

Table 2.7: Summary of Survey Results.

	Count	Percent
Total Count	81	
Front	81	100%
Wing	46	57%
Underbody	32	40%
Tow Plow	4	5%
Pre-wet	76	94%
Do not Pre-wet	1	1%
Sometimes Pre-wet	3	4%
Tripping Mechanism	79	98%
No Tripping Mechanism	2	2%
Use Carbide Inserts	31	38%
Do Not Use Carbide Inserts	50	62%
Use Plow Shows	43	53%
Do Not Use Plow Shoes	38	47%
Use Plow Guards	61	75%
Do Not Use Plow Guards	20	25%
Use Counterbalance	65	80%
Do Not Use Counterbalance	15	19%
Spring Counterbalance	41	51%
Hydraulic Counterbalance	28	35%
Use Full Length Blade	67	83%
Do not use Full Length Blade	14	17%
Use Partial Length Blade	54	67%
Do Not Use Partial Length Blade	27	33%
Use Cover Plow Blade (for joints)	46	57%
Do Not Use Cover Plow Blade (for joints)	35	43%
Polymer Blade	0	0%
Rubber Blade	7	9%
Steel Blade	81	100%
Other	8	10%
Concrete	56	69%
Asphalt	80	99%
Chip Seal	38	47%
Use Different Blades for Different Road Surfaces	1	1%
Do Not Use Different Blades	80	99%
Use Different Blades for Different Weather Conditions	2	2%
Do Not Use Different Blades	78	96%
Notice a Difference in Life Spans	8	10%
Do Not Notice a Difference in Life Spans	71	88%
Change Blades at County Garage	81	100%
Change Blades at Outposts	13	16%
Head of Bolts Face Front	55	68%
Head of Bolts Face Back	33	41%
Safety Protocol for Changing Blades	41	51%
No Safety Protocol	36	44%
Training Program for Changing Blades	17	21%
No Training Program	63	78%

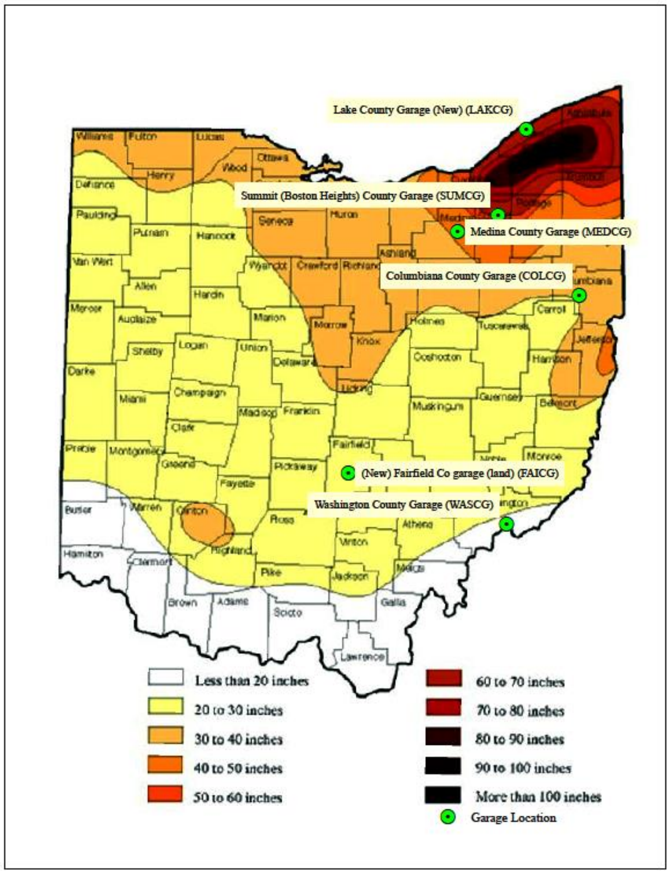
CHAPTER III PROJECT SETTING

This chapter provides information about the geographical setting for the project as well as descriptions of the equipment used in this study. This chapter is divided into two sections:

- Section One – Project Setting, and
- Section Two – Plow Blade Systems.

3.1 Project Setting

Through the survey and discussions with the technical liaison committee, the research team has identified six garages to use in the evaluation. The garages are shown in Figure 3.1, which also shows the average annual snowfall for the state of Ohio.



Note: Snowfall map is provided by ODOT *Snow and Ice Practices*, March 2011

Figure 3.1: Garages for Plow Blade Evaluation.

Selecting the six garages presented in Figure 3.1 will allow the blades to be evaluated in snowfall ranging from less than 20 inches to more than 100 inches annually. Also, the blades will be evaluated on high speed urban interstates as well as rural two-lane highways, which will capture high speed and low speed plowing operations. Columbiana County is conducting an in-house test of the Winter Blockbuster XL Classic (XL Classic) blade in the first winter season, and therefore the research team utilized the test blade from this county garage; however, once the XL Classic test blade wore through, the research team focused on the blades at the other five county garages in the second winter season of this evaluation.

3.2 Plow Blade Systems

Table 3.1 presents the blades selected in the first year of this evaluation, which are identified through the literature review and discussions with ODOT.

Table 3.1: Blade Selection Information for Year One.

District	County	Blades(*) (**)	Counterbalance	Snowfall (in.)	Road Surface
3	Medina	Steel, Carbide (Existing)**	Spring	30 – 60	Asphalt
4	Summit	Steel, JOMA (Spring)*, PolarFlex (Spring)*	Spring	40 – 80	Asphalt and Concrete
5	Fairfield	Steel, Winter XL Classic (Hydraulic)*	Hydraulic	20 – 30	Asphalt and Concrete
10	Washington	Steel, JOMA (Spring)*	Spring, Hydraulic	<20 – 30	Asphalt and Concrete
11	Columbiana	Steel, Winter XL Classic (Hydraulic*, Existing**)	Spring, Hydraulic	20 – 40	Asphalt and Concrete
12	Lake	Steel, PolarFlex (Spring*, Existing**)	Spring	60 – 100	Asphalt and Concrete

Note: (*) Indicates the type of counterbalance that should be on the truck the specific blade type is placed on.
(**) Indicates the blade type is currently being used in the county.

As presented in Table 3.1, the blades selected for this evaluation include the following:

- The standard flame-hardened steel blade with straight end curb guards on each side (referred to as the “Standard” blade), which is the primary configuration for many ODOT garages;
- The standard carbide-tipped steel blade with straight end curb guards on each side (Carbide), which some ODOT garages implement currently;

- The JOMA™ 6000 blade (JOMA), which contains carbide insert castings encased in rubber, with two Winter® CURBRUNNER® Plow Guards for each side;
- The PolarFlex blade (PolarFlex), which contains tungsten carbide inserts encased in synthetic rubber pads; and
- The Winter® BlockBuster® XL Classic™ Carbide blade system (XL Classic), which contains tungsten carbide inserts with cast steel wear blocks with Carbide Matrix™ Wear Pads. (Note that this blade was referred to as the "Xtreme" in the beginning of the study; however, the name was changed to "XL Classic" during the course of this research project).

Additionally, Table 3.1 presents the corresponding type of counterbalance used with each blade. Counterbalances are used to reduce the downward force when placing the plow on the ground. There are two types of counterbalances: hydraulic and spring. The spring counterbalance utilizes large springs that are considered to be manual, since they need to be manually calibrated to the weight of the plow. The hydraulic counterbalance, in contrast, reduces the downward force on the plow through the hydraulic system installed in the truck, and it is considered to be automatic. Spring counterbalances are calibrated when the blades are installed, while hydraulic counterbalances are calibrated when an issue arises. The research team contacted Gledhill Road Machinery Co., a plow manufacturer, to determine how frequently the counterbalances should be calibrated. According to Gledhill, the actual cutting edge or blade is a minimal component of the total weight of the entire plow; the springs should be checked periodically, as they may lose tension. The hydraulic units are checked only when there appears to be an issue, such as when increased blade wear is observed or when the operator senses that the blade's downward force needs to be adjusted. Each of the duplicate blades tested in the evaluation share the same type of counterbalance in order to prevent any differences in wear due to the counterbalance employed. Figure 3.2 presents photos of each blade type evaluated.

A) Standard Blade

B) Carbide Blade

C) JOMA Blade

D) PolarFlex Blade

E) XL Classic Blade

Figure 3.2: Blades Evaluted – A) Standard Blade, B) Carbide Blade, C) JOMA Blade, D) PolarFlex Blade, E) XL Classic Blade.

The standard blade shown in Figure 3.2A appears to have an additional steel blade or guard across the middle. However, the additional piece in the center is an old blade that does not make any contact with the road; its only purpose is to cover the joint of the blade when two blade sections (which are five or six feet in length) are installed on the 11- or 12-foot plow. The PolarFlex is the only blade without additional guards on each side; while additional guards are included with the purchase of the other specialty blades, they are not supplied with the PolarFlex.

Once the blades for the first winter season (Year One) are analyzed, as presented in Chapter 5, the blades for the second winter season (Year Two) are selected through meetings with ODOT. For the second winter season, the number of trucks included in the evaluation is increased from 13 trucks to 20 and the number of garages decreased from six to five, as discussed in Section 3.1. Table 3.2 presents the blades tested in each of the five garages during Year Two.

Table 3.2: Blade Selection Information for Year Two.

County	Counterbalance	Blade 1	Blade 2	Blade 3	Blade 4
Medina	Spring	Standard	XL Classic	PolarFlex	Middle Guard
Summit	Spring	Standard	XL Classic	Carbide	No Counterbalance
Lake	Spring	Standard	XL Classic	Carbide	Middle Guard
Fairfield	Hydraulic	Standard	PolarFlex	Carbide	Double Stacked
Washington	Hydraulic	Standard	PolarFlex	Double Stacked	No Counterbalance

Note: "Middle Guard" refers to a standard blade configuration with an additional straight edge guard placed in the middle of the blade. "No Counterbalance" refers to a standard blade configuration with no counterbalance used over the course of the season. "Double Stacked" refers to a setup having two full standard steel blades with straight edge guards on each end.

During Year Two, each garage is testing one Standard blade as a control blade, similar to Year One. XL Classic blades, PolarFlex blades, and Carbide blades are each used in three different counties to increase redundancy. After reviewing the results from Year One and meeting with ODOT, it is decided that the JOMA blade would not be tested during the second year of the study. While the JOMA blade had a similar life span when compared to the PolarFlex, it had a much higher cost; consequently, ODOT and the research team decided to review the XL Classic and PolarFlex (but not the JOMA) in the second winter season. The Carbide-tipped blades are only tested in one garage during the first year of the study; therefore, through discussions with ODOT, more data on this blade is gathered during Year Two. Additional details about the results obtained during Year One may be found in Chapter 5.

Through discussions with ODOT, it is decided to test different configurations of a standard blade in the second year of the study, along with the specialty blades. As discussed in the note section of Table 3.2, a standard blade with an additional guard placed in the middle section of the blade (middle guard) is tested in two garages. During Year Two, the research team is also testing the effects of the counterbalances by reviewing a standard blade without a counterbalance; two garages are involved in the testing of the standard blade with no counterbalance on the plow. Some counties use a standard blade setup that consists of two steel blades stacked on top of each other ("double stacked") with guards on each side; therefore, the research team included the testing of two plows with double stacked blades in Year

Two. Please note that the term “standard blade” is used in this study to refer to a single steel blade with guards on each side.

CHAPTER IV DATA COLLECTION METHODOLOGY

This chapter provides information about the data collection methodology for the project. There are three main components of the data collection:

- Section One – Field Data Collection and Archiving,
- Section Two – Video Data Analysis, and
- Section Two – Plow Blade Measurement Data.

These three sections provide a summary of the collection methods used to gather the data needed to properly analyze the various blades included in this study. The goal of the data collection is to obtain information on all of the contributing factors associated with the wear of a blade. These factors include:

- The speed of the truck while plowing,
- The pavement type of the plowing area,
- The duration of plowing activity and miles plowed, and
- Operator variability.

Therefore, the data collection methodology will collect information on all factors used to determine the field performance of each blade.

4.1 Field Data Collection and Archiving

During field research activities, data must be collected at multiple locations throughout the entire winter season, at any time of day, and for any length of time. The optimal way to collect such a large amount of data is through video recording. For this purpose, the research team acquired a digital video recorder (DVR) equipped with a global positioning system (GPS) and an infrared vision camera for each truck in the study. Figure 4.1 presents the video system installed in one of the trucks.

A) Digital Video Recorder B) Camera Facing Front Plow

Figure 4.1: Data Collection Equipment – A) Digital Video Recorder, B) Camera.

The cameras are installed on the ceiling inside the truck's cab; they are positioned facing forward so that they are able to capture the action of the front plow. The DVRs are installed in various locations in the cab, depending on the truck's current equipment configuration. The DVRs are wired to turn on when the ignition is started, and the DVR is used to supply power to the camera. It should be noted that no audio signals are recorded by the camera. Figure 4.2 presents a sample of the front-facing camera to determine the plow's position.

A) Plow in "Down" Position, Utilized B) Plow in "Up" Position, not Utilized

Figure 4.2: Sample of Plow Position on Video – A) Plow on Road Surface, B) Plow not Utilized.

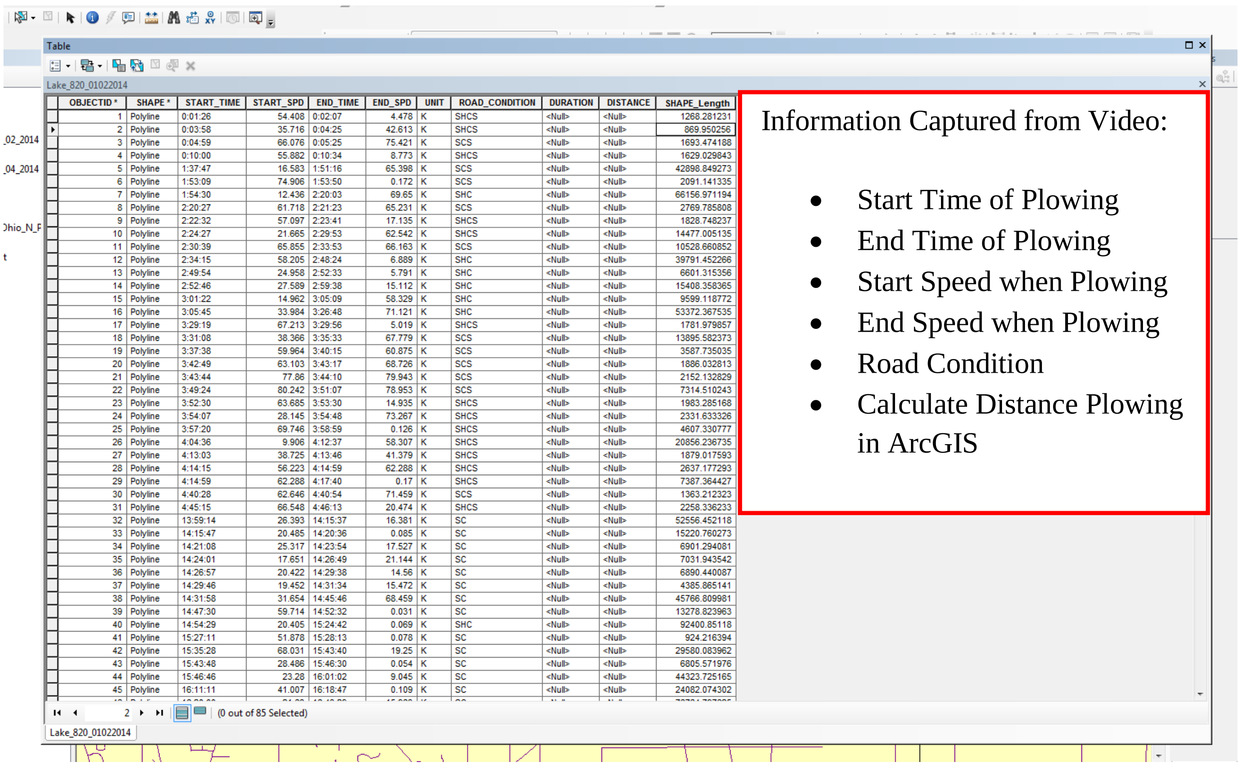
The DVR contains a hard drive that allows all the video data to be stored. Throughout the winter season, the research team would periodically retrieve the hard drive with recorded data and replace it with a blank hard drive. The video data from each hard drive are downloaded to a large storage drive with a mirroring function that allows the data to be stored in two separate locations, preventing any loss of data should one of the drives fail. Once the video footage is downloaded onto the storage drive, the video files on the DVR's hard drive are removed and the drive may be reused in the field for further data collection. The video data are organized on the storage drive and may be reviewed throughout and after the winter plowing season. Figure 4.3 presents a sample frame of video footage showing the information captured by the DVR.

Figure 4.3: Data Captured from a Frame of Video Footage.

The information contained in the video footage allows the research team to record the location, truck speed, and length of time when the plow is placed on the road.

4.2 Video Data Analysis

ArcGIS (produced by Esri in Redlands, California) is utilized for recording the video data. This program is selected for its ease of use and because it is available to the State of Ohio. Any time that a plow truck begins to plow or stops plowing, the route may be captured by tracing the roads in ArcGIS and the associated variables obtained from the video footage (as described above) may be recorded in an attribute table. Each route segment that is captured is then associated with the appropriate variables collected from the video feed. Figure 4.4 shows a sample attribute table with plowing data in ArcGIS.



OBJECTID *	SHAPE *	START_TIME	START_SPD	END_TIME	END_SPD	UNIT	ROAD_CONDITION	DURATION	DISTANCE	SHAPE_Length
1	Polyline	0:01:26	54.408	0:02:07	4.478	K	SHCS	<Null>	<Null>	1268.281231
2	Polyline	0:03:58	35.716	0:04:25	42.613	K	SHCS	<Null>	<Null>	869.950256
3	Polyline	0:04:59	66.076	0:05:25	75.421	K	SCS	<Null>	<Null>	1693.474188
4	Polyline	0:10:00	55.882	0:10:34	8.773	K	SHCS	<Null>	<Null>	1629.029843
5	Polyline	1:37:47	16.583	1:51:16	65.398	K	SCS	<Null>	<Null>	42898.849273
6	Polyline	1:53:09	74.906	1:53:50	0.172	K	SCS	<Null>	<Null>	2091.141335
7	Polyline	1:54:30	12.436	2:20:03	69.65	K	SHC	<Null>	<Null>	66156.971194
8	Polyline	2:20:27	61.718	2:21:23	65.231	K	SCS	<Null>	<Null>	2769.785808
9	Polyline	2:22:32	57.097	2:23:41	17.135	K	SHCS	<Null>	<Null>	1828.748237
10	Polyline	2:24:27	21.665	2:29:53	62.542	K	SHCS	<Null>	<Null>	14477.005135
11	Polyline	2:30:39	65.855	2:33:53	66.163	K	SCS	<Null>	<Null>	10528.660852
12	Polyline	2:34:15	58.205	2:48:24	6.889	K	SHC	<Null>	<Null>	39791.452266
13	Polyline	2:49:54	24.958	2:52:33	5.791	K	SHC	<Null>	<Null>	6601.315356
14	Polyline	2:52:46	27.589	2:59:38	15.112	K	SHC	<Null>	<Null>	15408.358365
15	Polyline	3:01:22	14.962	3:05:09	58.329	K	SHC	<Null>	<Null>	9599.118772
16	Polyline	3:05:45	33.984	3:26:48	71.121	K	SHC	<Null>	<Null>	53372.367535
17	Polyline	3:29:19	67.213	3:29:56	5.019	K	SHCS	<Null>	<Null>	1781.979857
18	Polyline	3:31:08	38.366	3:35:33	67.779	K	SCS	<Null>	<Null>	13895.582373
19	Polyline	3:37:38	59.964	3:40:15	60.875	K	SCS	<Null>	<Null>	3587.735035
20	Polyline	3:42:49	63.103	3:43:17	68.726	K	SCS	<Null>	<Null>	1886.032813
21	Polyline	3:43:44	77.86	3:44:10	79.943	K	SCS	<Null>	<Null>	2152.132829
22	Polyline	3:49:24	80.242	3:51:07	78.953	K	SCS	<Null>	<Null>	7314.510243
23	Polyline	3:52:30	63.685	3:53:30	14.935	K	SHCS	<Null>	<Null>	1983.285168
24	Polyline	3:54:07	28.145	3:54:48	73.267	K	SHCS	<Null>	<Null>	2331.633326
25	Polyline	3:57:20	69.746	3:58:59	0.126	K	SHCS	<Null>	<Null>	4607.330777
26	Polyline	4:04:36	9.906	4:12:37	58.307	K	SHCS	<Null>	<Null>	20856.236735
27	Polyline	4:13:03	38.725	4:13:46	41.379	K	SHCS	<Null>	<Null>	1879.017593
28	Polyline	4:14:15	56.223	4:14:59	62.288	K	SHCS	<Null>	<Null>	2637.177293
29	Polyline	4:14:59	62.288	4:17:40	0.17	K	SHCS	<Null>	<Null>	7387.364427
30	Polyline	4:40:28	62.646	4:40:54	71.459	K	SCS	<Null>	<Null>	1363.212323
31	Polyline	4:45:15	66.548	4:46:13	20.474	K	SHCS	<Null>	<Null>	2258.336233
32	Polyline	13:59:14	26.393	14:15:37	16.381	K	SC	<Null>	<Null>	52556.452118
33	Polyline	14:15:47	20.485	14:20:36	0.085	K	SC	<Null>	<Null>	15220.760273
34	Polyline	14:21:08	25.317	14:23:54	17.527	K	SC	<Null>	<Null>	6901.294081
35	Polyline	14:24:01	17.651	14:26:49	21.144	K	SC	<Null>	<Null>	7031.943542
36	Polyline	14:26:57	20.422	14:29:38	14.56	K	SC	<Null>	<Null>	6890.440087
37	Polyline	14:29:46	19.452	14:31:34	15.472	K	SC	<Null>	<Null>	4385.865141
38	Polyline	14:31:58	31.654	14:45:46	68.459	K	SC	<Null>	<Null>	45766.809981
39	Polyline	14:47:30	59.714	14:52:32	0.031	K	SC	<Null>	<Null>	13278.823963
40	Polyline	14:54:29	20.405	15:24:42	0.069	K	SHC	<Null>	<Null>	92400.85118
41	Polyline	15:27:11	51.878	15:28:13	0.078	K	SC	<Null>	<Null>	924.216394
42	Polyline	15:35:28	68.031	15:43:40	19.25	K	SC	<Null>	<Null>	29580.083962
43	Polyline	15:43:48	28.486	15:46:30	0.054	K	SC	<Null>	<Null>	6805.571976
44	Polyline	15:46:46	23.28	16:01:02	9.045	K	SC	<Null>	<Null>	44323.725165
45	Polyline	16:11:11	41.007	16:18:47	0.109	K	SC	<Null>	<Null>	24082.074302

Figure 4.4: Sample of an Attribute Table with Recorded Video Data.

The data collected during winter plowing activities may be used to determine the average speed of the trucks when they are plowing, the road conditions during plowing, and the distance the trucks are plowing. Figure 4.5 shows a sample ArcGIS map of the routes that are plowed in Fairfield County on January 5, 2014, by a plow truck equipped with the XL Classic blade.

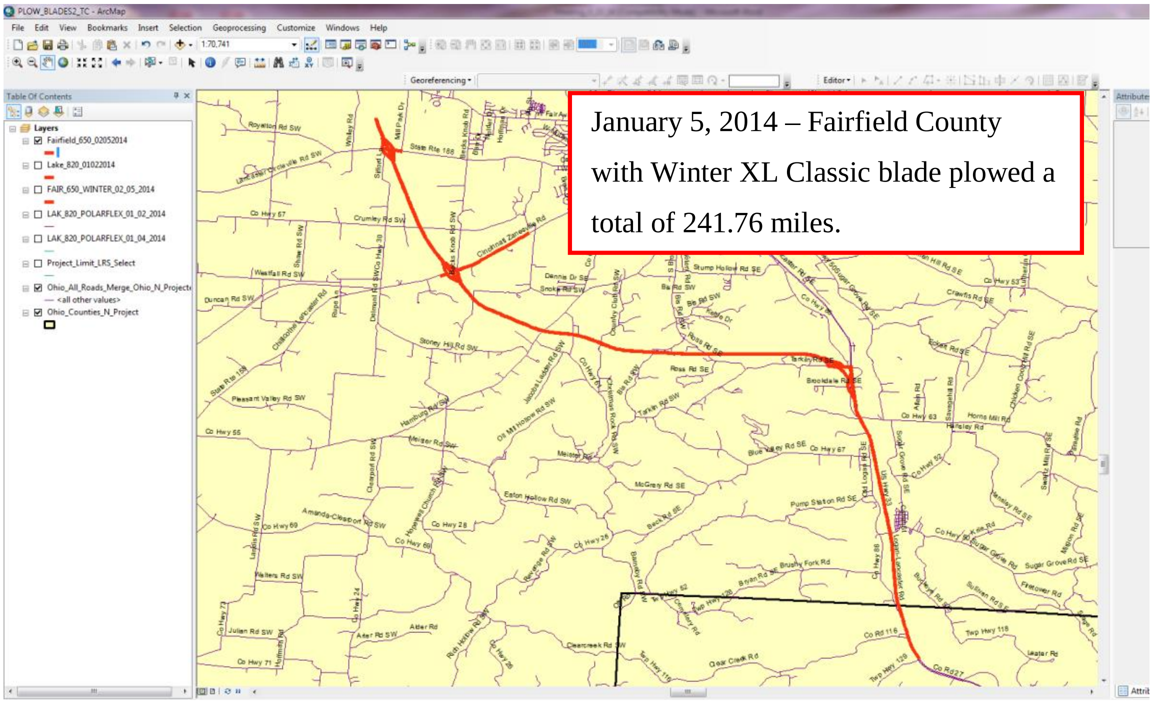


Figure 4.5: ArcMAP for a Route Plowed during a Snow and Ice Event (With Plow Route Shown in Red).

Knowing the locations of routes the trucks are plowing allows the research team to determine the plowing duration and distance plowed on various road surface types by trucks using each type of blade.

4.3 Plow Blade Measurement Data

Blade measurements are collected throughout the winter season to aid in determining how each of the variables collected will affect the life span of the blade. Since a blade does not wear evenly along its entire span due to the angle of the blade and the crown of the road, the research team collected measurements at five distinct locations along the span of the blade at various points in time during the winter season. Figure 4.6 presents a photograph of a 12-foot plow blade that indicates the five measurement locations.

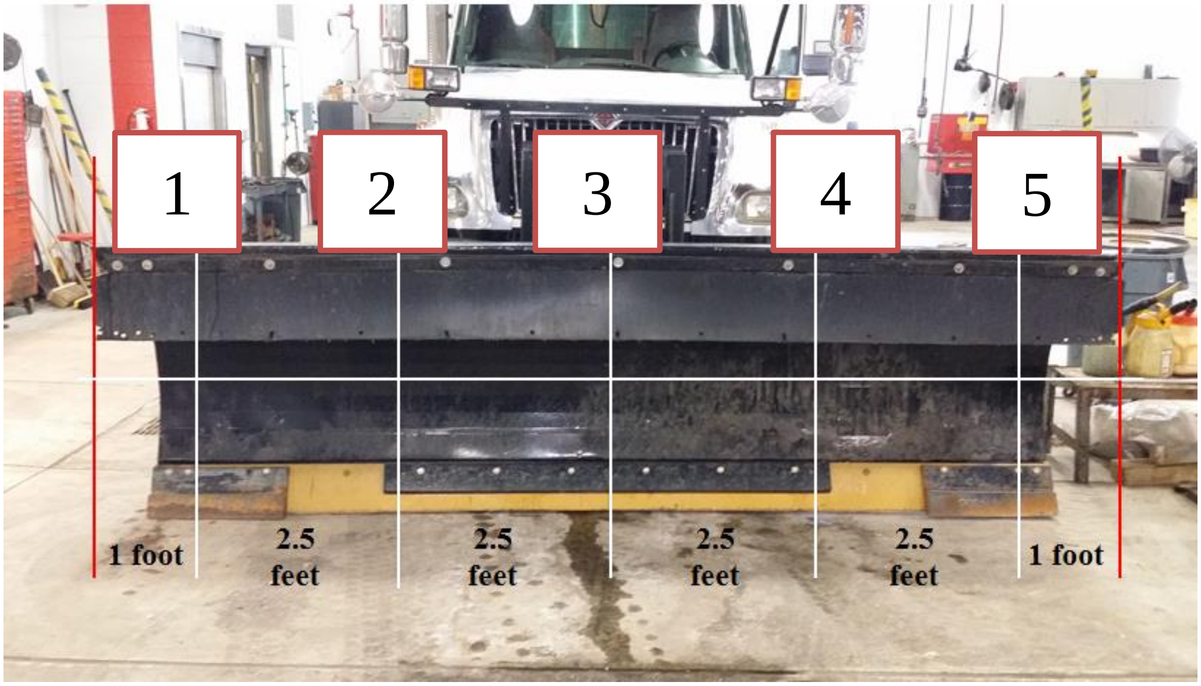
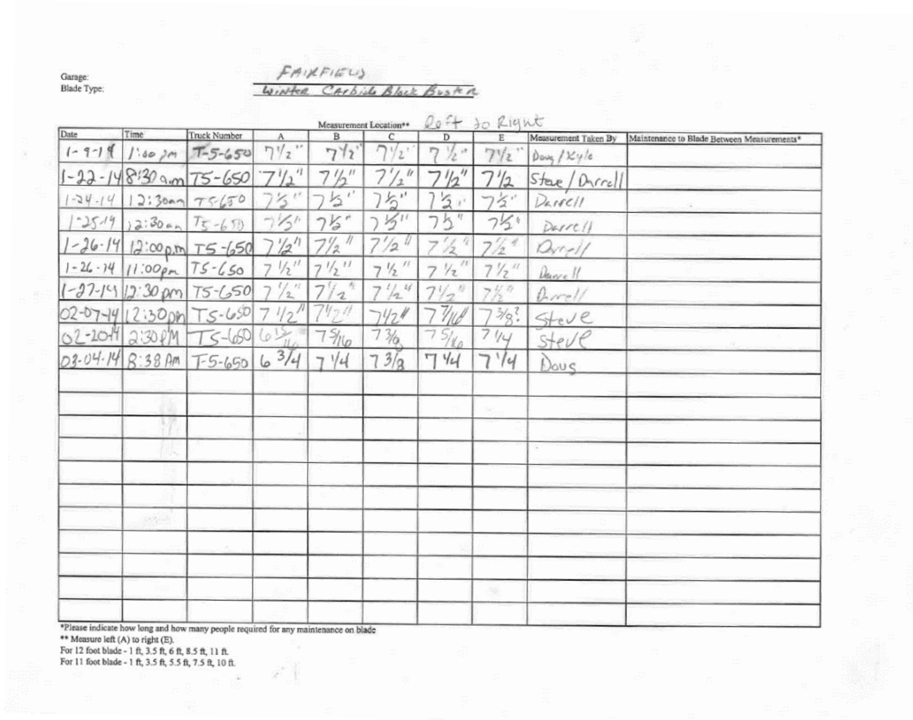


Figure 4.6: Five Locations at which Measurements are Taken along a 12-Foot Blade.

The five measurement locations are adjusted proportionally for 11-foot blades, as needed. To record the data, the measurements collected for each blade are documented on a measurement sheet, along with the truck number and the date and time that the measurements are collected. A sample measurement sheet is presented in Figure 4.7.



Garage: FAIRFIELD
Blade Type: Winter Carbide Black Buster

Measurement Location** Left to Right

Date	Time	Truck Number	A	B	C	D	E	Measurement Taken By	Maintenance to Blade Between Measurements*
1-9-14	1:00 pm	T-5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Doug / Kyle	
1-22-14	8:30 a.m	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2	Steve / Darrell	
1-24-14	12:30am	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Darrell	
1-25-14	12:30am	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Darrell	
1-26-14	12:00p.m	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Darrell	
1-26-14	11:00pm	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Darrell	
1-27-14	12:30 pm	T5-650	7 1/2"	7 1/2"	7 1/2"	7 1/2"	7 1/2"	Darrell	
02-07-14	12:30pm	T5-650	7 1/2"	7 1/2"	7 1/2"	7 7/16	7 3/8?	Steve	
02-20-14	2:30PM	T5-650	6 15/16	7 5/16	7 3/8	7 5/16	7 1/4	Steve	
03-04-14	8:38 Am	T-5-650	6 3/4	7 1/4	7 3/8	7 1/4	7 1/4	Doug	

*Please indicate how long and how many people required for any maintenance on blade
** Measure left (A) to right (E).
For 12 foot blade - 1 ft, 3.5 ft, 6 ft, 8.5 ft, 11 ft.
For 11 foot blade - 1 ft, 3.5 ft, 5.5 ft, 7.5 ft, 10 ft.

Figure 4.7: Sample of Measurement Sheet for an XL Classic Blade in Fairfield County.

The operators of all trucks included in the study are asked to collect blade measurements as frequently as possible.

The blade measurement sheets are collected periodically by the research team throughout the study period. All data collected throughout the two seasons are used to determine the rate of wear (amount of wear per mile) for each blade type to aid in determining the number of standard blades that are equivalent to each specialty blade. The plowing speed, road surface type, and operator variables are all considered in the calculation of the rate of wear.

CHAPTER V YEAR ONE RESULTS

This chapter provides information about the analysis of the data collected for the project and the cost analysis for each blade evaluated in the first winter season of this project. There are three main components of this chapter:

- Section One – Year One Results,
- Section Two – Cost Analysis, and
- Section Three – Conclusion.

Using the field data collected over the first winter season, an evaluation may be conducted to determine the lifespan of each blade. Following the field data collection, the feasibility of implementation will be determined by comparing each specialty blade to a standard blade based on the life cycle costs. The two main components of the data collection are the video data and the blade measurement data. While the research team did experience minor issues with the video data collection system placed in the trucks, the equipment is able to successfully capture over 95% of the data throughout the first winter season. Figure 5.1 provides the analysis process utilized by the research team in determining the cost-effectiveness of each blade.

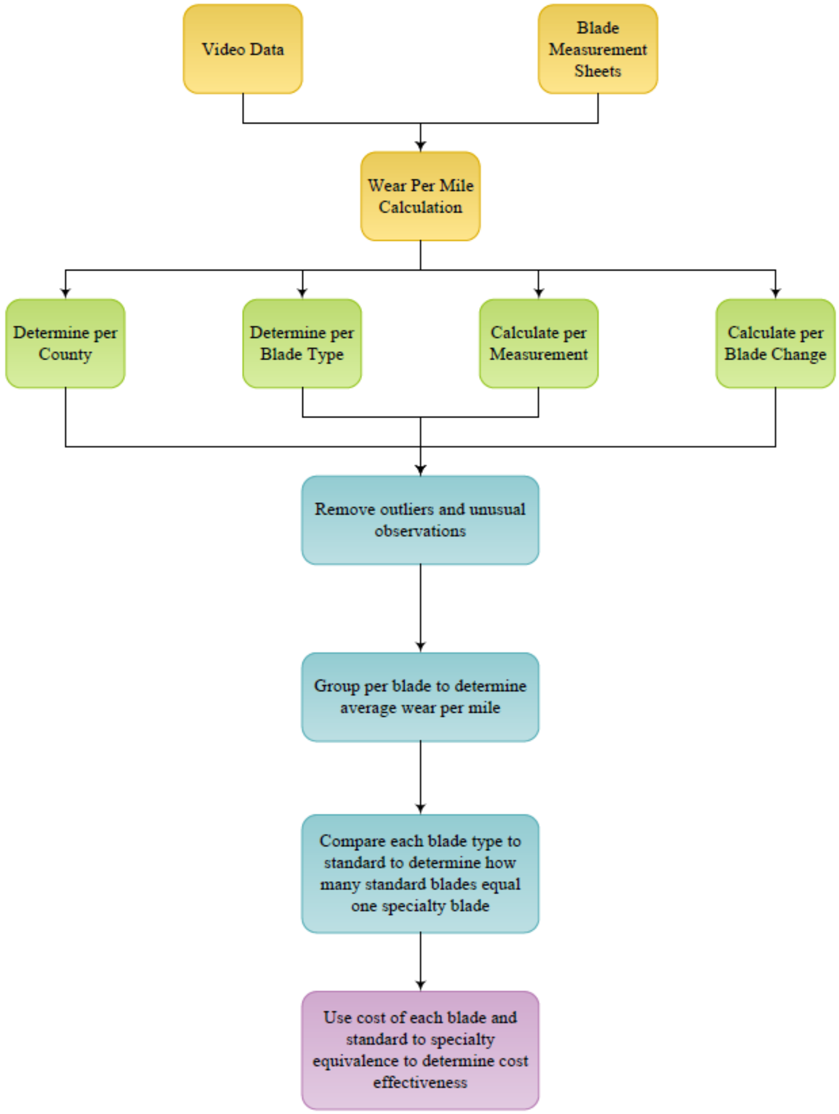


Figure 5.1: Data Analysis for Each Blade in the Evaluation.

By combining the information retrieved from the video data (such as the miles plowed, the speed while plowing, and the road surface type) with the measurement data, the blade wear per mile while plowing may be calculated. This wear rate may be determined by county, blade type, wear between measurements, and wear between each blade change, as presented in Figure 5.1. By reviewing the wear rate within each category, the outliers may be identified and removed from the data set. Once the outliers are removed, the average wear per mile may be determined for each blade type and then compared to the wear rate of the standard blades. The cost of each specialty blade as compared to a standard blade will be calculated, as presented in in Section 5.2 of this report.

5.1 Year One Results

During the first winter season, 2013–2014, a total of 13 trucks at six garages in Ohio are analyzed as a part of this study. Table 5.1 presents a summary of the results for Year One.

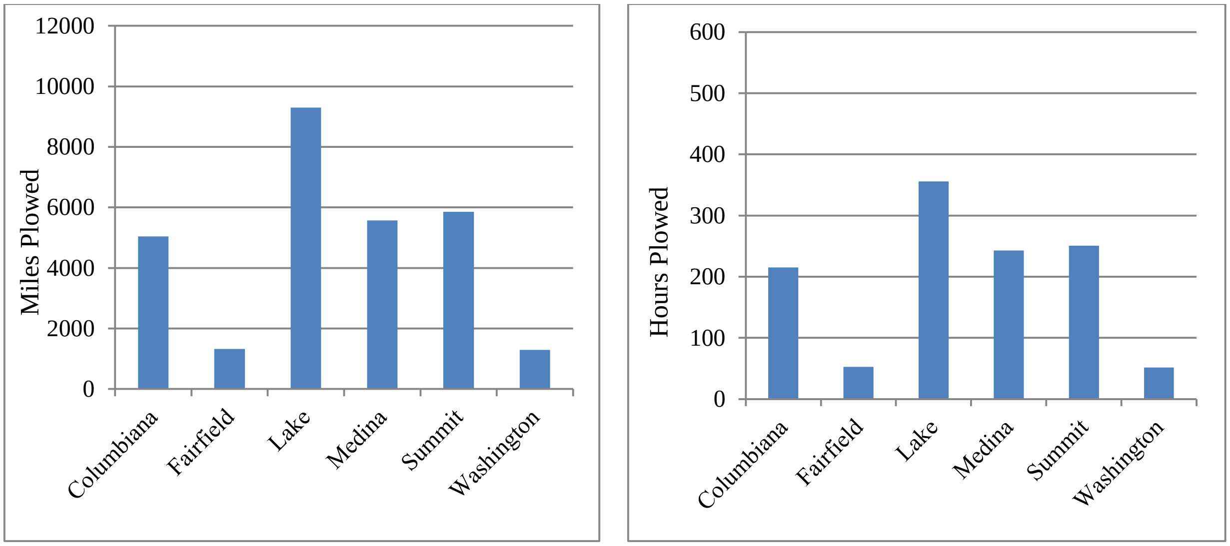
Table 5.1: Summary of Year One Results.

County	**Blade Type**	**Average Wear (inches)**	**Distance Plowed (miles)**	**Time Plowed (hours)**	**Blades Used**	**Average Plowing Speed (mph)**	**Cost**
Columbiana	Standard	3.36	2107	88	2	40	$1,078
Columbiana	XL Classic	0.45	2690	118	1	34	$3,021
Fairfield	Double	0.71	831	35	1	33	$745
Fairfield	XL Classic	0.33	495	18	1	27	$3,021
Lake	Standard	14.86	3310	142	5	34	$2,695
Lake	PolarFlex	0.91	5526	198	1	40	$2,507
Medina	Standard	1.1	2367	124	1	33	$539
Medina	Carbide	1.88	2908	109	2	31	$836
Summit	Standard	2.85	1469	56	3	33	$1617
Summit	PolarFlex	1.91	1842	92	1	35	$2,507
Summit	JOMA	0.73	2547	103	1	32	$3,402
Washington	Standard	0.9	781	32	1	27	$539
Washington	JOMA	0.5	513	20	1	27	$3,402

Note: The average wear is determined from adding the wear of each measurement location over the entire season for each blade type, in each county, then averaging the wear across the blade. For example, Lake County went through 5 standard blades, and the cumulative average wear across the blade equals 14.86. The cost includes the labor for blade changing.

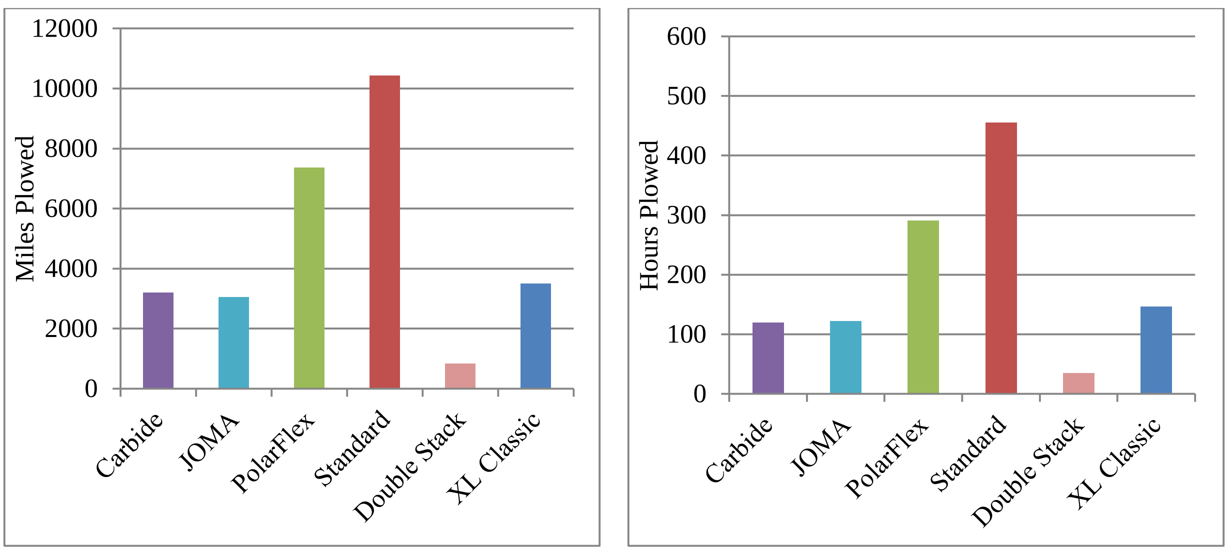
Table 5.1 presents the average wear, distance plowed, time plowed, number of blades used, and the average plowing speed of each of the blades tested in Year One. Additional data, such as pavement condition while plowing and the amount of snow cover on the road, are collected by the research team and are presented in Appendix A.

Figure 5.2 presents a graphical summary of the total miles and hours plowed within each county and the time and distance plowed by trucks using each blade type.



A) Distance Plowed Per County

B) Time Plowed Per County



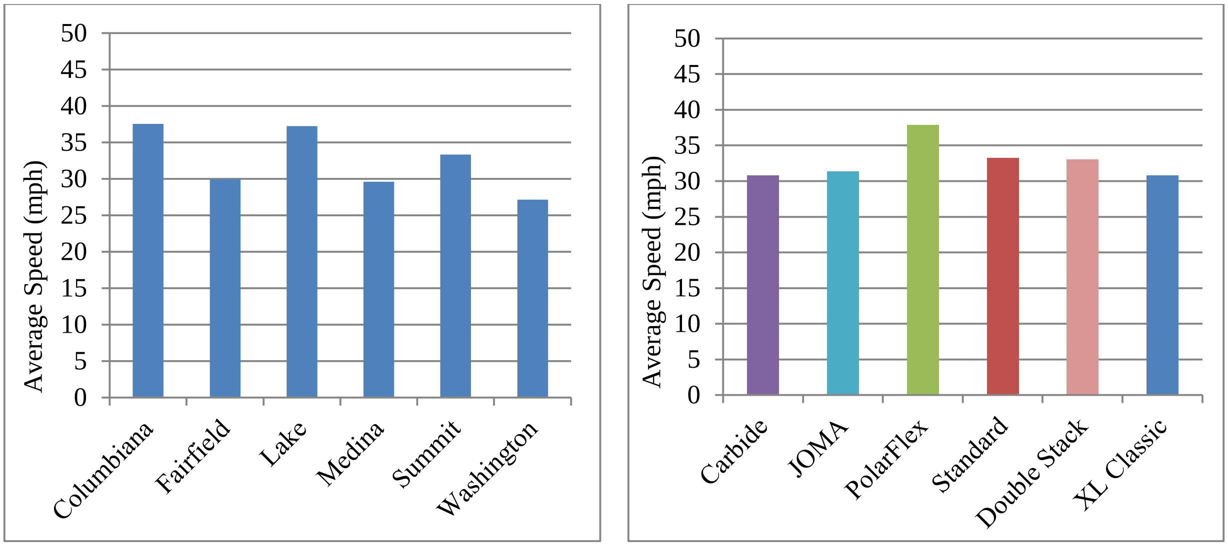
C) Distance Plowed by Blade Type

D) Time Plowed by Blade Type

Figure 5.2: Year One Overall Summary – A) Distance Plowed Per County, B) Time Plowed Per County, C) Distance Plowed by Blade Type, and D) Time Plowed by Blade Type.

It is important to note that the data presented in Figure 5.2 is the total for all blades of a given type for the entire season. For example, in Figure 5.2C, the miles plowed for standard blades is the total of all 12 standard blades, which are used to plow a total of 10,429 miles; the miles plowed for the JOMA blades is the total of only two JOMA blades, which are used to plow a total of 3,060 miles.

As mentioned in Chapter 4, the video files created by the DVRs provide the time and GPS location data, which are documented in ArcGIS. Using the distance of each road segment where the plow is used and the time it took the truck to plow each segment, the space mean speed is calculated to determine the plowing speed. Figure 5.3 presents the average plowing speed for each county and blade over the entire 2013–2014 winter season.



A) Average Plowing Speed Per County B) Average Plowing Speed by Blade Type

Figure 5.3: Year One Average Plowing Speed Summary – A) Average Speed Pre County, B) Average Speed by Blade Type.

When reviewing Figure 5.3A, it may be seen that the average plowing speeds range from 27 mph (in Washington County) to 37 mph (in Columbiana and Lake counties). From Figure 5.3B, it appears that the trucks equipped with PolarFlex blades plowed at an average speed of 37 mph, while the trucks equipped with Carbide and XL Classic blades plowed at an average speed of 31 mph. The average speeds for all blades are consistent with ODOT guidelines for plowing and therefore, speed is not considered a factor in the comparison.

Once all plowing segments are mapped in ArcGIS, the road surface and bridge joint exposure may be determined. A majority of the routes treated by ODOT are asphalt; however, the exposure to concrete surfaces is calculated to determine its effect of the road surface type on the wear of the blades. Table 5.2 presents the number of bridge joints encountered by each blade type as well as the percentage of roadways having concrete surfaces that are plowed in the participating counties.

Table 5.2: Number of Bridge Joints and Percent of Concrete Plowed by Each Blade in Each County during Year One.

		Standard Blade		Specialty Blade	
County	**Specialty Blade**	**Number of Joints**	**Percent Concrete**	**Number of Joints**	**Percent Concrete**
Columbiana	XL Classic	244	0.1%	3106	0.8%
Fairfield	XL Classic	1868	3.7%	1848	4.9%
Lake	PolarFlex	20104	19.1%	44726	5.2%
Medina	Carbide	2680	0.8%	1370	0.3%
Summit	PolarFlex	15804	5.9%	61798	15.8%
Summit	JOMA	15804	5.9%	96094	13.6%
Washington	JOMA	646	1.1%	1800	16.1%

Note: The standard blade used in Fairfield County is a double-stacked blade. The number of joints is calculated by counting the number of concrete segments plowed and multiplying by two. This method assumes that each concrete segment is a bridge deck with two joints at each end.

As seen in Table 5.2, the blades with the highest percentage of concrete treated are: the Lake County standard blade, the Washington County JOMA blade, and the JOMA and PolarFlex blades in Summit County. The average speed and the data on the percentage of roads plowed that are concrete are analyzed to determine the impact and effects of these variables. Due to the high variance of the data and the low sample size, there is no significant effect to the wear based on average speed and pavement type. In addition to the plowing speed and exposure to bridge joints and varying road surfaces, the actions of an individual truck operator could have an impact on the lifespan of the blade. Each operator may utilize the blade differently based on past experience and prior training; therefore, the research plan ensured that each blade is used by multiple operators to average out the operator's effect on the wear of the blade.

In any winter season, a blade may be damaged and rendered unusable before the blade is worn through. Table 5.3 presents the issues experienced with blades during the first year of the evaluation.

Table 5.3: Test Blade Damage Observed in Year One.

County	Blade Type	2013–2014 Winter Season Notes	Photo
Summit	JOMA	The driver-side curb guard on the JOMA was lost on a barrier wall drain. The plow continued to be used without the curb guard. Photo shows the JOMA blade with a missing a curb guard.	
Summit	PolarFlex	On 1/26/2014, this blade hit a bridge expansion joint – the middle section was bent to the point where the blade was unusable. New teeth were ordered for the blade; the new teeth were installed on 2/5/2014.	
Summit	PolarFlex	The PolarFlex blade hit a monument box. The middle section and trip edge were slightly bent, but the plow was still useable. This blade went through three trip edges during Year One.	
Medina	Carbide	On 1/26/2014, the first carbide blade was broken on a bridge expansion.	no photo available

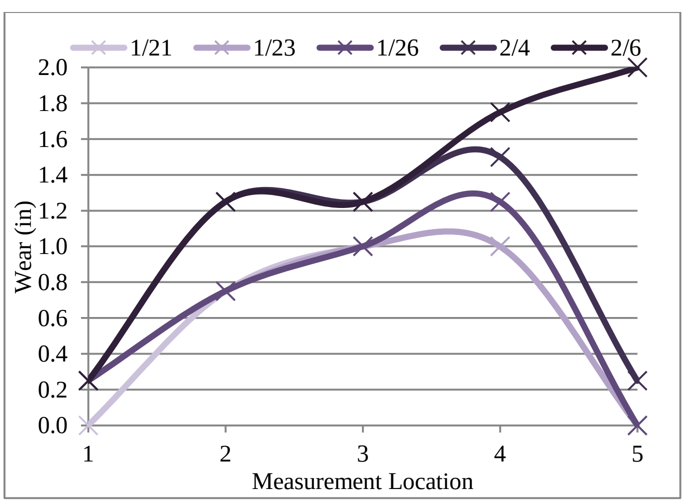
As observed in Table 5.3, the Summit County JOMA blade lost a curb guard; however, this did not render the blade unusable. The Summit County PolarFlex blade hit a bridge expansion joint, which damaged the blade to a degree where it is no longer able to be used. The PolarFlex blade is designed to allow for the carbide steel teeth to be replaced (at a cost of $100 per linear foot); the hardware (if not worn out) and teeth holder may continue to be used.

After the Summit County PolarFlex hit the bridge expansion joint, the research team ordered new carbide teeth for the blade. All the carbide teeth on the blade had to be replaced due to the wear along the entire length of the blade, even though only two teeth are damaged in the impact with the bridge expansion joint. The extensive wear on one of the carbide teeth may be seen in the photo presented in Figure 5.4.

Figure 5.4: Original Carbide Tooth (on the left) compared to Replacement Carbide Tooth (on the right) for the PolarFlex Blade.

As shown in Figure 5.4, too much wear is observed for the first set of carbide teeth to consider replacing only the two bent sections, as this would result in insufficient snow removal. The cost to replace the entire 12-foot blade with new carbide teeth is $1200, which is less costly than having to replace the entire PolarFlex blade. In Section 5.2 of this report, cost information will be provided for replacement teeth as well as for the blade itself.

When analyzing the wear at each measurement location, the wear pattern for each blade may be observed. Figures 5.5 to 5.8 present the wear observed over the first winter season for each of the specialty blades. Each line presented in the graph (on the left side of each figure) shows the wear on the date the measurement is taken. The lines will have darker shades of color to indicate the wear measurements that are obtained later in the season. The tables on the right side of each figure present the blade measurements at each date. Figure 5.5 presents the wear pattern of one carbide blade. The carbide blade presented in this figure broke on a bridge joint during Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
1/15	7	7	7	7	7
1/21	7	6.25	6	6	7
1/23	6.75	6.25	6	6	7
1/26	6.75	6.25	6	5.75	7
2/4	6.75	5.75	5.75	5.5	6.75
2/6	6.75	5.75	5.75	5.25	5

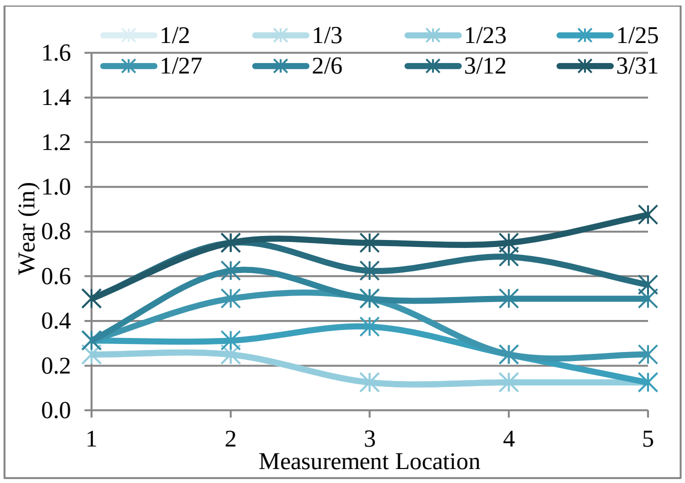
Mechanical Counterbalance

Note: The wear scale maximum is set to 2.0 in., while the other graphs in this figure are set to 1.6 in to help improve resolution.

Figure 5.5: Medina Carbide Tipped Blade Wear Pattern – Broke on Bridge Joint in Year One.

When reviewing the wear pattern in Figure 5.5, it is observed that the middle section of the blade wore at a faster rate than the ends. This wear pattern may be due to the angle of plowing along with the crown of the road. Also, each end of the blade is equipped with a guard, which helps reduce wear on the each side of the blade. A wear measurement of two inches on the driver's side (noted on February 6, 2014) is associated with the breaking of the blade.

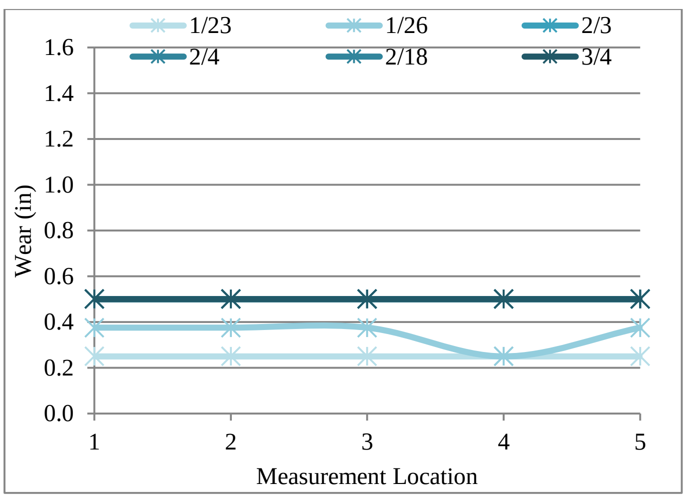
Figure 5.6 presents the wear of the JOMA blades during Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
12/26	6	6	6	6	6
1/2	5.75	5.75	5.88	5.88	5.88
1/3	5.75	5.75	5.88	5.88	5.88
1/23	5.75	5.75	5.88	5.88	5.88
1/25	5.69	5.69	5.63	5.75	5.88
1/27	5.69	5.5	5.5	5.75	5.75
2/6	5.69	5.38	5.5	5.5	5.5
3/12	5.5	5.25	5.38	5.31	5.44
3/31	5.5	5.25	5.25	5.25	5.13

Mechanical Counterbalance

A) Summit JOMA Wear Pattern – Nearly Worn Through at the End of Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
1/6	9	9	9	9	9
1/23	8.75	8.75	8.75	8.75	8.75
1/26	8.63	8.63	8.63	8.38	8.63
2/3	8.5	8.5	8.5	8.5	8.5
2/4	8.5	8.5	8.5	8.5	8.5
2/18	8.5	8.5	8.5	8.5	8.5
3/4	8.5	8.5	8.5	8.5	8.5

Mechanical Counterbalance

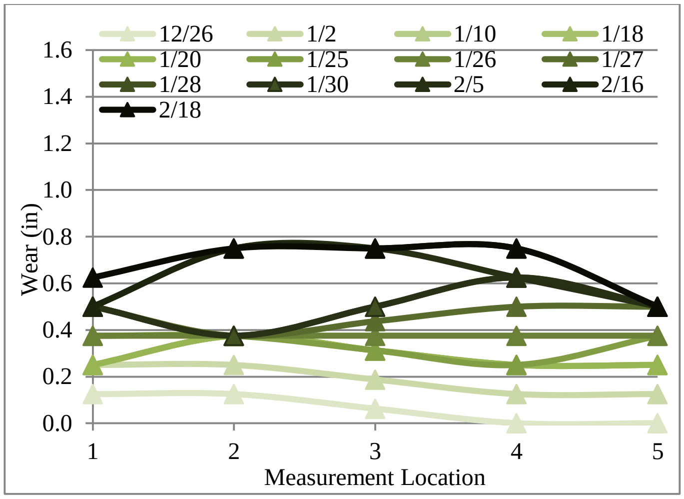
B) Washington JOMA Wear Pattern – Still On at the End of Year One.

Figure 5.6: JOMA Blade Wear Patterns – A) Summit County JOMA, B) Washington County JOMA.

For the JOMA blade in Summit County, the highest degree of wear is observed on the driver side at measurement location 5, which may be due to the loss of the driver side guard, as mentioned in Table 5.2.

The JOMA blade in Washington County maintained its blade length from February 3, 2014, through the end of the first winter season and is still able to be utilized the following year. Washington County averages less than 20 inches of snow per year; consequently, plow blades are used less in this county than blades in other areas of the state, as presented in Figure 5.2A.

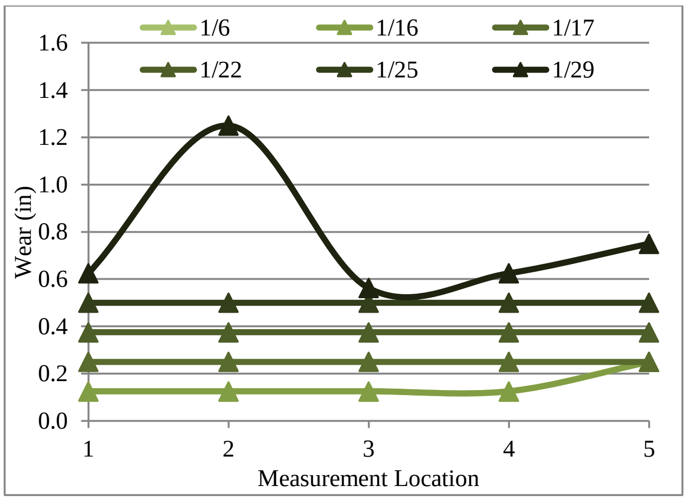
Figure 5.7 presents the wear pattern for the PolarFlex blades used in Lake County and Summit County during Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
12/19	6	6	6	6	6
12/26	5.88	5.88	6	6	6
1/2	5.75	5.75	5.80	5.88	5.88
1/10	5.75	5.63	5.66	5.75	5.75
1/18	5.75	5.63	5.66	5.75	5.75
1/20	5.75	5.63	5.66	5.75	5.75
1/25	5.63	5.63	5.63	5.63	5.63
1/26	5.63	5.63	5.63	5.63	5.63
1/27	5.5	5.63	5.57	5.5	5.5
1/28	5.5	5.63	5.5	5.38	5.5
1/30	5.5	5.63	5.5	5.38	5.5
2/5	5.5	5.25	5.25	5.38	5.5
2/16	5.5	5.25	5.25	5.25	5.5
2/18	5.38	5.25	5.25	5.25	5.5

Mechanical Counterbalance

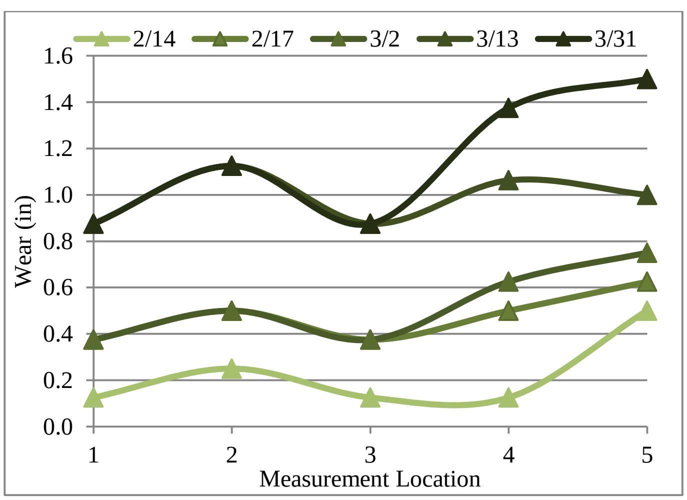
Lake PolarFlex Wear Pattern – Wore Through in Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
12/26	6	6	6	6	6
1/6	5.88	5.88	5.88	5.88	5.75
1/16	5.88	5.88	5.88	5.88	5.75
1/17	5.75	5.75	5.75	5.75	5.75
1/22	5.63	5.63	5.63	5.63	5.63
1/25	5.5	5.5	5.5	5.5	5.5
1/29	5.38	4.75	5.44	5.38	5.25

Mechanical Counterbalance

Summit PolarFlex – Broke on Bridge Joint, Bent at Location 2 During Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
2/13	6.63	6.75	6.63	6.63	6.75
2/14	6.5	6.5	6.5	6.5	6.25
2/17	6.25	6.25	6.25	6.13	6.13
3/2	6.25	6.25	6.25	6	6
3/13	5.75	5.63	5.75	5.56	5.75
3/31	5.75	5.63	5.75	5.25	5.25

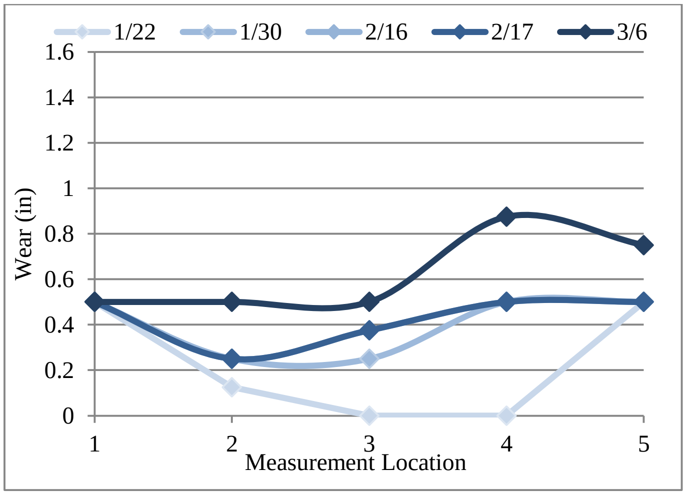
Mechanical Counterbalance

Summit PolarFlex Wear Pattern after New Teeth Installed in Year One.

Figure 5.7: PolarFlex Blade Wear Patterns – A) Lake County PolarFlex, B) Summit County PolarFlex, C) Summit County New Teeth.

The PolarFlex tested in Lake County (presented in Figure 5.7A) is observed to have worn evenly across the blade, with a minor wear increase in the center of the blade toward the end of the blade's lifespan. The PolarFlex tested in Summit County broke on a bridge expansion joint on January 29, 2014. The wear on this blade up to and including the day of damage is shown in Figure 5.7B. The damage to this blade occurred at Location 2, as seen by the photo included in Table 5.2 and by the much lower measurement at this location listed in Figure 5.7B. The wear of the PolarFlex blade in Summit County following the replacement of all the carbide steel teeth is presented in Figure 5.7C.

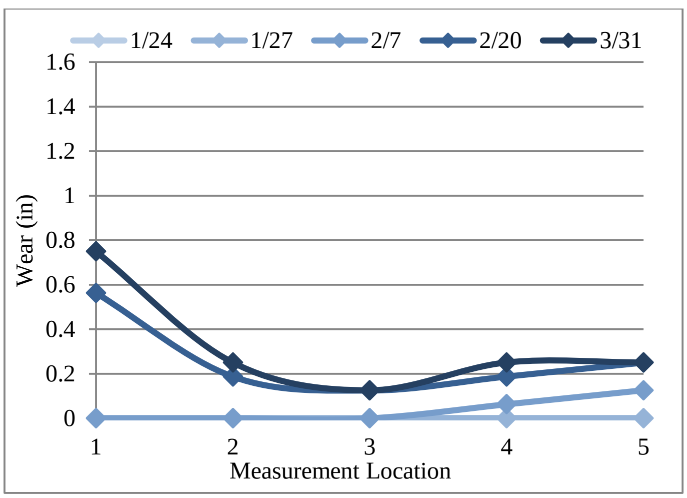
Figure 5.8 presents the wear pattern of the XL Classic blade tested in Columbiana and Fairfield counties over the first year of the evaluation.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
12/25	7.5	7.5	7.5	7.5	7.5
1/22	7	7.38	7.5	7.5	7
1/30	7	7.25	7.25	7	7
2/16	7	7.25	7.13	7	7
2/17	7	7.25	7.13	7	7
3/6	7	7	7	6.63	6.75

Hydraulic Counterbalance

A) Columbiana XL Classic Wear Pattern – Wore Through in Year One.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
1/9	7.5	7.5	7.5	7.5	7.5
1/24	7.5	7.5	7.5	7.5	7.5
1/27	7.5	7.5	7.5	7.5	7.5
2/7	7.5	7.5	7.5	7.44	7.38
2/20	6.94	7.31	7.38	7.33	7.25
3/31	6.75	7.25	7.38	7.25	7.25

Hydraulic Counterbalance

B) Fairfield XL Classic Wear Pattern – Still On in Year One.

Figure 5.8: XL Classic Blade Wear Patterns – A) Columbiana County XL Classic, B) Fairfield County XL Classic.

As seen in Figure 5.8A, a high amount of wear to the XL Classic blade in Columbiana County is observed on each side of the blade between December 25, 2013, and January 22, 2014. The XL Classic blade in Fairfield County, shown in Figure 5.8B, did not show much wear during the first year of the study, and the passenger side of the blade showed a larger amount of wear than the driver's side of the blade.

Using the data collected, the total miles each blade is plowing and the average wear across the blade are used to determine the wear rate (wear per mile) for each of the blade types. With the calculated wear rate, the number of standard blades needed to match the lifespan of each specialty blade may be determined, which is presented as the equivalent to standard ratio. Table 5.4 presents the resulting equivalence ratios.

Table 5.4: Year One Resulting Equivalence Ratios for Each Blade Type.

Blade Type	**Average Total Wear (in)**	**Total Miles**	**Wear/Mile (in/mile)**	**Equivalent Standard Blade Ratio**
Carbide	1.975	1709.2	1.16 E-03	1.7
JOMA	1.225	3060	4.00 E-04	5.0
PolarFlex	2.4375	5547	4.39 E-04	4.5
Standard	15.2	7666.6	1.98 E-03	1
XL Classic	0.95	3185.8	2.98 E-04	6.6

Note: Fairfield's double-stacked standard blade is an outlier to the data and is removed from the analysis; therefore, it is not presented in this table. In Year Two of this study, additional double-stacked blades are tested in order to determine a standard blade equivalence ratio, presented in Table 6.4.

As presented in Table 5.4, the XL Classic blade is observed to have the highest equivalence ratio, meaning that one XL Classic blade may last as long as 6.6 standard blades. At the other end of the spectrum, one carbide insert blade is equivalent to 1.7 standard blades. Each of the equivalent to standard ratios are used when determining the costs associated with each of the blades as presented in Section 5.2 on this report.

5.2 Cost Analysis

This section presents the comparison between the costs of each specialty blade tested and the cost of the equivalent number of standard blades. The data utilized in this analysis are collected in the field during the first year of this two-year evaluation. Section 5.2 is divided into three subsections as follows:

- Subsection One - Introduction to Monte Carlo simulation, the statistical methodology used for the cost analysis,
- Subsection Two – The variables and equations used in the Monte Carlo simulation, and
- Subsection Three – Cost of each blade when compared to the cost of the equivalent standard blade.

The analysis summarized in these subsections will be used to determine the costs associated with each of the blades evaluated throughout this study.

5.2.1 Introduction to Monte Carlo Simulation

Monte Carlo simulations are used to determine the cost for implementing each of the blades, as well as to determine the equivalent cost of the standard blades required to match the specialty blades. In Monte Carlo simulation, a set of functions are 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 analysis, a Monte Carlo simulation is used to determine a distribution of the costs for deploying each type of blade evaluated in this study. This method may provide a more realistic overall average cost associated with each blade, since every season may bring different blade costs due to fluctuation of weather conditions and material cost.

5.2.2 Variables and Equations

This section presents all the variables and equations used to determine the costs for each of the blades. Figure 5.9 presents the variables used in the cost analysis.

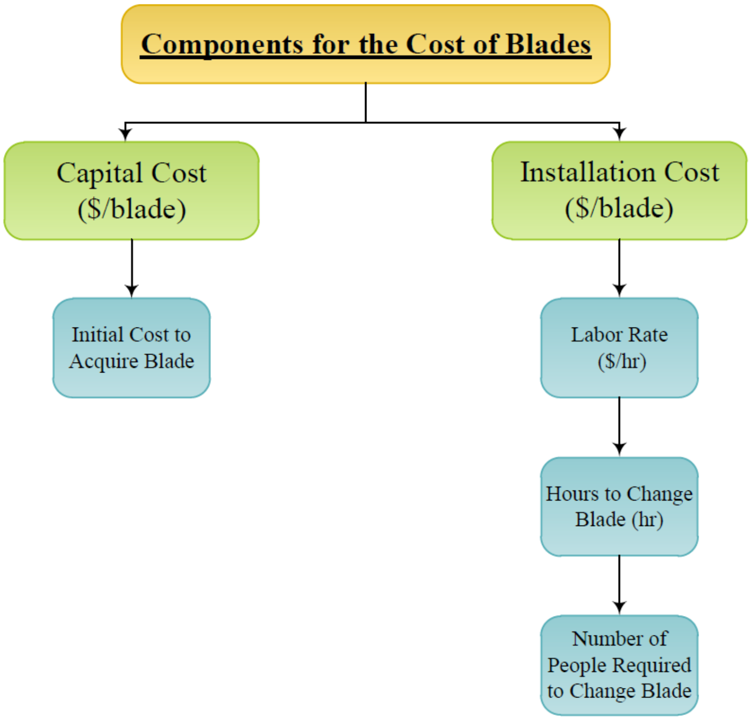


Figure 5.9: Variables Used to Determine the Cost for Each Blade Tested.

As presented in Figure 5.9, there are two categories when determining the cost of the blades: the capital cost of each blade and the installation cost each of the blades. The cost calculation is presented in Equation 5.1.

$$Cost\ (\$) = Capital\ Cost\ (\$) + Installation\ Cost\ (\$)$$

Equation 5.1

The capital cost accounts for the initial purchase of the blades. Along with the capital cost, there is also the cost of installing the blade on the truck for winter maintenance purposes, which includes time and personnel required to lift and guide the blades into place. A major benefit to using a blade with a longer lifespan than the standard blade is that fewer blade changes are needed. Equation 5.2 presents the calculation of the installation cost of the blades.

$$Installation\ Cost\ (\$) =$$

$$Labor\ Rate\ (\$/hr) \times Hours\ to\ Change\ Blade\ (hr) \times Number\ of\ People\ Need\ to\ Change\ Blade$$

Equation 5.2

Each variable in Equation 5.2 is determined by using information gathered by the research team and obtained during discussions with ODOT throughout the course of the study.

To calculate the true cost associated with the specialty blade as compared to the standard blade, the number of standard blades that are equivalent to each specialty blade must be determined, as shown in Figure 5.1 of this report. The total miles plowed and the total wear observed over each winter season are used to find the wear rate (wear per mile) for each blade. Equation 5.3 presents the calculation of the wear rate for the blades.

$$Each\ blade's\ wear\ rate\ (in/mil) = \frac{Total\ Wear\ Observed\ (in)}{Total\ Plowing\ Miles\ (mile)}$$

Equation 5.3

Once the wear rate for each blade is determined, the equivalent standard ratio for each of the specialty blades may be calculated using Equation 5.4.

$$Equivalent\ Standard\ Blade\ Ratio = \frac{Wear\ per\ mile\ of\ the\ Standard\ Blade}{Wear\ per\ mile\ of\ the\ Specialty\ Blade}$$

Equation 5.4

Each specialty blade is compared to the standard blade using Equation 5.4, and the results are presented in Table 5.5. The equivalent standard blade ratio represents the number of standard blades needed to match the lifespan of each of the specialty blades.

Most of the variables in the equations used for calculating costs are assigned an average and standard deviation, which the Monte Carlo simulation uses when selecting a random variable. The cost of the PolarFlex and JOMA are fixed values, since the cost for this equipment did not change during the study period; therefore, no standard deviation is able to be calculated for those variables. Table 5.5 provides the average and standard deviation value (if available) for each variable, along with the source used to derive that particular variable.

Table 5.5: Average and Standard Deviation of Variables Used in Blade Costs.

	Variables	Average	Standard Deviation	Source
Capital Cost	Carbide-Tipped Blade Capital Cost ($)	796.4	90.8	ODOT
	JOMA Blade Capital Cost ($)	3361.8	--	Field Evaluation
	PolarFlex Blade Capital Cost ($)	2466.0	--	Field Evaluation
	Standard Blade Capital Cost ($)	498.3	97.8	ODOT
	Winter XL Classic Blade Capital Cost ($)	2980.0	--	Field Evaluation
Labor Cost	Hourly Labor Rate ($/hour)	18	3	ODOT
	Number of People to Change One Blade (unitless)	3	0.5	ODOT
	Time to Change One Blade (hour)	0.75	0.25	ODOT
Standard Blade Cost Factor Multiplier	Carbide-Tipped Blade Equivalence	1.7	0.5	Field Evaluation
	JOMA Blade Equivalence	5	0.5	Field Evaluation
	PolarFlex Blade Equivalence	4.5	0.5	Field Evaluation
	Winter XL Classic Blade Equivalence	6.6	0.5	Field Evaluation

Note: All data are provided by or approved by ODOT to reflect their current practices. Blade equivalencies are calculated from field data. The cost of standard and carbide blades are calculated using pricing from 2012 to 2014. When the source indicates “ODOT”, the data are provided by ODOT; for a source indicated by “Field Evaluation”, the data are obtained from the two years of field evaluations of the blades conducted for ODOT by the research team. “Standard Blade Cost Factor Multiplier” refers to the number multiplied by the standard blade cost in order to compare to the cost for the number of standard blades needed to match the life of one specialty blade.

The cost for the standard blades is determined using the equipment pricing from the 2012–2013 and 2013–2014 winter seasons. There are multiple ways to create each blade, i.e., using a full 12-foot blade or using two 6-foot sections to equip a 12-foot plow blade; therefore, multiple variations of the blades are priced and then averaged over the two years of data provided by ODOT. The blade equivalences refer to the number of standard blades needed to match the lifespan of the various test blades; these equivalences are calculated from field data, as presented in Table 5.4 of this report.

5.2.1 Cost for Each Blade and Equivalent Blades

Monte Carlo simulations are run for the cost of each blade and the equivalent standard blade cost for each blade type in order to determine the savings associated with each blade, if any. The simulation is repeated 500,000 times to determine an average cost when randomly selecting values within the average and standard deviation of each variable. Figure 5.10 presents a sample of the histogram produced from the Monte Carlo simulation; the example shown is the histogram for the standard blade.

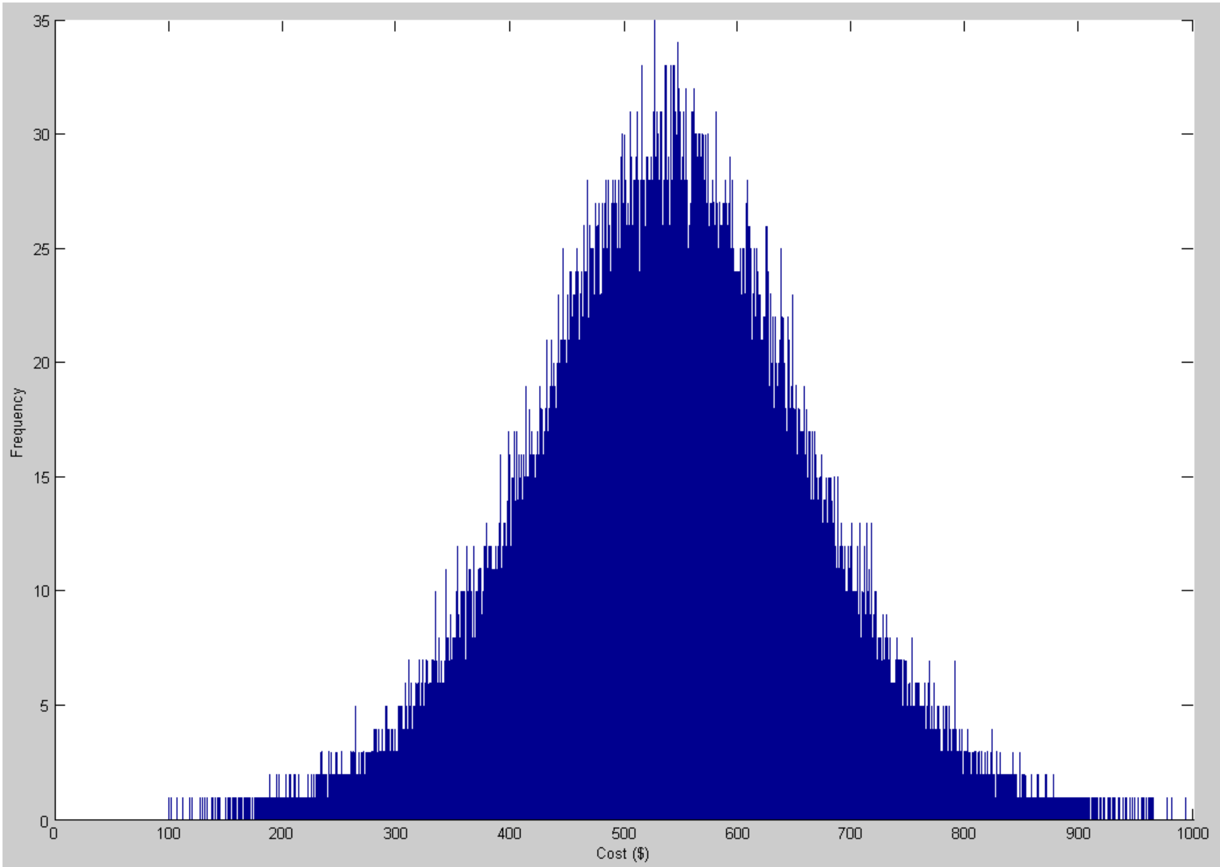


Figure 5.10: Example of Histogram for a Standard Blade produced with the Monte Carlo Simulation.

The final cost for each blade may be represented as a histogram, similar to the one presented in Figure 5.10. The *x*-axis represents the cost, and the *y*-axis represents the frequency in which that cost for the blade is found over the total number of simulations. Each model is simulated 500,000 times to produce an overall average cost and variance. Table 5.6 presents the average cost for each specialty blade as compared to the cost of the equivalent number of standard blades.

Table 5.6: Average Cost for Standard Blade Equivalent and Specialty Blades in Year One.

Specialty Blade	Specialty Quantity	Specialty Cost	Standard Quantity	Standard Cost	Savings per Blade
Carbide Single	1	$836	1.7	$916	$80
JOMA	1	$3,402	5	$2,695	($707)
PolarFlex	1	$2,507	4.5	$2,424	($83)
Standard	1	$539	1	$539	$0
XL Classic	1	$3,021	6.6	$3,554	$534

Note: The savings represents the cost savings per one specialty blade. Maintenance costs for blade changes are included in these costs. In the "Savings per Blade" column, it is more economical to use a standard blade if the cost presented in red, and it is more economical to use a specialty blade if the cost is green. i.e. the JOMA blades cost the more than a standard blades by $707 per JOMA implemented, and the XL Classic cost less than the standard blades by $534 per XL Classic implemented.

As seen in Table 5.6, the carbide blade with a standard blade equivalence of 1.7 has a savings of $80 per carbide blade implemented. Similarly, the XL Classic blade with a standard blade equivalence of 6.6 has a savings of $534 per XL Classic blade implemented in place of a standard blade. The JOMA and PolarFlex are not observed to have a cost savings when compared to the standard equivalent blade. Note that this cost calculation is performed using only the data from the first year of the study. During Year One, it is observed that blades may become damaged randomly throughout the season. This is important to note, since a new standard blade costs less to replace than a new specialty blade. When deciding whether or not to invest in specialty blades, it is important to consider the operators of the trucks and the routes that the blades are being implemented on, since new hires may not be familiar with the location of all the bridge expansion joints or other characteristics on each route that may result in damage to a blade if the driver is not careful. If implementing a blade with a longer lifespan, there may be a decrease in downtime needed to change blades during an event and a reduced risk of injuries that result from changing the blades.

5.3 Conclusion

The Year One data are reviewed and the blades for the second season are selected during meetings with ODOT. As a result of these meetings, the PolarFlex and XL Classic blades are selected for testing in the second year of the evaluation. Since the carbide blades are only tested on a single truck during Year One, it is decided to test additional carbide blades during the second year of the evaluation. The first year data suggests that the carbide and XL Classic blades are the only two blades having a cost savings associated with them. The PolarFlex has an $83 additional cost as compared to a standard blade, while the JOMA has a $707 additional cost as compared to a standard blade. The PolarFlex may not result in a cost savings when implemented; however, since the additional cost for the PolarFlex is far less than that for the JOMA, it is decided with ODOT that more data should be collected on the PolarFlex during the second year of the evaluation.

Along with continuing to collect data on the PolarFlex, XL Classic, and carbide blades, ODOT and the research team are testing different configurations of the standard flame-hardened steel blades and different guards, as well as evaluating the effectiveness of different types of counterbalances. Chapter 6 of this report presents the results obtained during Year Two of the evaluation.

CHAPTER VI YEAR TWO RESULTS

This chapter provides information about the analysis of the data collected in the second winter season for the project and the cost analysis of each blade evaluated. There are three main components of this chapter:

- Section One – Year Two Results,
- Section Two – Cost Analysis, and
- Section Three – Conclusion.

Using the field data collected over the second winter season, an evaluation may be conducted to determine the lifespan of each blade. Following the field data collection, the feasibility of implementation will be determined by comparing each specialty blade to a standard blade based on the life cycle costs. There are two main components of the data collection are the video data and the blade measurement data, as presented in Chapter 5 of this report. While the research team did experience minor issues with the video data collection system placed in the trucks, the equipment is able to successfully capture over 95% of the data throughout the second winter season. Figure 5.1 provided in Chapter 5 of this report, presents the analysis process utilized by the research team in determining the cost-effectiveness of each blade.

6.1 Year Two Results

During the second winter season, 2014–2015, a total of 20 trucks at five garages in Ohio are analyzed as a part of this study. Table 6.1 presents a summary of the year two data.

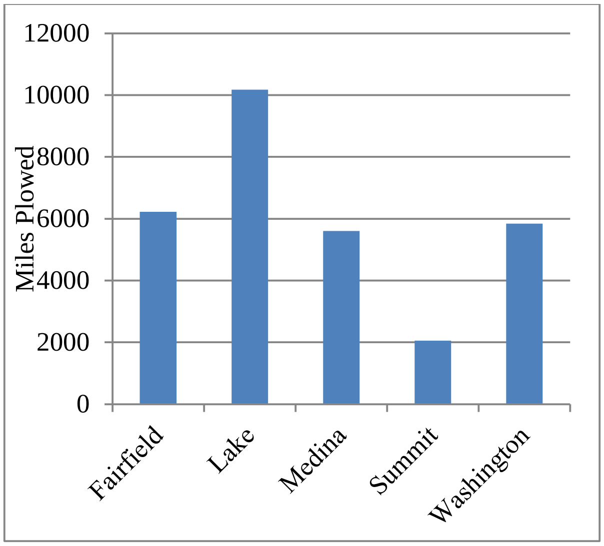
Table 6.1: Summary of Year Two Results.

County	Blade Type	Average Wear Across Blade (in)	Distance Plowed (miles)	Time Plowed (hours)	Blades Used	Average Plowing Speed (mph)	Cost
Fairfield	Carbide - Single	1.88	480	14	1	47	$836
Fairfield	Carbide - Double	1.75	719	24	2	45	$2,832
Fairfield	Double Stack	5.44	2322	124	3	37	$2,235
Fairfield	Standard	3	443	16	1	43	$539
Fairfield	PolarFlex	0.75	1448	44	1	44	$2,507
Lake	Carbide - Single	1.13	437	16	1	26	$836
Lake	Carbide - Double	3.13	2797	118	3	34	$4,248
Lake	Middle Guard	2.38	1102	40	1	37	$648
Lake	Standard	6.88	1254	43	3	43	$1,671
Lake	XL Classic	1.13	1490	53	2	48	$6,042
Medina	Middle Guard	5.63	2013	76	2	31	$1,296
Medina	PolarFlex	0.7	1466	66	1	32	$2,507
Medina	Standard	2.38	576	22	1	33	$539
Medina	XL Classic	0.38	418	14	1	34	$3,021
Summit	Carbide - Double	1.25	217	8	1	30	$1,416
Summit	No Counterbalance	2.25	91	3	1	38	$539
Summit	XL Classic	0.13	790	35	1	29	$3,021
Washington	Double Stack	2.88	956	41	2	27	$1,490
Washington	No Counterbalance	3.5	895	37	1	29	$539
Washington	PolarFlex	0.5	1014	50	1	31	$2,507
Washington	Standard	4.67	1237	46	3	34	$1,671

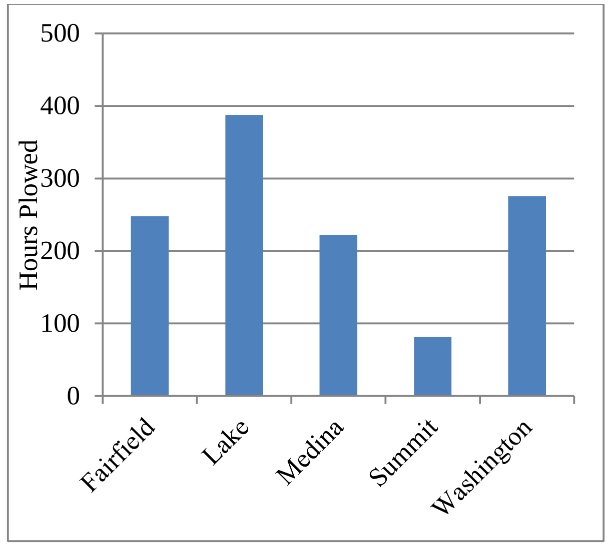
Note: The average wear is determined from adding the wear of each measurement location over the entire season for each blade type, in each county, then averaging the wear across the blade. "No Counterbalance" is a standard blade on a truck with no counterbalance. The cost includes the labor for blade changing.

Table 6.1 presents the average wear, distance plowed, time plowed, number of blades used, and the average plowing speed of each of the blades tested in Year Two. Additional data, such as pavement condition while plowing and the amount of snow cover on the road, are collected by the research team and are presented in Appendix A.

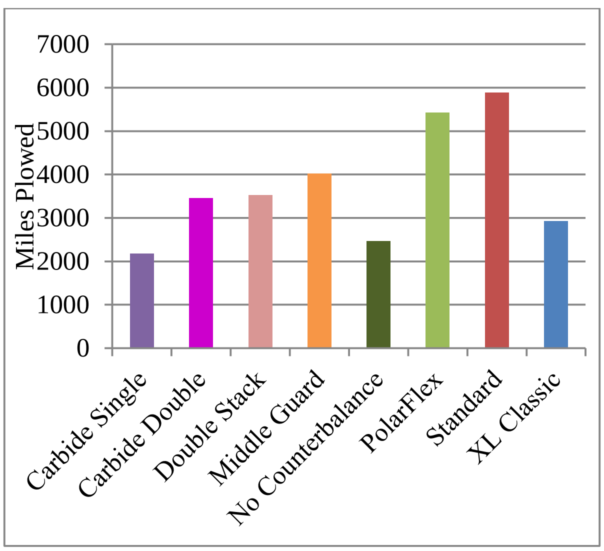
Figure 6.1 presents a graphical summary of the total miles and hours plowed within each county and the time and distance plowed by trucks using each blade type.



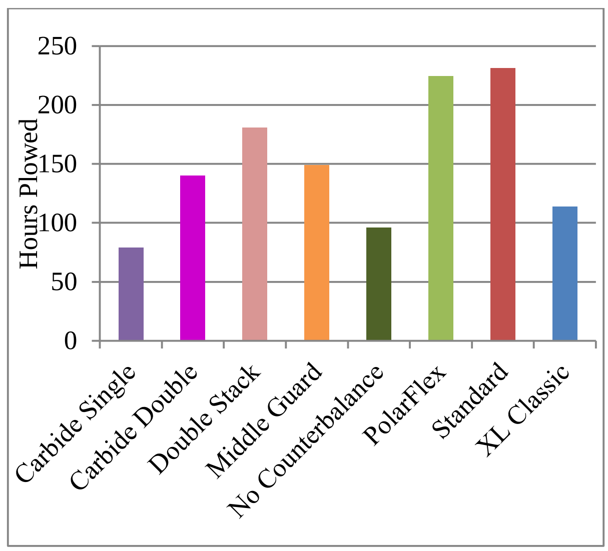
A) Distance Plowed Per County



B) Time Plowed Per County



C) Distance Plowed by Blade Type



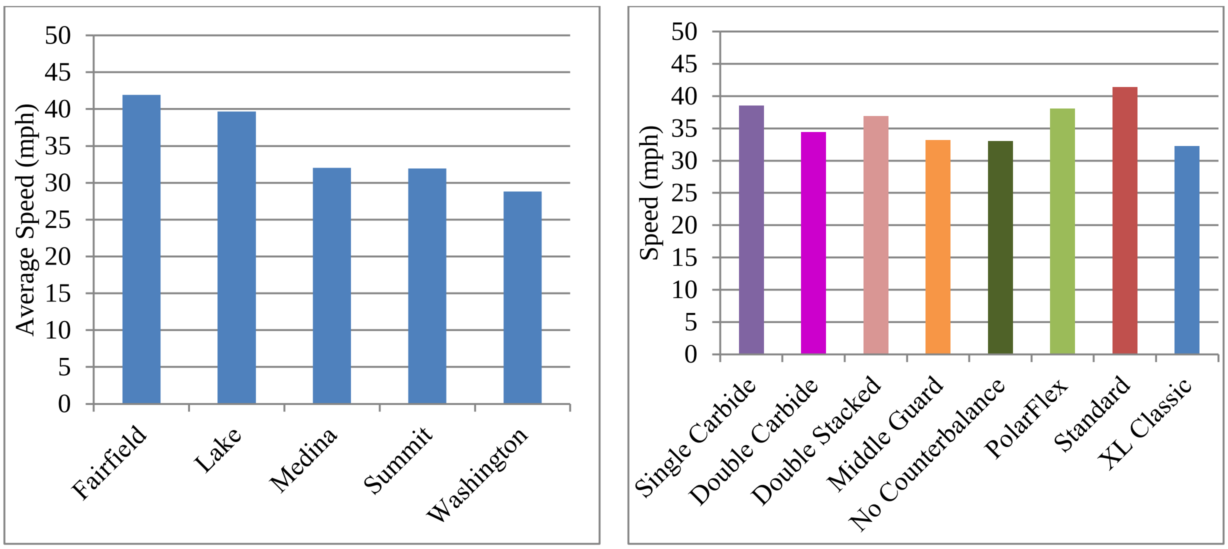
D) Time Plowed by Blade Type

Note: "No Counterbalance" is a standard blade on a truck without a counterbalance.

Figure 6.1: Year Two Overall Summary – A) Distance Plowed Per County, B) Time Plowed Per County, C) Distance Plowed by Blade Type, and D) Time Plowed by Blade Type.

As seen in Figure 6.1(A), Lake County plowed the most miles throughout the season due to the high amount of snowfall received in that area. While Summit County plowed the least amount of miles due to GPS issues on two of the four test trucks and because trucks were down for maintenance, which prohibited the research team from analyzing all the video data over the season. Although a small portion of the data collected is unusable due to the GPS issues, over 92% of the data are used in this analysis. Figure 6.1(B) presents the amount of hours plowing in each county, and these results are similar to the number of miles plowed that are presented in Figure 6.1(A). Figure 6.1(C) presents the miles plowed for each blade type. It is important to note that the Figure 6.1(C, D) are cumulative of all the blades' miles and hours plowing, similar to Figure 5.2 in Section 5.1 of this report.

As mentioned in Chapter 4 and Section 5.1 of this report, the video files created by the DVRs provide the time and GPS location data, which are documented in ArcGIS. Using the distance of each road segment where the plow is used and the time it took the truck to plow each segment, the space mean speed is calculated to determine the plowing speed. Figure 6.2 presents the average plowing speed for each county and blade over the entire 2014–2015 winter season.



A) Average Plowing Speed Per County

B) Average Plowing Speed by Blade Type

Note: "No Counterbalance" is a standard blade on a truck without a counterbalance.

Figure 6.2: Year Two Average Plowing Speed Summary – A) Average Speed Pre County, B) Average Speed by Blade Type.

From Figure 6.2(A), Fairfield and Lake counties plowed at the highest average speeds of 42 mph and 40 mph, respectively. Medina, Summit, and Washington counties plowed at slightly lower average speeds of 32 mph, 32 mph, and 29 mph, respectively. These average speeds at typical for ODOT due to the higher functional roadways they treat. The average speeds per blade range from 32 mph for the XL Classic blades to 41 mph for the standard blades, as presented in Figure 6.2(B). The speeds in year two varied more than the Year One data presented in Figure 5.3.

These data are applied to a block linear regression in order to determine the significance. Table 6.2 presents the results of the linear regression model.

Table 6.2: Linear Regression Results.

Predictors	Coefficients	t-statistics	Significant
Constant	-1.073	-2.24	95%
Speed	-0.016	-1.48	< 90%
Miles	-0.001	-3.35	99%
Blade			
Carbide - Single	-0.63	-1.69	90%
Carbide - Double	0.131	-4.70	99%
No Counterbalance	-0.87	-2.45	95%
Double Stack	-0.679	-2.45	95%
Middle Guard	-1.351	-4.03	99%
PolarFlex	2.078	-5.67	99%
XL Classic	1.851	-6.63	99%

Note: All regressions estimated with ordinary least squares using Minitab. The square root of the mean square error of the model is 0.20, the F-Test for the model is 10.3, the adjusted R^2 value, which is how close the data are to the fitted regression line is 74.3%, and the model consists of 33 data points. "No Counterbalance" is a standard blade on a truck with no counterbalance.

When reviewing the results in Table 6.2, the linear regression model, the blade types and miles plowed are significant within the model, while the speed of the trucks while plowing shows no significance with 90% confidences. Please note that a number of different models are tested; however, the optimal model is the one presented in Table 6.2. The research team tested models with road condition speeds, percentage of time plowing under each road condition, and an interaction term of miles plowed multiplied by the percentage of time plowing under each road condition; however, these models did not show significance on many of the predictors and reduced the adjusted R^2 and F-values along with an increase in the root mean square error (root MSE).   From the regression results, it appears that the miles plowed and the blade type are the most significant factors that influence the blade wear.

Similar to the Year One analysis presented in Table 5.2, once all plowing segments are mapped in ArcGIS, the road surface and bridge joint exposure may be determined. A majority of the routes treated by ODOT are asphalt; however, the exposure to concrete surfaces is calculated to determine the effect of the road surface type on the wear of the blades. Table 6.3 presents the number of bridge joints encountered by each blade type as well as the percentage of roadways having concrete surfaces that are plowed in the participating counties.

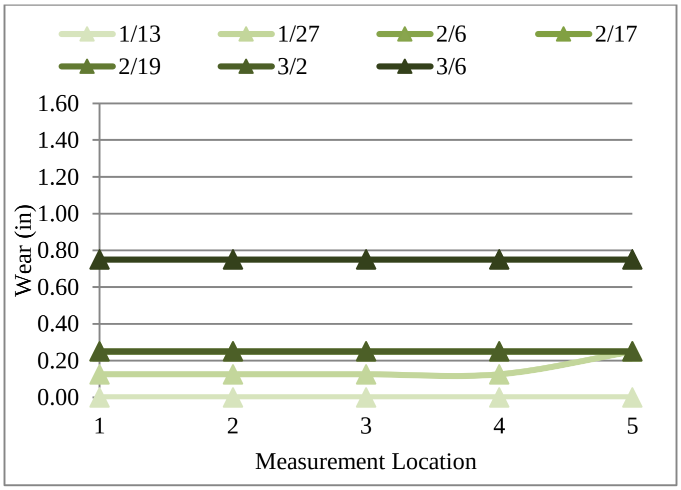
Table 6.3: Number of Bridge Joints and Percent of Concrete Plowed by Each Blade in Each County during Year Two.

County	Blade	Number of Joints	Percent Concrete
Fairfield	Carbide - Single	2386	3.6%
Fairfield	Carbide - Double	4518	3.99%
Fairfield	Double Stack	11076	2.13%
Fairfield	Standard	18	0.03%
Fairfield	PolarFlex	10032	2%
Lake	Carbide - Single	0	0%
Lake	Carbide - Double	664	0.14%
Lake	Middle Guard	1316	0.56%
Lake	Standard	8902	2.34%
Lake	XL Classic	12526	25.67%
Medina	Middle Guard	2860	0.83%
Medina	PolarFlex	808	0.44%
Medina	Standard	1038	0.72%
Medina	XL Classic	760	0.75%
Summit	Carbide - Double	526	1.34%
Summit	No Counterbalance	8334	7.65%
Summit	XL Classic	268	0.18%
Washington	Double Stack	1624	1.4%
Washington	No Counterbalance	0	0%
Washington	PolarFlex	0	0%
Washington	Standard	844	0.46%

Note: The number of joints is calculated by counting the number of concrete segments plowed and multiplying by two. This method assumes that each concrete segment is a bridge deck with two joints at each end. "No Counterbalance" is a standard blade on a truck with no counterbalance.

These data are applied within the linear regression model to determine significance. When adding concrete, joints, and the combination of both, no significant evidence is found that pavement type is associated with increased wear of a blade. This may be due to the low exposure to concrete throughout the winter season, as ODOT routes are primarily asphalt surfaces. The XL Classic is Lake treats the highest percentage of concrete roads, with 25.67% of the time plowing on concrete; however, the second highest percentage for blades treating concrete is Summit County's No Counterbalance blade, which treats concrete roads7.65% of the time it is plowing in Year Two.

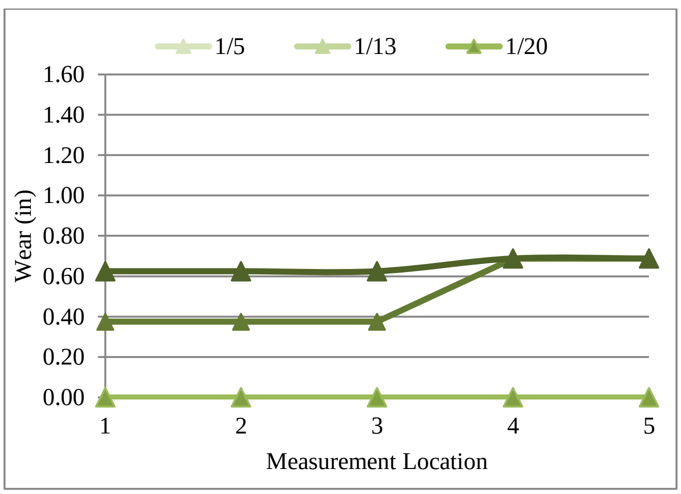
When analyzing the wear at each measurement location, the wear pattern for each blade may be observed. Figures 6.3 and 6.4 present the wear observed over the second winter season for two of the specialty blades, the PolarFlex and the XL Classic. Similar to the Year One wear data presented in Figures 5.5 to 5.8, each line presented in the graph (on the left side of each figure) shows the wear on the date the measurement is taken. The lines will have darker shades of color to indicate the wear measurements that are obtained later in the season. The tables on the right side of each figure present the blade measurements at each date. Figure 6.3 presents the wear pattern of one PolarFlex blade in Fairfield and Medina Counties.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
11/14	6	6	6	6	6
11/19	6	6	6	6	6
1/6	6	6	6	6	6
1/13	6	6	6	6	6
1/27	5.88	5.88	5.88	5.88	5.75
2/6	5.75	5.75	5.75	5.75	5.75
2/17	5.75	5.75	5.75	5.75	5.75
2/19	5.75	5.75	5.75	5.75	5.75
3/2	5.75	5.75	5.75	5.75	5.75
3/6	5.25	5.25	5.25	5.25	5.25

Hydraulic Counterbalance

A) Fairfield PolarFlex – Still On Truck at End of Year Two.



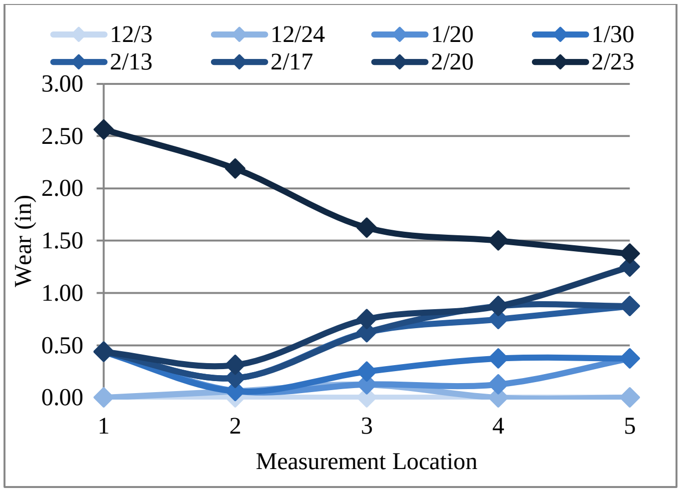
Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
1/5	6	6	6	6	6
1/13	6	6	6	6	6
1/20	6	6	6	6	6
2/13	5.63	5.63	5.63	5.31	5.31
3/17	5.38	5.38	5.38	5.31	5.31

Hydraulic Counterbalance

B) Medina PolarFlex Wear Pattern – Still On Truck at End of Year Two.

Figure 6.3: Examples of PolarFlex Wear Patterns during Year Two – A) Fairfield PolarFlex, B) Medina PolarFlex.

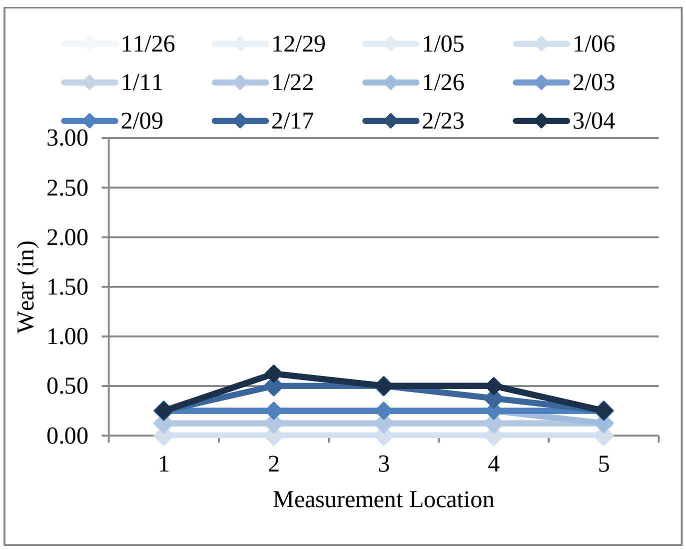
The PolarFlex blade in Fairfield County, presented in Figure 6.3(A), wore evenly throughout the season and remains on the truck at the end of Year Two. When reviewing the wear pattern of the Medina County PolarFlex blade, slightly higher wear is found on the driver-side of the plow, and this blade also remains on the truck at the end of the season. Figure 6.4 presents the wear patterns for the Medina and Summit County XL Classic blades.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
12/3	7.06	7.06	7.25	7.38	7.25
12/24	7.06	7.00	7.13	7.38	7.25
1/20	6.63	7.00	7.13	7.25	6.88
1/30	6.63	7.00	7.00	7.00	6.88
2/13	6.63	6.88	6.63	6.63	6.38
2/17	6.63	6.88	6.63	6.50	6.38
2/20	6.63	6.75	6.50	6.50	6.00
2/23	4.50	4.88	5.63	5.88	5.88

Spring Counterbalance

A) Medina XL Classic Wear Pattern – Loss of Driver-side Guard on February 2, 2015.



Date	Measurement Location				
	1 (in)	2 (in)	3 (in)	4 (in)	5 (in)
11/26	7.5	7.5	7.5	7.5	7.5
12/29	7.5	7.5	7.5	7.5	7.5
1/5	7.5	7.5	7.5	7.5	7.5
1/6	7.5	7.5	7.5	7.5	7.5
1/11	7.375	7.375	7.375	7.375	7.375
1/22	7.375	7.375	7.375	7.375	7.375
1/26	7.25	7.25	7.25	7.25	7.375
2/3	7.25	7.25	7.25	7.25	7.25
2/9	7.25	7.25	7.25	7.25	7.25
2/17	7.25	7	7	7.125	7.25
2/23	7.25	6.875	7	7	7.25
3/4	7.25	6.875	7	7	7.25

Spring Counterbalance

B) Summit XL Classic Wear Pattern – Still on Truck at End of Year Two.
Note: The vertical scale of the graphs in this figure is greater than Figure 6.3 in order to accommodate the results for the Medina blade, which wore through and fell apart on February 23, 2015, as presented in Figure 6.4(A).

Figure 6.4: Examples of XL Classic Wear Patterns during Year Two – A) Medina XL Classic, B) Summit XL Classic.

As presented in Figure 6.4(A), the Medina County XL Classic has more wear on the driver-side of the plow, which may be a result of the loss of the driver-side guard. This increase in wear continues until the last measurement date, when the blade wore through completely and the passenger side of the blade appears to have a high wear, which is a result of the blade failing and falling apart before it is able to be changed. The XL Classic in Summit County is still on the truck and appears to have higher wear in the center of the blade than at the sides due to the use of plow guards on either end of the plow.

Using the data collected, the total miles each blade is used for plowing and the average wear across the blade are used to determine the wear rate (wear per mile) for each blade type. Using the wear rate, the number of standard blades needed to match the lifespan of each specialty blade may be determined, which is presented as the equivalent to standard ratio. Table 6.4 presents the Year Two results for equivalent standard blade ratios for each blade tested.

Table 6.4: Year Two Resulting Equivalence Ratios for Each Blade Type.

Blade Type	**Average Total Wear (in)**	**Total Miles**	**Wear/Mile (in/mile)**	**Equivalent Standard Blade Ratio**
Carbide - Single	3.00	917	3.27E-03	1.5
Carbide - Double	6.13	3733	1.64E-03	2.9
Double Stack	8.31	3278	2.54E-03	1.9
Middle Guard	8.00	3115	2.57E-03	1.9
No Counterbalance	5.75	986	5.83E-03	0.8
PolarFlex	1.94	3929	4.93E-04	9.4
Standard	16.94	3510	4.82E-03	1
XL Classic	1.63	2698	6.02E-04	7.7

Note: The average wear is determined from adding the wear of each measurement location over the entire season for each blade type, in each county, then averaging the wear across the blade. “No Counterbalance” is a standard blade on a truck with no counterbalance.

The equivalent standard blade ratio represents the number of standard blades needed to match the life span of the other blade types tested. As presented in Table 6.4, a single stacked carbide blade is equivalent to 1.5 standard blades, and the carbide double stacked blade is equivalent to 2.9 standard blades. The double stacked flame hardened blades and the standard blade with an additional middle guard is equivalent to 1.9 standard blades. When a truck does not utilize a counterbalance, the standard blade life is reduced to 80% of that of a standard blade with a counterbalance. The PolarFlex equivalent ratio is 9.4 standard blades. The XL Classic is observed to be equivalent to 7.7 standard blades.

6.2 Cost Analysis

This section presents the comparison between the costs of each specialty blade tested and the cost of the equivalent number of standard blades. The data utilized in this analysis are collected in the field during the second year of this two-year evaluation. This chapter is divided into two subsections as follows:

- Subsection One – The variables and equations used in the Monte Carlo simulation, and
- Subsection Two – Cost of each blade when compared to the cost of the equivalent standard blade.

Note that the introduction to the Monte Carlo simulation is presented in Section 5.2.1 of this report. The analysis summarized in these subsections will be used to determine the costs associated with each of the blades evaluated throughout this study.

6.2.1 Variables and Equations

This section presents all the variables and equations used to determine the costs for each of the blades. Figure 5.9 in Section 5.2.2 of this report presents the variables used in the cost analysis. There are two categories when determining the cost of the blades: the capital cost of each blade and the installation cost each of the blades. Equations 5.1 through 5.4 presented in Section 5.2.2 of this report are utilized for the data collected in Year Two of this two-year evaluation, as the methodology used to determine costs in Year Two is similar to that used to analyze the Year One data.

Most of the variables in the equations used for calculating costs are assigned an average and standard deviation, which the Monte Carlo simulation uses to define a range within the appropriate distribution when selecting a random variable. The cost of the PolarFlex and XL Classic is a fixed value, since the cost for this equipment did not change during the study period; therefore, no standard deviation is able to be calculated for the cost variables. Table 6.5 provides the average and standard deviation value (if available) for each variable, along with the source used to derive that particular variable.

Table 6.5: Average and Standard Deviation of Variables Used in Blade Costs.

	Variables	Average	Standard Deviation	Source
Capital Cost	Standard Blade Capital Cost ($)	498.3	97.8	ODOT
	Double-Stacked Blade Capital Cost ($)	704.2	149.7	ODOT
	Carbide-Tipped Blade Capital Cost ($)	796.4	90.8	ODOT
	Double-Stacked Carbide-Tipped Blade Capital Cost ($)	1375.2	156.5	ODOT
	Standard Blade with Middle Guard Capital Cost ($)	607.0	110.5	ODOT
	PolarFlex Blade Capital Cost ($)	2466.0	--	Field Evaluation
	Winter XL Classic Blade Capital Cost ($)	2980.0	--	Field Evaluation
Labor Cost	Hourly Labor Rate ($/hour)	18	3	ODOT
	Number of People to Change One Blade (unitless)	3	0.5	ODOT
	Time to Change One Blade (hour)	0.75	0.25	ODOT
Standard Blade Cost Factor Multiplier	Carbide-Tipped Blade Equivalence	1.5	0.5	Field Evaluation
	Carbide-Tipped Double Stacked Blade Equivalence	2.9	0.5	Field Evaluation
	Double Stacked Standard Blade Equivalence	1.9	0.5	Field Evaluation
	Middle Guard Standard Blade Equivalence	1.9	0.5	Field Evaluation
	No Counterbalance Standard Blade Equivalence	0.8	0.5	Field Evaluation
	PolarFlex Blade Equivalence	9.4	0.5	Field Evaluation
	Winter XL Classic Blade Equivalence	7.7	0.5	Field Evaluation

Note: All data are provided by or approved by ODOT to reflect their current practices. Blade equivalencies are calculated from field data. The cost of standard and carbide blades (including double-stacked blades and additional middle guards) are calculated using pricing from 2012 to 2014. When the source indicates "ODOT", the data are provided by ODOT; for a source indicated by "Field Evaluation", the data are obtained from the two years of field evaluations of the blades conducted for ODOT by the research team. "No Counterbalance" is a standard blade on a truck with no counterbalance. "Standard Blade Cost Factor Multiplier" refers to the number multiplied by the standard blade cost in order to compare to the cost for the number of standard blades needed to match the lifespan of one specialty blade.

The cost of the standard blades and the different standard blade configurations, such as the additional middle guards or the double-stacked blades, are determined using the equipment pricing from the 2012–2013 and 2013–2014 winter seasons. As previously mentioned, there are multiple ways to create each blade, i.e., using a full 12-foot blade or using two 6-foot sections to equip a 12-foot plow blade; therefore, multiple variations of the blades are priced and then averaged over the two years of data provided by ODOT. The blade equivalences refer to the number of standard blades needed to match the lifespan of the various test blades; these equivalences are calculated from field data, as presented in Table 6.4 of this report.

6.2.1 *Cost for Each Blade and Equivalent Blades*

Monte Carlo simulations are run for the cost of each blade and the equivalent standard blade cost for each blade type in order to determine the savings associated with each blade, if any. The simulation is repeated 500,000 times to determine an average cost when randomly selecting values within the average and standard deviation of each variable. Figure 5.10 in Section 5.2.1 of this report presents an example of the histogram for the standard blade cost. The final cost for each blade may be represented as a histogram, similar to the one presented in Section 5.2.1 on Figure 5.10. Table 6.6 presents the average cost for each specialty blade as compared to the cost of the equivalent number of standard blades utilizing the data collected in Year Two of this evaluation.

Table 6.6: Average Cost for Standard Blade Equivalent and Specialty Blades in Year Two.

Specialty Blade	**Specialty Quantity**	**Specialty Cost**	**Standard Quantity**	**Standard Cost**	**Savings per Blade**
Carbide Single	1	$836	1.5	$807	($29)
Carbide Double	1	$1,416	2.9	$1,561	$145
Double Stack	1	$745	1.9	$1,023	$278
Middle Guard	1	$648	1.9	$1,023	$375
No Counterbalance	1	$539	0.8	$432	($107)
PolarFlex	1	$2,507	9.4	$5,061	$2,554
Standard	1	$539	1	$539	$0
XL Classic	1	$3,021	7.7	$4,145	$1,125

Note: The savings represents the cost savings associated with one specialty blade. Maintenance costs for blade changes are included in these costs. “No Counterbalance” is a standard blade on a truck with no counterbalance. In the “Savings per Blade” column, it is more economical to use a standard blade if the cost presented in red, and it is more economical to use a specialty blade if the cost is green. i.e. the No Counterbalance blades cost the more than a standard blades by $107 per blade, and the PolarFlex cost less than the standard blades by $2,554 per PolarFlex implemented.

As seen in Table 6.6, the use of a single carbide blade with a standard blade equivalence of 1.5 results in no savings; however, when double stacking the carbide blades there is a $145 cost savings for every blade implemented in place of the standard blade. The XL Classic blade with a standard blade equivalence of 7.7 has a savings of $1,125 per XL Classic blade implemented in place of a standard blade. The PolarFlex are observed to have a cost savings of $2,554 per blade when compared to the standard blade. When reviewing the different standard blade configuration tested during Year Two, the double stacked standard blade and the standard blade with a middle guard have a savings of $278 and $375 per blade, respectively, when implementing instead of a standard blade. The standard blade on a truck with no counterbalance costs ODOT $107 per blade implemented in place of a standard blade on a truck with a properly calibrated counterbalance. During Year Two, it is observed that one carbide blade became damaged randomly throughout the season. This is important to note, since a new standard blade costs less to replace than a new specialty blade. When deciding whether or not to invest in specialty blades, it is important to consider the operators of the trucks and the routes that the blades are being implemented on, since new hires may not be familiar with the location of all the bridge expansion joints or other characteristics on each route that may result in damage to a blade if the driver is not careful. If implementing a blade with a longer lifespan, there may be a decrease in downtime needed to change blades during an event and a reduced risk of injuries that result from changing the blades.

6.3 Conclusion

The second year data suggest that the single carbide blade and the standard blade on a truck with no counterbalance are the blades that have no cost savings associated with them. The PolarFlex has a $2,554 cost savings when compared to a standard blade, while the XL Classic has a $1,000 cost savings when compared to a standard blade. The blade equivalence ratio for the PolarFlex may have doubled from Year One to Year Two; however, it is important to note that the Fairfield County garage tested both the XL Classic and PolarFlex during this study, and the XL Classic has lasted through both winter seasons and is still on the truck and ready to be used for a third season.

The single stacked carbide, standard, PolarFlex, and XL Classic blades are tested in both seasons and therefore yielded data over two years, which may be used to determine an equivalent standard blade ratio. When utilizing the data from both years, the average resulting equivalent ratios for each blade type are found; these ratios are presented in Table 6.7.

Table 6.7: Average Resulting Equivalence Ratios for Each Blade Type.

Blade	Total Average Wear (in)	Total Miles	Wear/Mile (in/mile)	Equivalent Standard Blade Ratio
Carbide Single	4.98	2626	1.89E-03	1.5
PolarFlex	4.38	9476	4.62E-04	6.1
Standard	31.54	11177	2.82E-03	1.0
XL Classic	2.58	5884	4.38E-04	6.4

Note: The average wear is determined from adding the wear of each measurement location over the entire season for each blade type, in each county, then averaging the wear across the blade.

When utilizing the data in both years for the four blades presented in Table 6.7, the single stacked carbide has a standard blade equivalence of 1.5, similar to Year Two. The PolarFlex has a 6.1 standard blade equivalence while the XL Classic has a 6.4 standard blade equivalence. Using the average ratios of equivalence, the cost per blade can be determined. Table 6.8 presents the cost per blade when compared to a standard blade.

Table 6.8: Average Cost for Standard Blade Equivalent and Specialty Blades with Year One and Two Data.

Specialty Blade	Specialty Quantity	Specialty Cost	Standard Quantity	Standard Cost	Savings per Blade
Carbide Single	1	$836	1.5	$807	($29)
PolarFlex	1	$2,507	6.1	$3,285	$778
Standard	1	$539	1	$539	$0
XL Classic	1	$3,021	6.4	$3,447	$426

Note: The savings represents the cost savings associated with one specialty blade. Maintenance costs for blade changes are included in these costs. In the “Savings per Blade” column, it is more economical to use a standard blade if the cost presented in red, and it is more economical to use a specialty blade if the cost is green. i.e. the Carbide Single blades cost the more than a standard blades by $29 per carbide single stacked implemented and the PolarFlex cost less than the standard blades by $778 per PolarFlex implemented.

Similar to the results obtained for Year Two, the single stacked carbide cost an additional $29 when implemented in place of a standard blade. The PolarFlex and XL Classic have a cost savings of $778 and $302, respectively, when implemented in place of a standard blade. The XL Classic is observed to have a cost savings in the first year, second year, and the average of the two years. The PolarFlex is observed to have a cost savings in the second year and the average of the two years; however, it did not have a cost savings in the first year. The differences in cost for the PolarFlex between the two years may be due to a number of factors, such as operators becoming familiar with the specialty blades and the research project, or the routes the trucks are assigned from one year to the next. The research team placed the blades in various garages and with multiple operators to account of the operator and route variability. This finding demonstrates the importance of operator training and frequent communication with operators during the winter season.

CHAPTER VII BLADE CHANGING

This chapter presents information regarding the blade changing procedure for the standard ODOT steel blades and carbide-tipped blades. The other specialty blades should be installed based on instructions provided by the manufacturer. Each county employs slightly different methods and techniques for changing blades based on the equipment available. Accordingly, this section is divided into two sections to determine the ideal blade changing procedure:

- Section One – Blade changing information, and
- Section Two – Recommended procedure to change blades.

The goal of this chapter is to present a best practice procedure for ODOT blade changing in order to ensure the safety of the operators and mechanics.

7.1 Blade Changing Information

As discussed in Chapter 2 of this report, an in-state survey was conducted at the beginning of the evaluation to determine the current practices used by ODOT for changing the plow blades. In addition to the types of blades being utilized, the survey addressed blade changing practices as well. A summary of the entire survey is presented in Table 2.7 of this report. Question #34 of the survey asked about safety concerns that arise when the blades are being changed. Figure 7.1 presents the number of counties that mentioned each of the safety concerns.

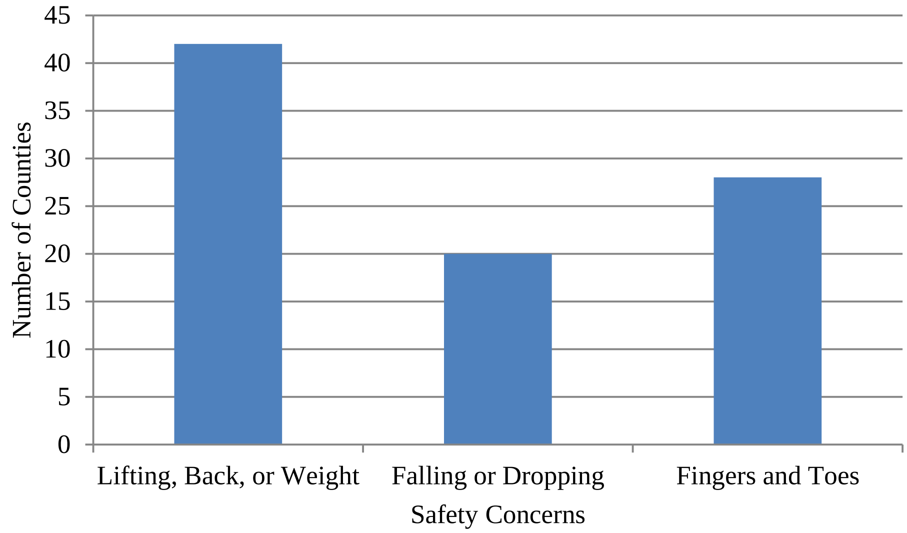


Figure 7.1: Safety Concerns when Changing Blades.

As seen in Figure 7.1, there are three main categories of safety concerns when changing blades: lifting the heavy blades (which may cause back injuries), the falling or dropping of the heavy blades, and pinch points (places where fingers and toes may become caught or pinched when working with the blades). A total of 75 of the 81 counties surveyed mentioned one or more of these categories as safety concerns. The weight of the blades and the need to lift the blades into place are the primary concerns the counties expressed during the survey.

Several standard tools are currently used by ODOT during blade changing. These include:

- Mounting pins – used to hold and align the blade on the plow before inserting the bolts,
- Impact wrench – used to mechanically tighten bolts, and
- Grinder – used to clean the trip edge of debris before installing the new blade.

Figure 7.2 presents a summary of the equipment commonly used by ODOT garages in various counties to assist with lifting the blades.

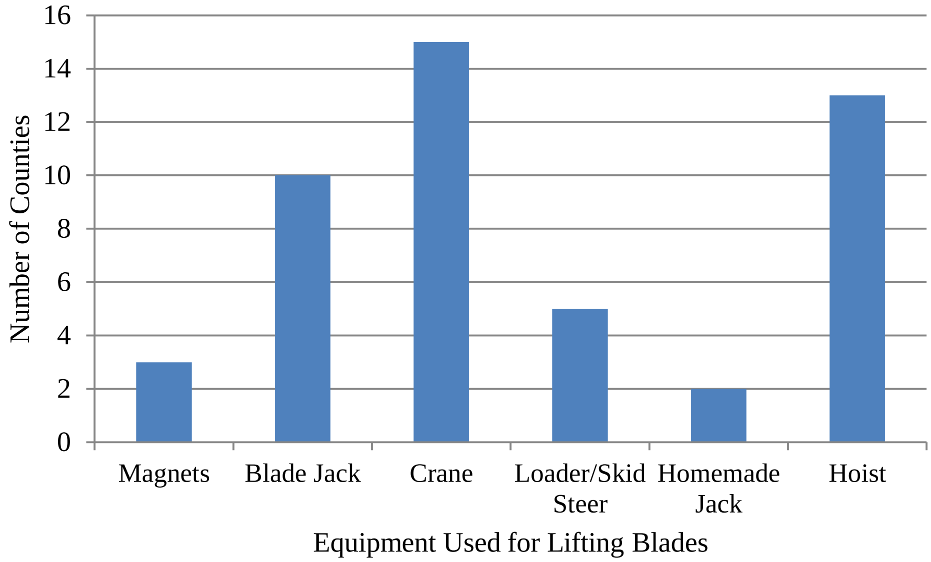


Figure 7.2: Survey Results of Equipment Used to Lift Blades during Installation.

The survey revealed that 48 counties utilize various types of equipment for lifting the blades during installation. Fifteen counties use cranes to assist in lifting blades, while two counties have created their own jack or rack for lifting blades using materials available at the garage. Figure 7.3 shows the rack created at Fairfield County to assist with lifting the blades.

Figure 7.3: Homemade Blade Lift in Fairfield County.

Similar to Fairfield County, which used a front loader and created a custom rack for lifting blades into position, most counties will repurpose some type of equipment readily available in the garage rather than purchase a new piece of equipment that is designed specifically for aiding with blade changing. Five counties mentioned that they have obtained OTC Blade Buddy Plow Jacks, a commercially available product that is designed to assist with lifting blades and is presented in Figure 7.4.

Figure 7.4: Sample of Blade Buddy Jacks. (Image from summitracing.com)

The Blade Buddy Jack may help lift the blade into position for installation. One of the five counties surveyed did not prefer to use this piece of equipment.

In addition to employing available equipment, most counties have also developed a process to reduce the possibility of injury from lifting the blades. A mechanic is not needed to assist in a blade change when the bolts holding the worn blade are able to be removed without using an acetylene cutting torch. However, it is not uncommon for bolts to be frozen in place; in these cases, the bolt needs to be cut off, and this may require the assistance of a mechanic. Due to the equipment needed and the possibility that a mechanic may be required, all counties are equipped to preform blade changing at the main county garage. However, some counties are also able to perform blade changing at outposts due to available equipment and operator training. Figure 7.5 presents the percentage of counties in which blade changing occurs at the outpost in addition to the main garage.

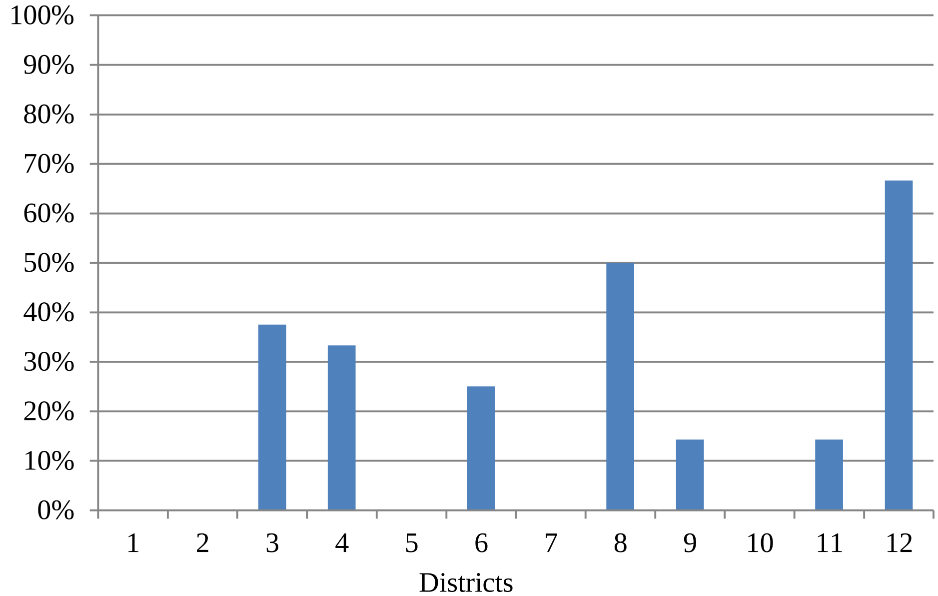


Figure 7.5: Percentage of Counties in Each District which Change Blades at the Outposts.

When blade changing only occurs at the main garage, additional costs are associated with mileage and increased downtime due to the trucks from the outpost having to travel some distance to reach the main garage. By requiring operators to travel to the main garage for a blade change, a route may remain untreated for a longer period of time during a winter weather event. In order to allow blade replacement to occur at an outpost, the proper equipment must be provided along with proper training for operators to ensure that they may safely replace the blades. If a manager feels that the blades may safely be changed at an outpost, a time and fuel savings may be realized along with less time off route.

One way in which Ashtabula County responded to the issue of needing a mechanic and having to replace blades at the main garage only was to modify the blade changing procedure to improve safety, downtime, and cost. Ashtabula County switched the direction in which the bolts are installed on the blade. The standard blade is design to have the bolt heads facing the front of the blade. The standard bolt direction requires the bolts to be tightened by an employee lying on a creeper underneath the supported plow. Ashtabula County started switching the direction of the bolts, so that the bolt heads are facing the back of the blade. This allow less time for the operator or mechanic to be positioned under the plow, since the bolts may be tightened while facing the plow and not underneath it. Other counties have also implemented the new bolt direction; Figure 7.6 presents the directions used for the bolt heads on the blades in each district.

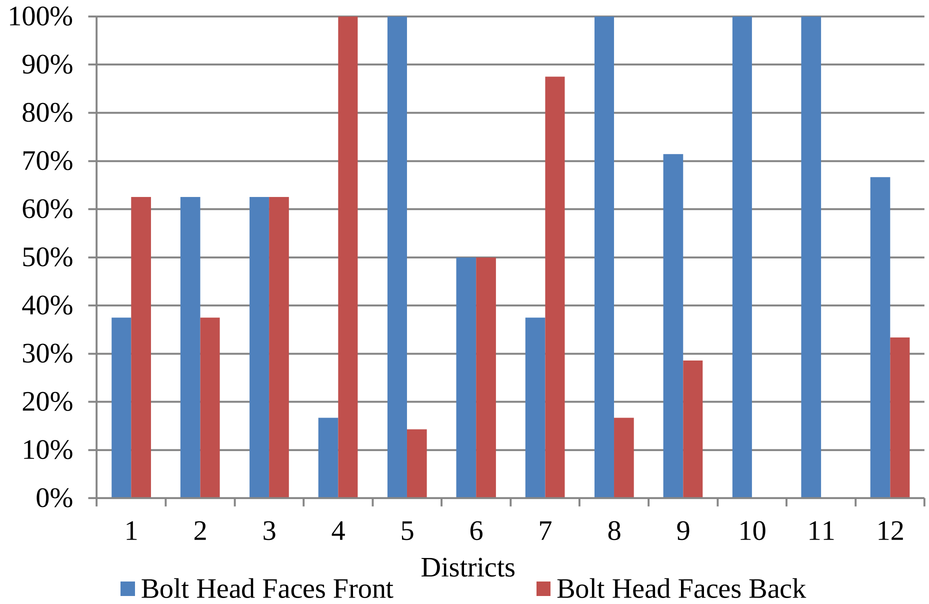


Figure 7.6: Direction of Bolts on Blades for each District.

Figure 7.6 presents the bolt head directions when installing a new blade. When the bolt head faces front, this would indicate that the bolts are in the standard direction and must be tightened by an employee on a creeper underneath the supported plow. When the bolt head faces back, the bolt is able to be tightened from the front of the plow.

7.2 Recommended Procedure for Changing Blades

Using the information collected through the survey and through further discussions with personnel in Ashtabula County, the following blade changing procedure was developed. Please note that safety equipment such as gloves and eye protection should be used at all times when blades are changed:

Step 1) Support the plow. The plow may be supported through the use of jack stands, use of an overhead crane, or by lifting the truck. It is important to avoid relying on the hydraulic system to hold the blade up while working on the plow. Figure 7.7 shows a method for supporting the plow with jack stands.

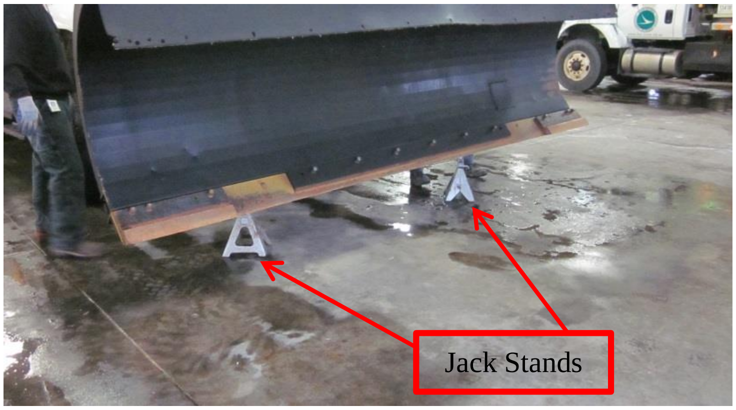


Figure 7.7: Jack Stands Used to Support Plow While Changing the Blade.

Step 2) Remove and discard the worn or broken blade. Mounting pins may be used while removing bolts to prevent the old blade from falling. Figure 7.8 presents the use of a mounting pin during blade removal.

Figure 7.8: Removing the Worn Blade from a Plow.

Step 3) Clean the trip edge so that it is free of any debris. Be sure to wear proper safety gear while using a grinder to remove the loose debris. Figure 7.9 shows the use of a grinder for removing debris from the trip edge.

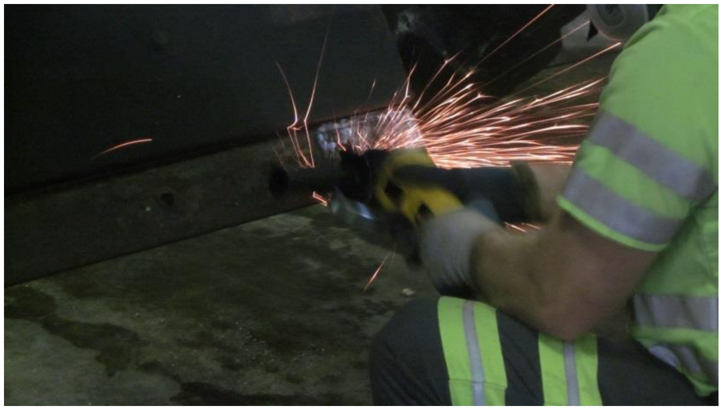


Figure 7.9: Removing Loose Debris from the Trip Edge Prior to Installing New Blade.

Step 4) Insert the mounting pins through the back side of the trip edge.

Step 5) Install new blades on the aligned mounting pins so that the countersink faces the trip edge. Figure 7.10 presents the installation of the new blade with the assistance of the mounting pins.

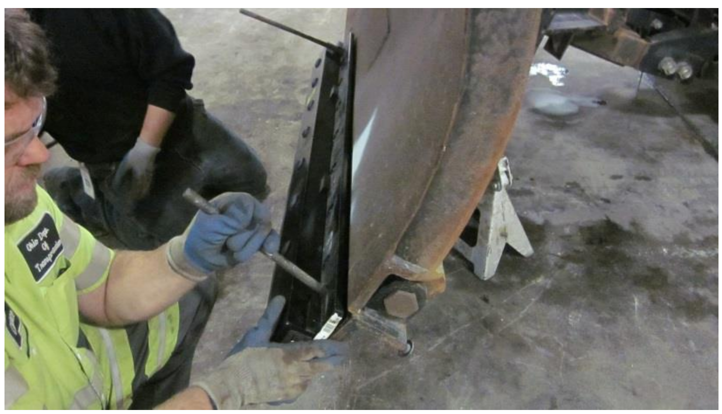


Figure 7.10: Installing a New Blade on Aligned Mounting Pins.

Step 6) Install new plow guards on each side of the blade.

Step 7) Insert 5/8” grade 8 hex head bolts from the back side of the trip edge through the blade.

Step 8) Install 5/8” nuts on plow bolts. Figure 7.11 present the head bolts facing the back side of the trip edge.

Figure 7.11: Head of Bolts Facing the Back Side of the Trip Edge.

Step 9) Torque all bolts to a minimum of 250 ft-lbs or use an impact wrench.

Step 10) Double-nut the plow guards if necessary.

Step 11) Check the counterbalance and adjust if necessary. A manual counterbalance is shown in Figure 7.12.

Figure 7.12: Adjusting the Spring Counterbalance after New Blade is Installed.

Using the recommended method of blade changing may result in faster blade changes utilizing fewer people by allowing access to remove or tighten bolts without requiring an operator or mechanic to work underneath the plow. The hex head bolts used in this procedure reduce the need for a cutting torch, since a wrench may be used on both sides of the plow to help remove difficult bolts. If a cutting torch is needed, the nut may be removed from the front face of the worn blade instead of requiring a worker to be positioned underneath the blade to remove the nut, which may require the assistance of a mechanic due to the difficult placement. Once operators are properly trained with the new technique and are trained on the use of a cutting torch, the recommended method may be employed at an outpost. Having the ability to change blades at the outpost may help reduce the costs associated with mileage and downtime of the trucks.

Due to the variation of equipment and blade configuration (i.e., using full length blades, double stacking blades, having the ability to lift truck, etc.) the blade changing method may need to be adjusted to work with each individual garage. It is important to change blades safely and efficiently, Table 7.1 presents recommendations to address ODOT's top three safety concerns as seen in Figure 7.1.

Table 7.1: Steps to address ODOT's top three safety concerns.

Safety Concern	Definition	Recommendation to Prevent Injury
Lifting, Back, and Weight	This safety concern refers to the lifting the heavy blades, which may cause back injuries or other issues. It is very important to minimize the weight, distance, and height when installing the blades.	• Use 5-6 foot blade sections, • Increase the number of operators helping, and • Use equipment to help assist with lifting the blades.
Falling or Dropping	This safety concern refers to dropping the blade while lifting or having the blade fall before it is secure.	• Be sure that the plow is secure before lifting blades, • Properly use mounting pins, and • Ensure proper communication between operators changing blades. • Use equipment to help assist with lifting the blades.
Fingers and Toes	This safety concern refers to the pinch points when installing new blades.	• Wear proper safety equipment such as gloves and boots, • Properly use mounting pins, and • Ensure proper communication between operators changing blades. • Use equipment to help assist with lifting the blades.

As seen in Table 7.1, all three top safety concerns are related to one another due to the heavy weight of the blades, whether it is lifting the blade, having the blade drop, or having fingers or toes become smashed; therefore, the recommendation for one concern will also help to address safety in the other concerns. It is important to discuss any safety concerns with managers, operators, and mechanics when reviewing the blade changing methodology utilized currently at the garage.

The recommended procedure may be used for steel and carbide-tipped blades. While specialty blades have a similar installation procedure, it is recommended that operators and mechanics follow the instructions provided by the blade manufacturer. Since many of the specialty blades have an extended lifespan, it is expected that blade changing would not occur as frequently with these blades. Less frequent blade changing is expected to reduce the costs associated with trucks traveling from the outposts to main garage to change blades as well as to reduce the downtime required for changing blades during a winter event.

CHAPTER VIII IMPLEMENTATION

This chapter presents the implementation of the specialty blades tested during this evaluation. This implementation plan is developed to aid with successfully implementing the results detailed in this report. Accordingly, this chapter is divided into eight sections:

- Section One – Recommendations for implementation of the specialty blades,
- 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.

8.1 Recommendations for the Implementation of the Specialty Blades

Implementation of specialty blades in ODOT's fleet is a decision that the managers of each garage must make. There are cost savings and risks to implementing each of the specialty blades. Cost savings are observed for two specialty blades, the carbide and XL Classic blade in the first year, while cost savings are observed for the double stacked carbide tipped, double stacked standard, standard with additional middle guard, PolarFlex, and the XL Classic blades during the second year of the study. The single carbide tipped and the standard blade on a truck with no counterbalance was found to have an additional cost when implemented in place of a standard blade in the second year of the evaluation. The single stacked carbide, PolarFlex, and XL Classic are tested in both seasons of the evaluation; when reviewing the data for both years, a cost savings is associated with implementing the PolarFlex and XL Classic. The XL Classic is observed to have a cost savings when reviewing the first year's data, the second year's data, and the combination of the two. The PolarFlex, however, does not appear to have a cost savings based on the first year's data, but it does in the second year and in the combination of the two years' data. Table 8.1 presents the ranking for each blade during each year of the evaluation and when data from both years are combined. Note that a ranking of one means the blade has the best cost savings.

Table 8.1: Ranking of Blade for Year One, Year Two, and a Combination of Data from Both Years.

Year One Data			**Year Two Data**			**Year One and Two Data**		
Blade	**Rank**	**Cost Savings when compared to Equivalent Standard Blades**	**Blade**	**Rank**	**Cost Savings when compared to Equivalent Standard Blades**	**Blade**	**Rank**	**Cost Savings when compared to Equivalent Standard Blades**
XL Classic	1	$534	PolarFlex	1	$2,554	PolarFlex	1	$778
Carbide Single	2	$80	XL Classic	2	$1,125	XL Classic	2	$426
Standard	3	$0	Middle Guard	3	$375	Standard	3	$0
PolarFlex	4	-$83	Double Stack	4	$278	Carbide Single	4	-$29
JOMA	5	-$707	Carbide Double	5	$145			
			Standard	6	$0			
			Carbide Single	7	-$29			
			No Counterbalance	8	-$107			

Note: A number 1 rank means the most cost savings per blade implemented in place of a standard blade. If a blade is below the standard blade rank, there is a cost associated with implementing that blade instead of a standard blade and will be denote with a negative sign on the cost.

More details regarding the costs associated with each blade tested are presented in Section 5.2 and Section 6.2 of this report. Table 5.3 in Chapter 5 of this report provides details regarding the damage to the test blades that is observed over the first winter season of this project and the breaking of one carbide blade during the second year of data collection. If a blade is damaged and is no longer useable, a specialty blade would cost more money to replace than a standard blade. Reviewing the routes and considering the operator's experience may help to reduce the likelihood of a blade breaking; however, there is no way to completely eliminate the risk of breaking a blade, regardless of the blade type.

8.2 Steps Needed to Implement Findings

The only steps needed to implement the findings of the evaluation are to purchase and install the specialty blades. Currently, ODOT Districts must request the blades in the desired type and quantity from ODOT's current inventory list. Accordingly, the steps for implementing the specialty blades would be similar to those for implementing standard blades.

If a garage or district would like to implement a specialty blade to part of their fleet – but not for all blades in its entire fleet – then it will be necessary to determine which routes are optimal for implementing the specialty blades and which routes are best to treat using the standard blades. The optimal routes may be chosen based on previous experience in using standard blades on these routes.

If a high number of standard blades break on a particular route, it may not be advisable to implement a more expensive specialty blade on that route, in case the blade is damaged before it wears through. It is important to calibrate and utilize counterbalances, especially on routes where the standard blades wear through at high rates. However, if there are no issues with the counterbalance, then a specialty blade may be best at this location to reduce the amount of downtime for blade changes and to reduce the risk of injury to workers while changing the blades.

8.3 Suggested Time Frame for Implementation

The implementation of the blades may begin immediately. The only time constraint with the implementation of blades is the time associated with ordering the blades. The time required to fill the order will depend on the distributor of the specialty blades, along with the time of year in which the order is submitted. During the first year of the evaluation, the average wait time for orders placed at the end of November was three to four weeks for the limited number of blades required in this project. There was an issue in obtaining the XL Classic blade in Fairfield County, and filling this order required an additional week. However, it should be noted that the blades were ordered late in the season and that the research team was ordering only a small number of blades. During the second winter season of the evaluation, the blades were ordered in September and were all delivered by the beginning of December. ODOT typically places orders in the month of May for blades it will use for the upcoming winter season, and this should prevent any difficulties in obtaining the blades prior to the winter season.

8.4 Benefits Expected from Implementation

Multiple benefits may be expected from implementing the specialty blades. Since the specialty blades all have a longer life expectancy than the standard blade, one important benefit of implementing specialty blades in place of standard blades is a reduction in the number of blade changes required over the course of a season. Chapter 5 and Chapter 6 of this report present the extended lifespan of each specialty blade, denoted as the number of standard blades that are equivalent to one specialty blade. When a blade wears through and is replaced, it takes time for multiple operators to change it; this will result in downtime, as a plow truck undergoing a blade change cannot be deployed to treat the roads. Table 8.2 presents the an estimate of cost in total and only labor when implementing the various blades tested in Year Two of this evaluation.

Table 8.2: Estimated Yearly Cost based on Blade Type and Number of Blades Required per Season.

Blade	Yearly Estimated Needed Blades	Yearly Estimated Cost with Labor	Yearly Estimated Labor Cost Only
PolarFlex	543	$ 1,361,500	$ 21,974
XL Classic	664	$ 2,006,000	$ 26,861
Carbide - Double	1813	$ 2,567,400	$ 73,386
Double Stacked	2942	$ 2,209,900	$ 118,370
Middle Guard	2917	$ 1,911,700	$ 118,770
Carbide - Single	4057	$ 3,449,200	$ 156,610
Standard blades	5093	$ 2,743,000	$ 205,930
No Counterbalance	7860	$ 4,296,200	$ 331,540

Note: Number of Standard blades is determined using purchasing data for 2013-2015 provided by ODOT. Year Two data is used for this table. "No Counterbalance" is a standard blade on a truck with no counterbalance. These estimations are calculated through the Monte Carlo method presented in Section 5.2 & 6.2 of this report. The estimated blades need is determined from divided the standard blades required by each blades equivalent number (which are presented in Table 6.5). The PolarFlex and XL Classic show less blades needed than ODOT has within the State, this is interpreted to mean that many blades would last multiple seasons. The blades are ranked from the least expensive yearly labor cost to the most expensive yearly labor cost.

In addition to the downtime, concerns about safety when changing blades are also an issue, as presented in the survey results in Chapter 2 on this report; therefore, reducing the frequency of blade changes may reduce the risk of injuries that may occur during blade changing. Cost savings may also be achieved when using certain blade types: the carbide and XL Classic blades evaluated in Year One are observed to have a cost savings, and implementing these blades within a fleet may reduce equipment costs. Year Two presents a cost savings when implementing the double stacked carbide tipped, double stacked standard, standard with additional middle guard, PolarFlex, and the XL Classic blades compared to the standard blade.

8.5 Potential Risks and Obstacles to Implementation

One of the potential risks and obstacles to implementation of the specialty blades is the risk that the specialty blades will break prior to wearing through, as the specialty blades all have a higher initial cost than a standard blade. Any potential cost savings of the specialty blades relies on the extended lifespan of the specialty blade as compared to the standard blade. Therefore, if the specialty blade breaks before wearing through and is not able to achieve an extended life, it will cost ODOT more to replace than a standard blade. As seen in Chapter 5, during the first year of this evaluation, one of the carbide-tipped blades in Medina County and the PolarFlex blade in Summit County were broken on bridge expansion joints. The broken carbide teeth on the PolarFlex in Summit County were replaced; the new teeth were bent shortly after, although the blade was still able to be used. One carbide blade was damaged in the second winter season of the evaluation.

8.6 Strategies to Overcome Potential Risks and Obstacles

There will always be a risk when plowing that a blade could break prior to wearing through. Even experienced operators may break a blade; however, proper training for operators may result in a reduced number of blades that are broken. Ensuring that each operator is familiar with the locations in which blades may break may help to reduce the number of damaged and broken blades. Training operators to exercise care in these locations may be achieved by providing operators with documentation that highlights hazardous areas. Summit County in District 4 tracks the problem areas that cause issues when treating the maintenance routes for snow and ice and provides additional information to operators about these areas. The District 4 route information forms, which are presented in Figure 8.1, are also available on the ODOT website.

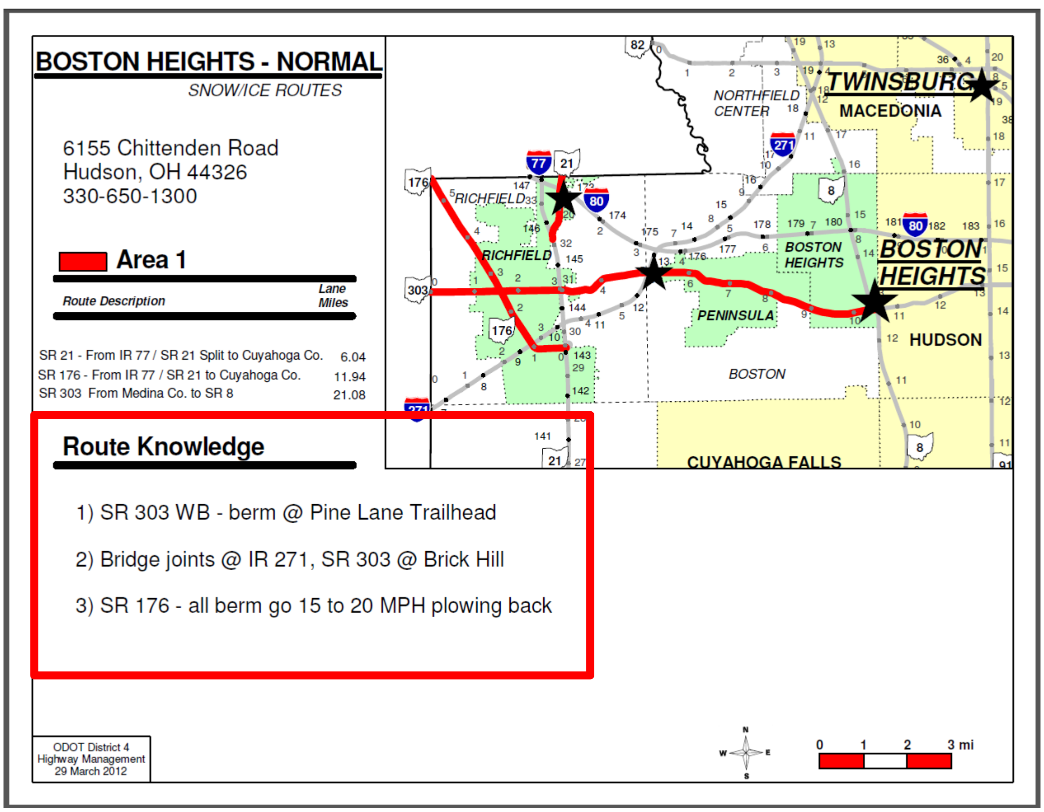


Figure 8.1: Summit County Route Maps with a Route Knowledge Section (in Red Box) to Educate Operators of Hazardous Areas along a Route. (Ref: http://www.dot.state.oh.us)

The information about potential hazards along maintenance routes may aid new operators or those who are unfamiliar with a given route to identify locations where blades may become damaged. In addition, the route knowledge presented in Figure 8.1 shows the locations of bridge joints to watch for when plowing. Typically, the plow truck operator will lift the blade to avoid damage to the blade at these locations. Managers should ensure that detailed route information is available to new operators, and these areas should be pointed out during training of the new operators as the new operators are driving the routes.

8.7 Potential Users and Other Organization that may be Affected

This evaluation of various types of blades may provide additional information to other potential users and organizations that may wish to implement specialty blades within their own winter fleets. The knowledge presented in this report may help guide readers in choosing the blades that are best for their fleet along with the various obstacles associated with investing in specialty blades as compared to the standard flame-hardened steel blades.

8.8 Estimated Cost of Implementation

The cost to implement the specialty blades will vary depending on the quantity and type of blades being implemented. The cost of implementation is the initial cost of purchasing the blades. Section 5.2 and Section 6.2 of this report presents the cost associated with each type of blade evaluated during this study. Tables 5.6, 6.6, and 6.8 present the cost per blade for Year One, Year Two, and a combination of the two seasons, respectively. The XL Classic is observed to have a cost savings in both seasons, while the PolarFlex has a cost savings in the second year and the combination of the two season’s data. There are cost savings associated with double stacking a standard blade, a double stacked carbide blade, and an additional middle guard blade. In the second year, it is observed that when no counterbalance is used, the standard blade life is reduced by 20% resulting in an additional cost when implementing a truck with no counterbalance or an improperly calibrated counterbalance.

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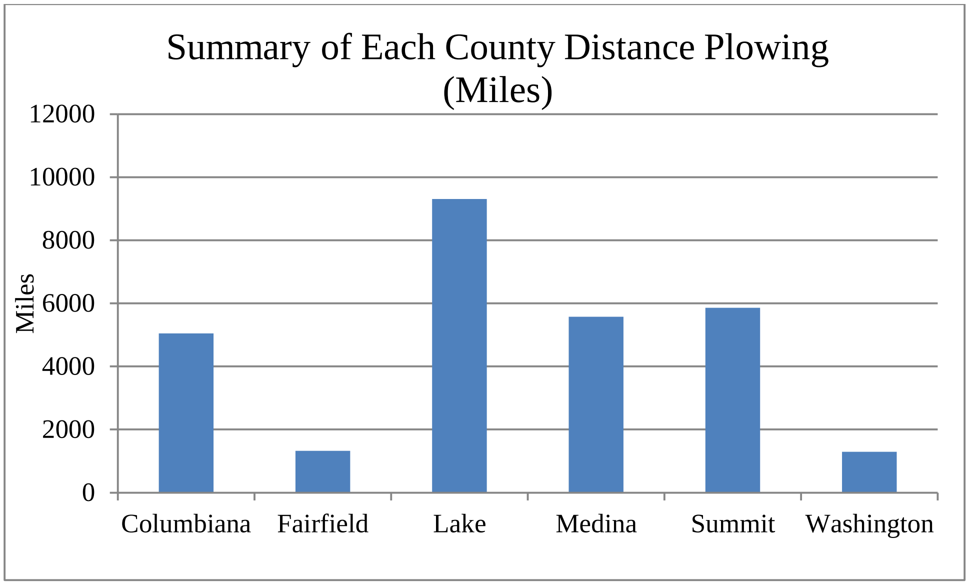
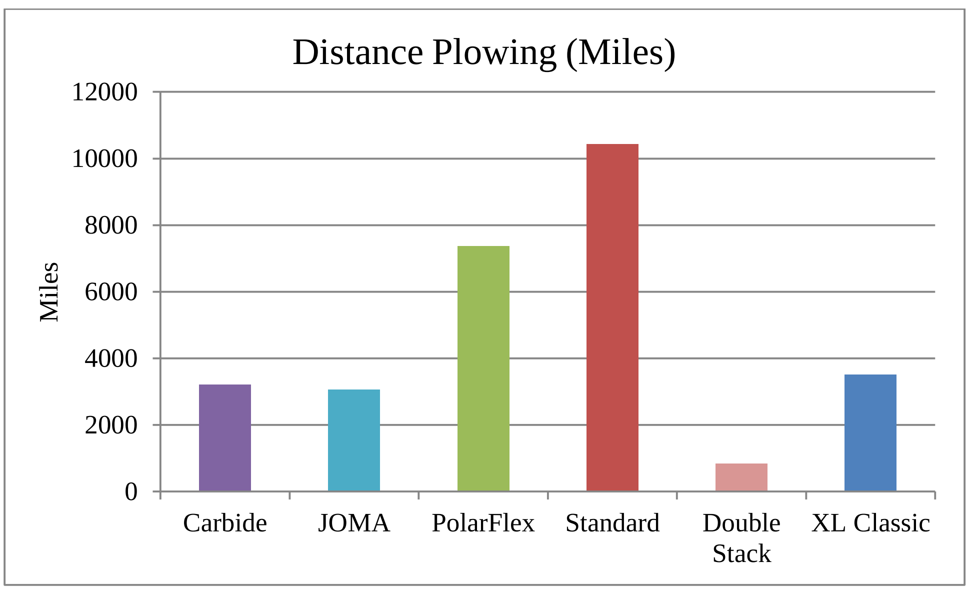
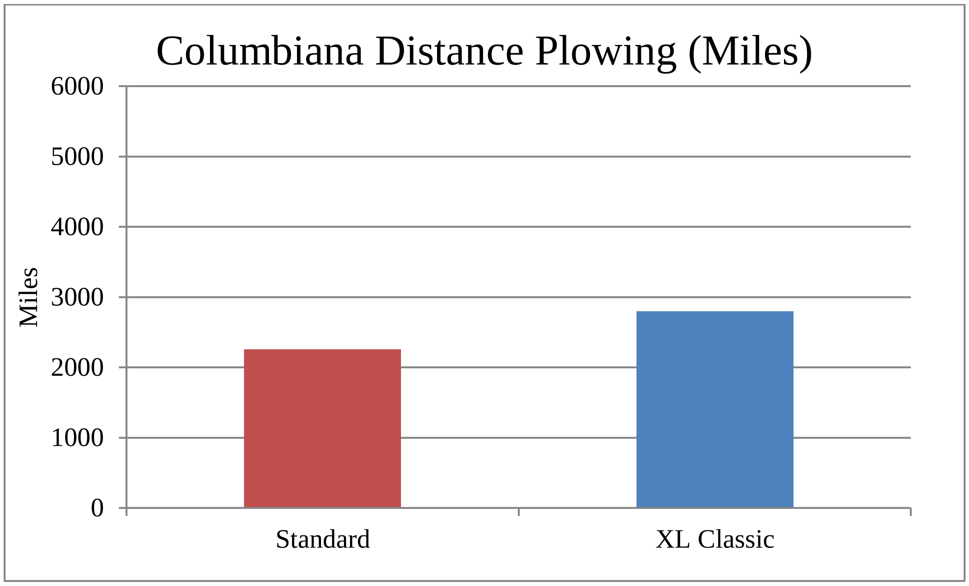
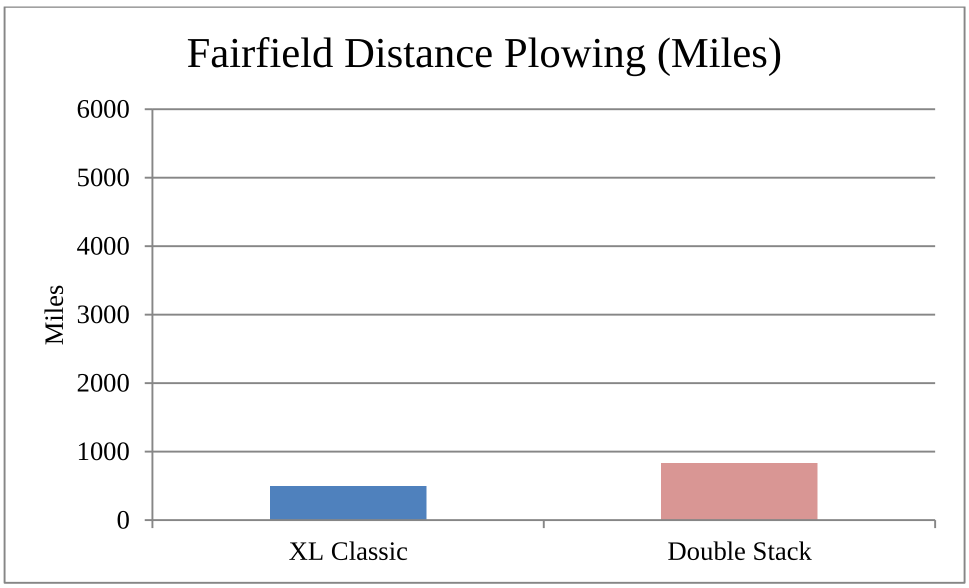
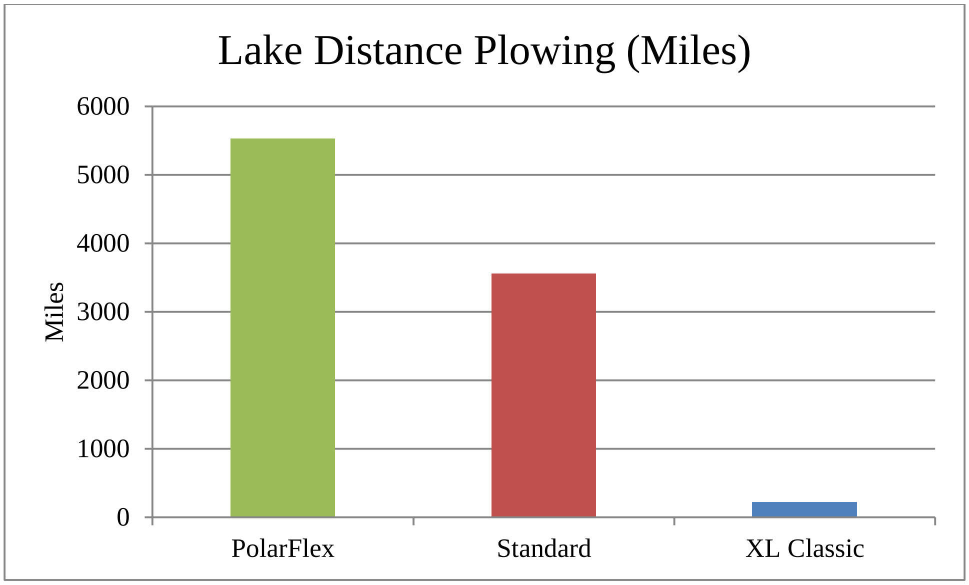
Year One

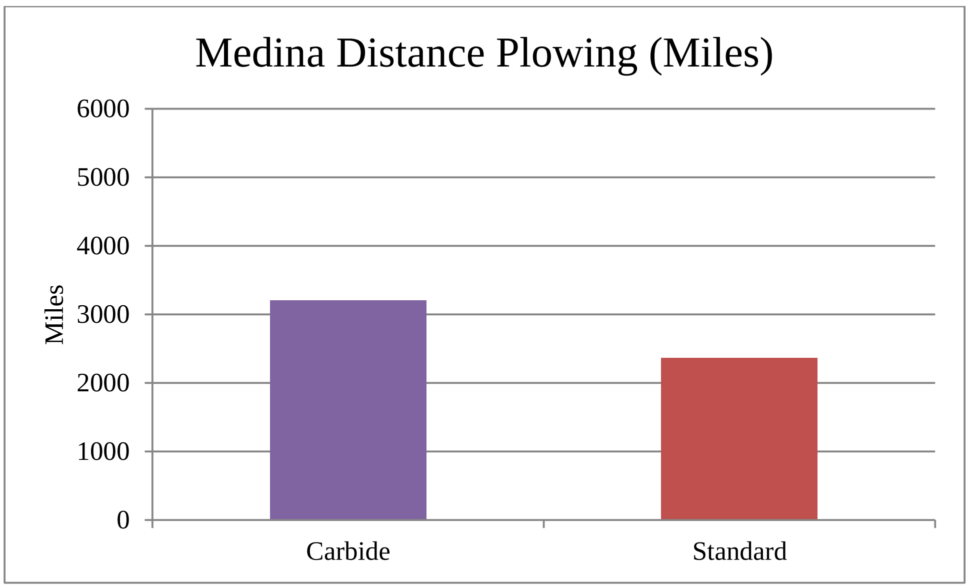

Summary of Each County Distance Plowing (Miles)
Miles
12000
10000
8000
6000
4000
2000
0
Columbiana
Fairfield
Lake
Medina
Summit
Washington

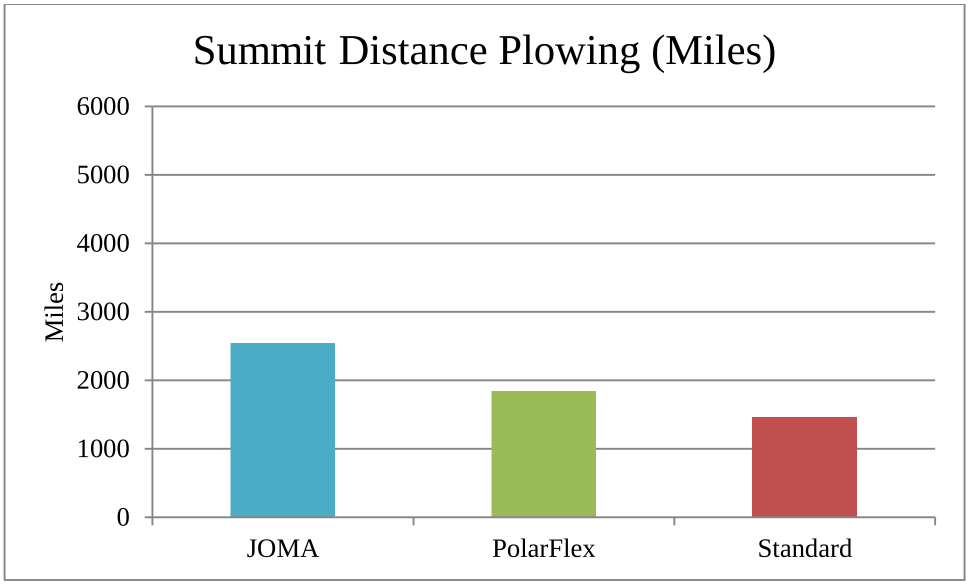

Distance Plowing (Miles)
Miles
12000
10000
8000
6000
4000
2000
0
Carbide
JOMA
PolarFlex
Standard
Double Stack
XL Classic

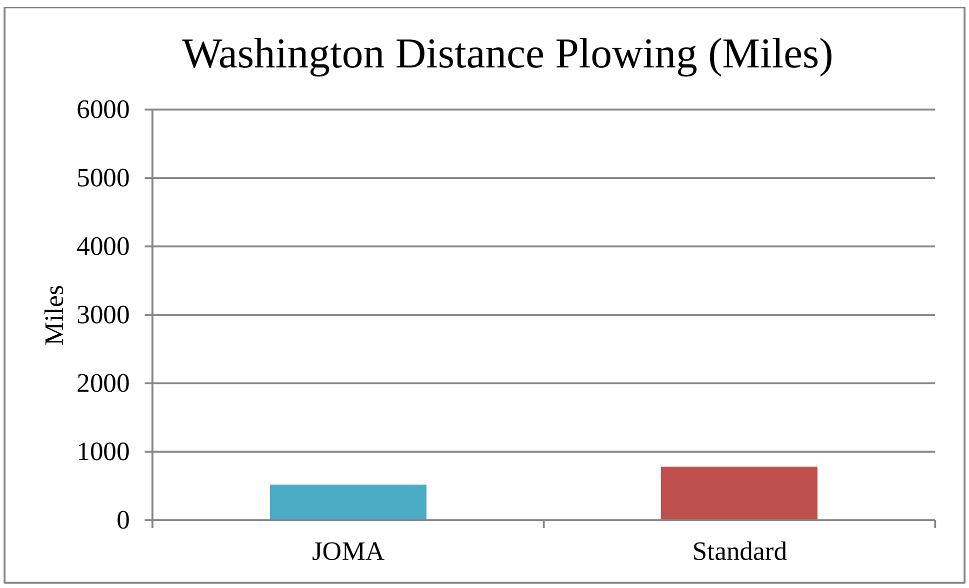

Columbiana Distance Plowing (Miles)
6000
5000
4000
3000
2000
1000
0
Miles
Standard
XL Classic

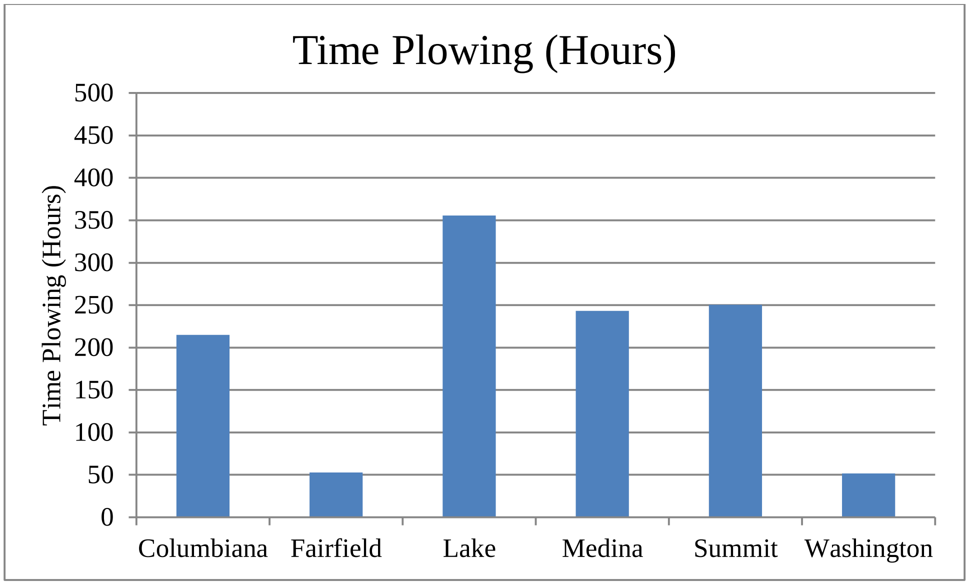

Fairfield Distance Plowing (Miles)
6000
5000
4000
3000
2000
1000
0
Miles
XL Classic
Double Stack

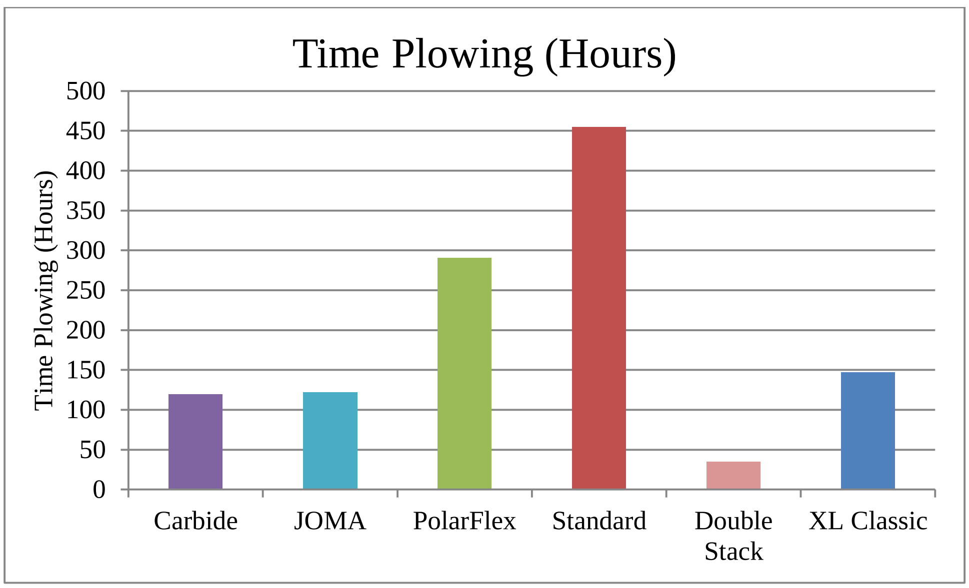

Lake Distance Plowing (Miles)
Miles
6000
5000
4000
3000
2000
1000
0
PolarFlex
Standard
XL Classic

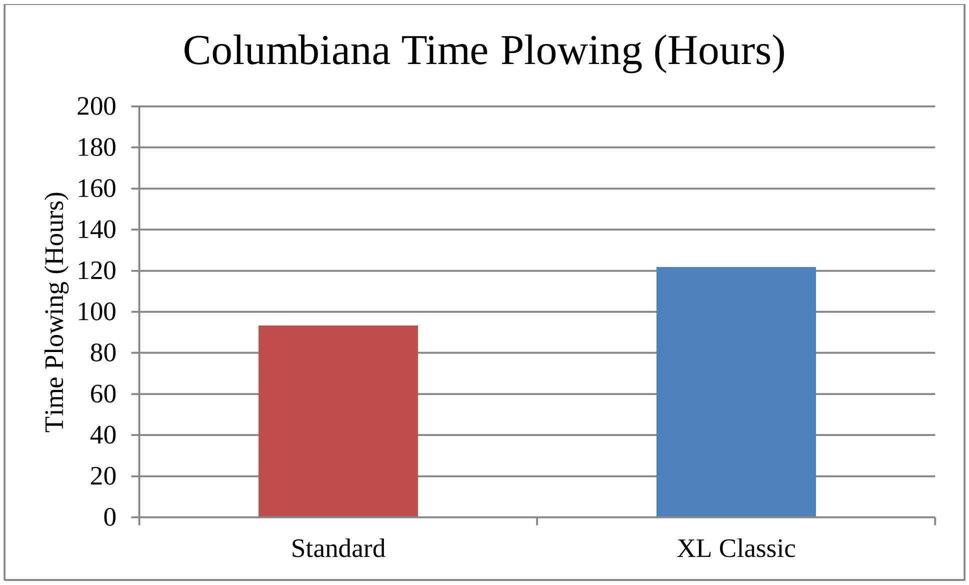

Medina Distance Plowing (Miles)
Miles
6000
5000
4000
3000
2000
1000
0
Carbide
Standard

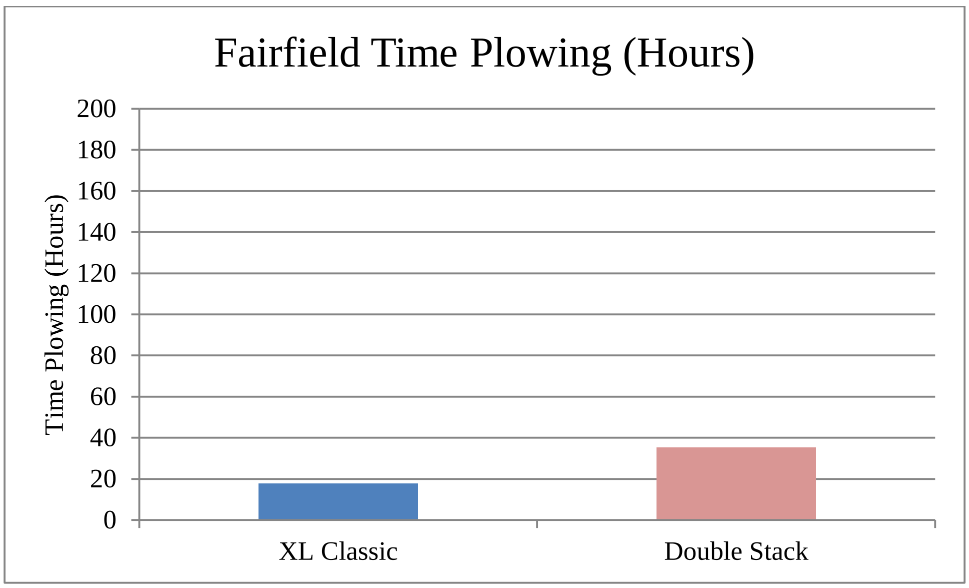

Summit Distance Plowing (Miles)
Miles
6000
5000
4000
3000
2000
1000
0
JOMA
PolarFlex
Standard

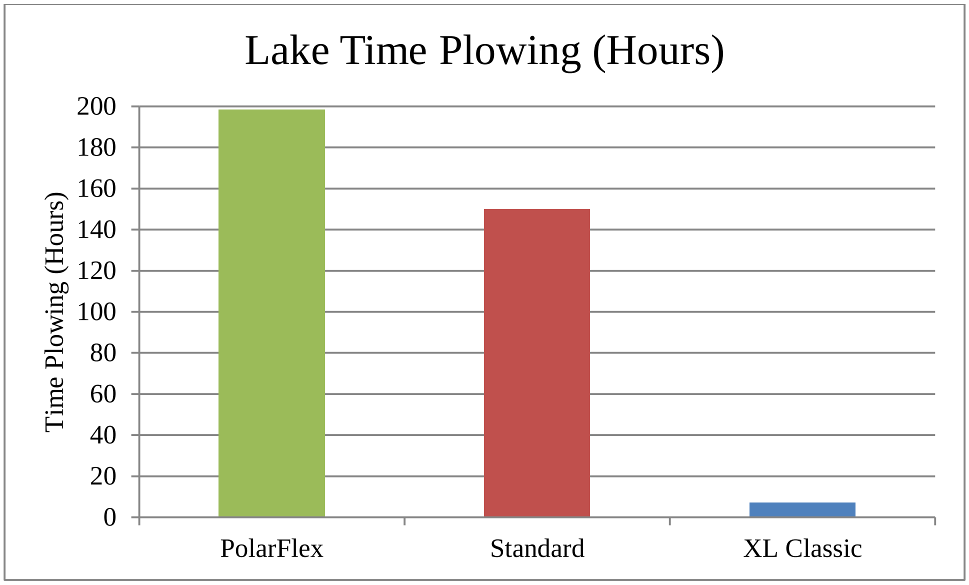

Washington Distance Plowing (Miles)
Miles
6000
5000
4000
3000
2000
1000
0
JOMA
Standard

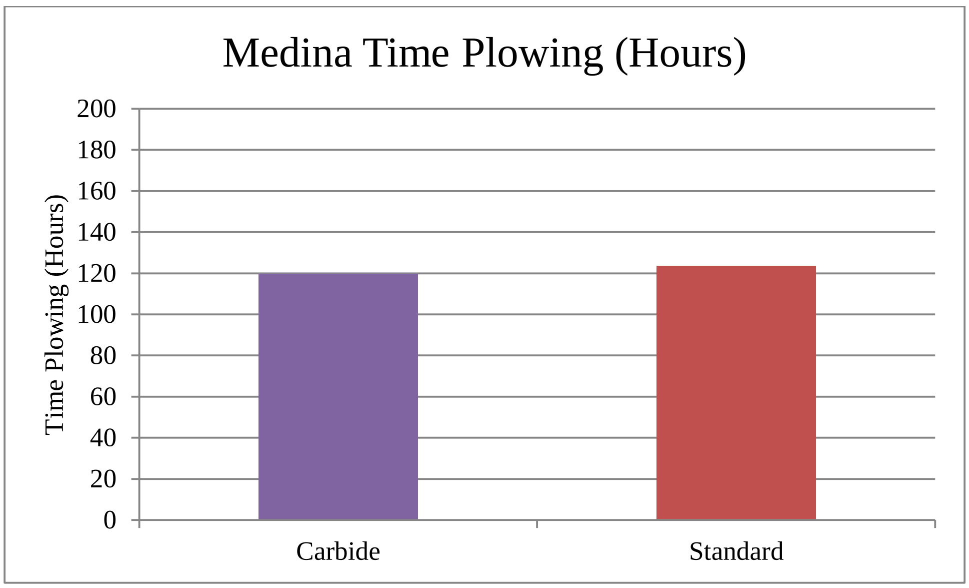

Time Plowing (Hours)
Time Plowing (Hours)
500
450
400
350
300
250
200
150
100
50
0
Columbiana
Fairfield
Lake
Medina
Summit
Washington

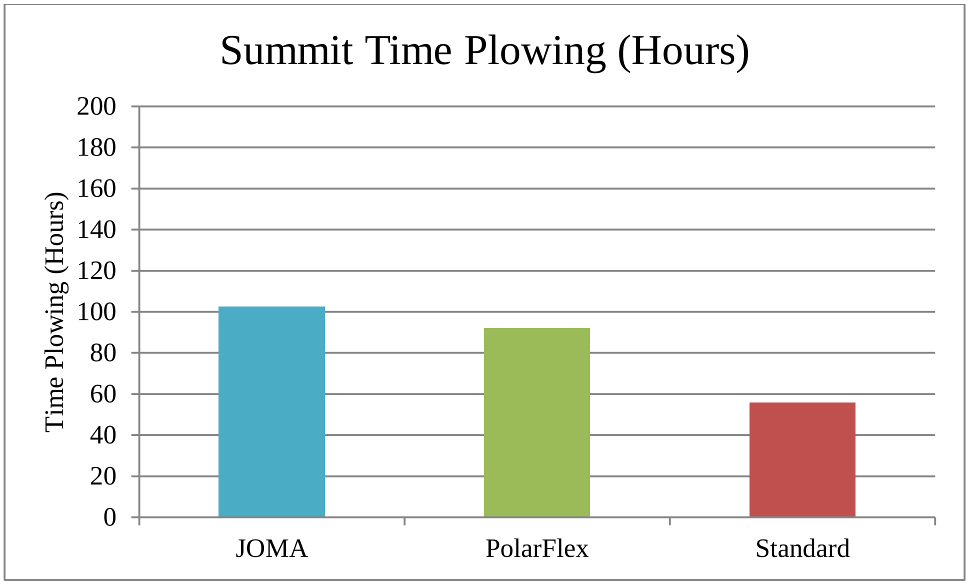

Time Plowing (Hours)
Time Plowing (Hours)
500
450
400
350
300
250
200
150
100
50
0
Carbide
JOMA
PolarFlex
Standard
Double Stack
XL Classic

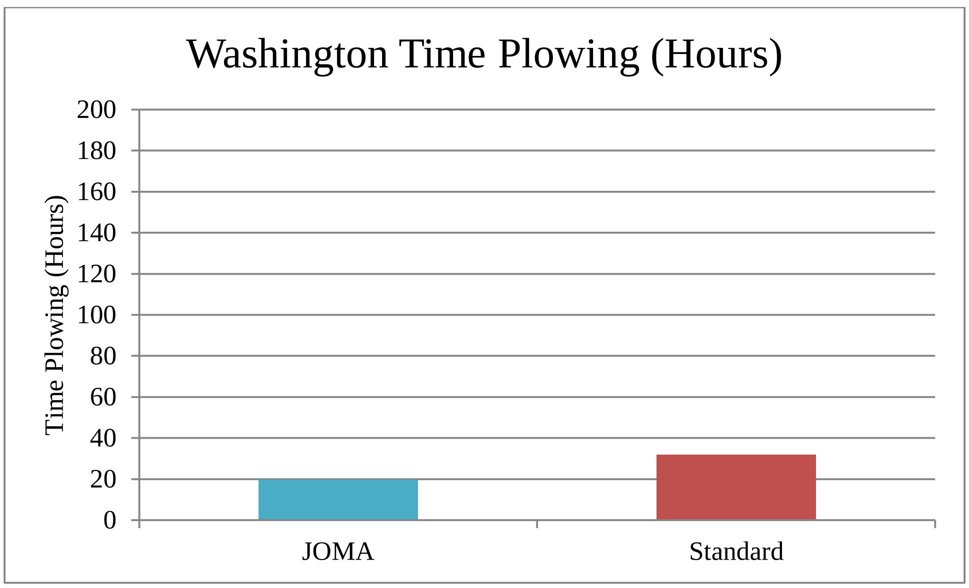

Columbiana Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
Standard
XL Classic

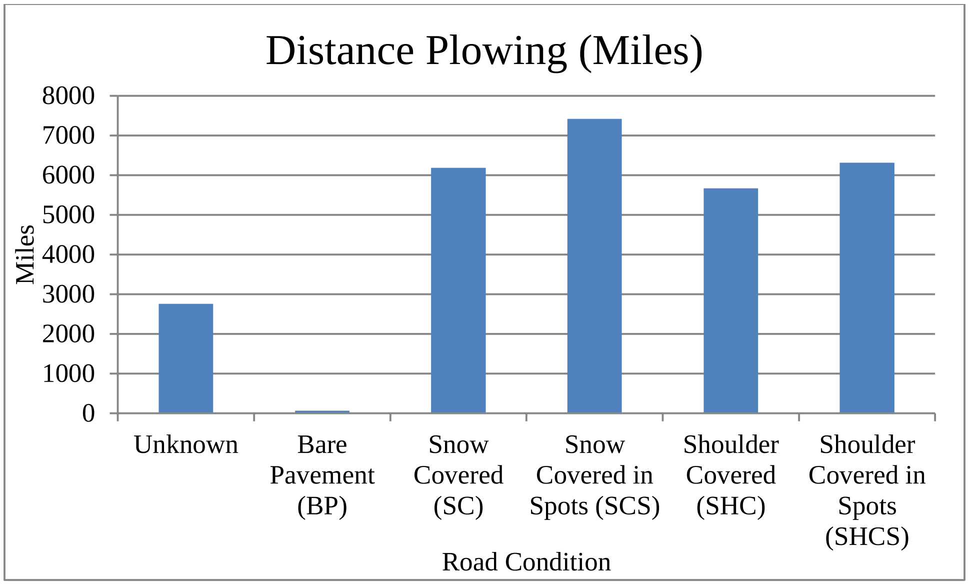

Fairfield Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
XL Classic
Double Stack

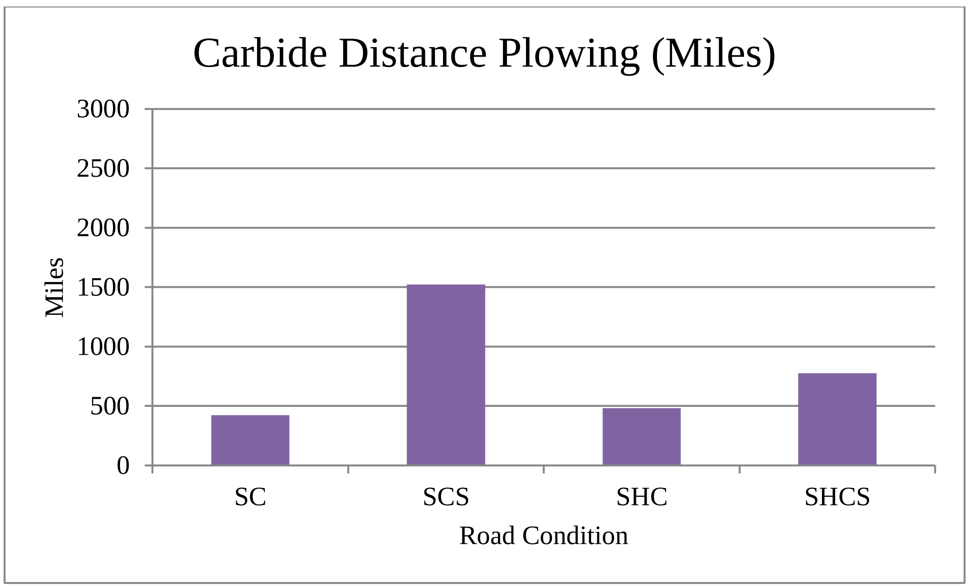

Lake Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
PolarFlex
Standard
XL Classic

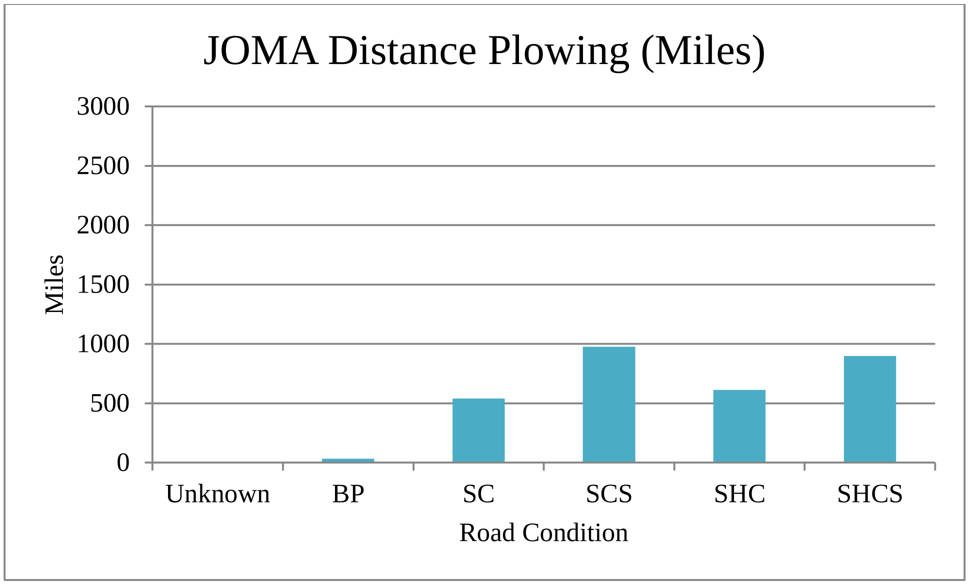

Medina Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
Carbide
Standard

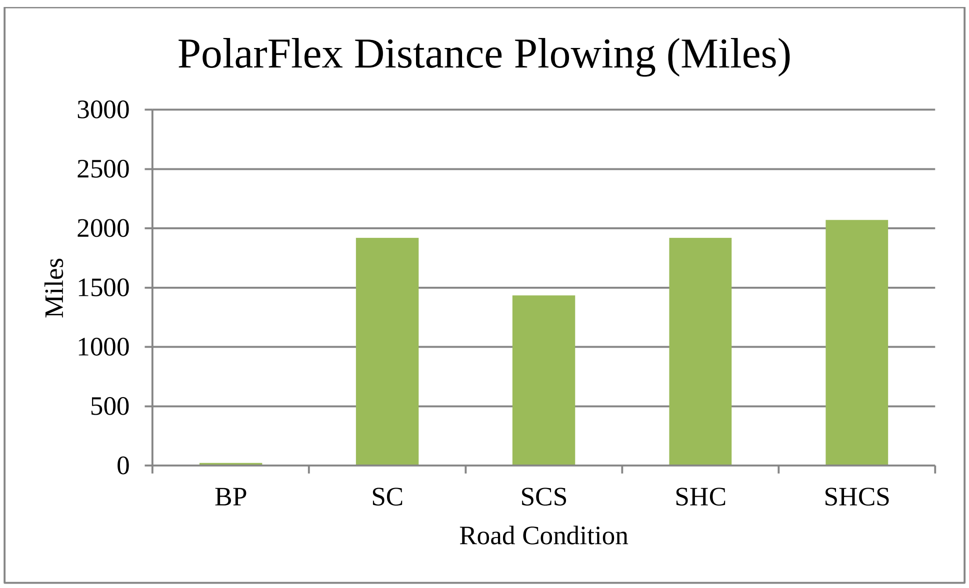

Summit Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
JOMA
PolarFlex
Standard

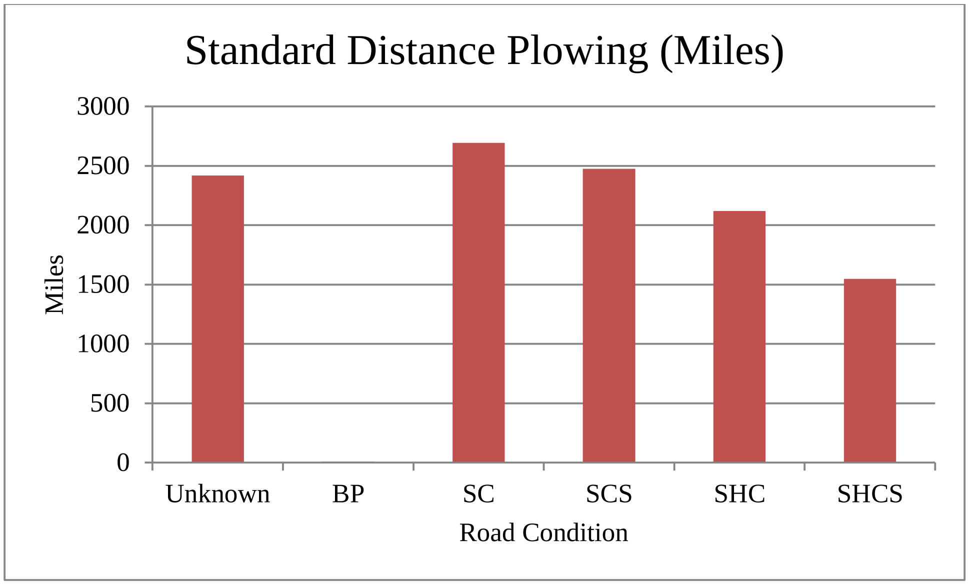

Washington Time Plowing (Hours)
Time Plowing (Hours)
200
180
160
140
120
100
80
60
40
20
0
JOMA
Standard

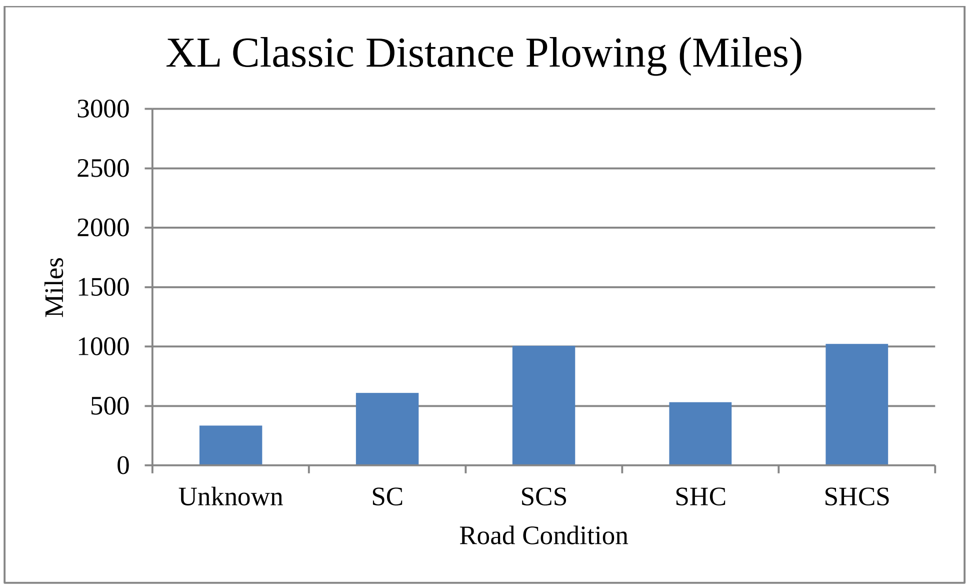

Distance Plowing (Miles)
Miles
8000
7000
6000
5000
4000
3000
2000
1000
0
Unknown
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)
Road Condition

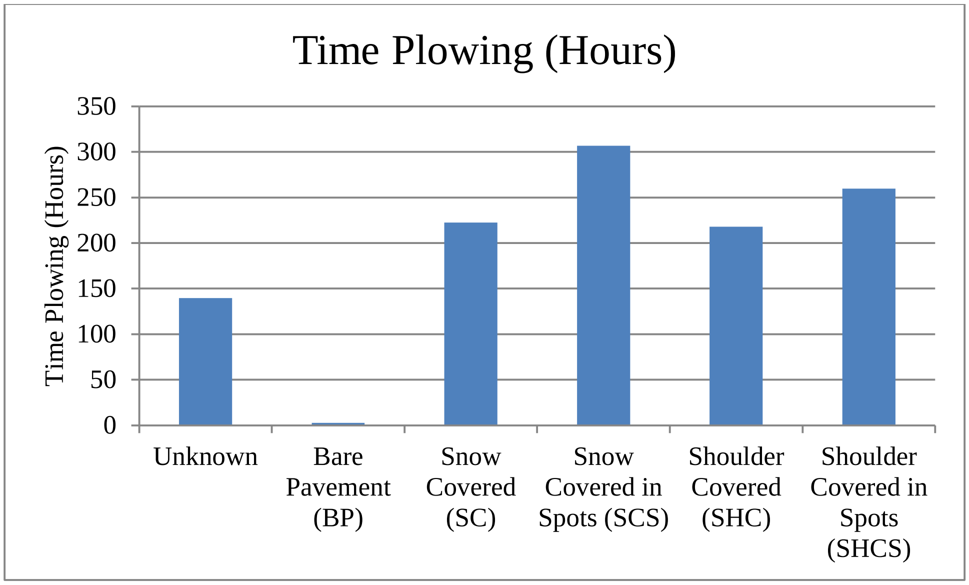

Carbide Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
SC
SCS
SHC
SHCS
Road Condition

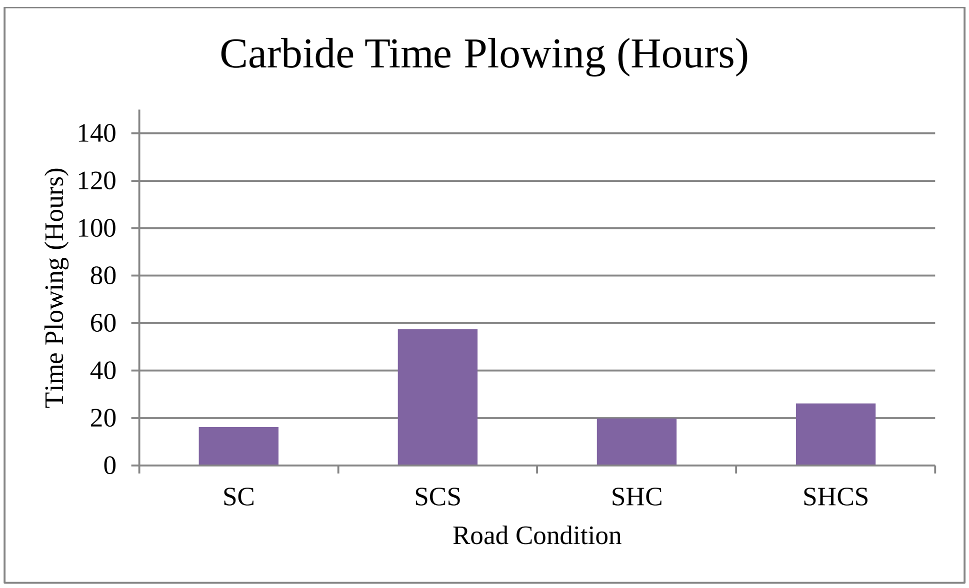

JOMA Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
Unknown
BP
SC
SCS
SHC
SHCS
Road Condition

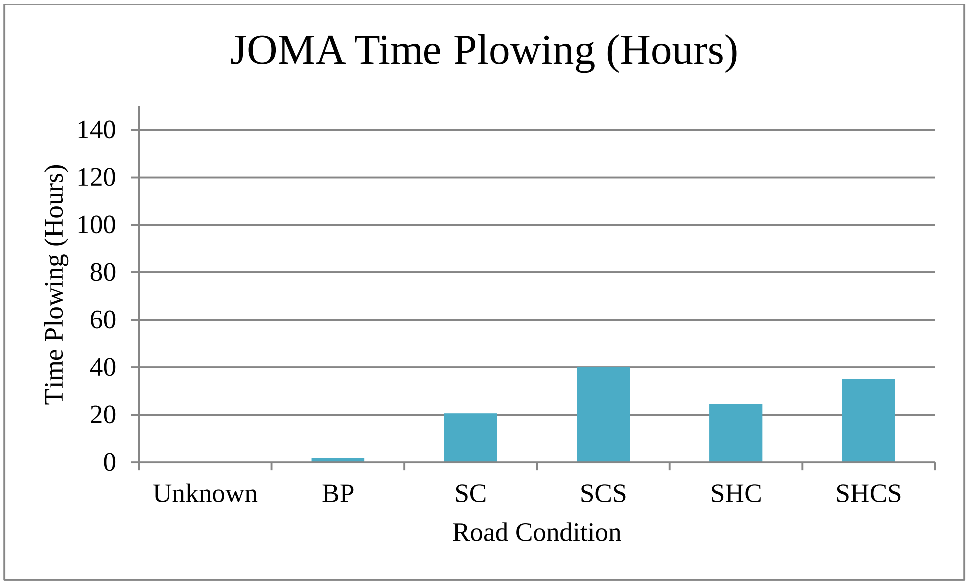

PolarFlex Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
BP
SC
SCS
SHC
SHCS
Road Condition


Standard Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
Unknown
BP
SC
SCS
SHC
SHCS
Road Condition

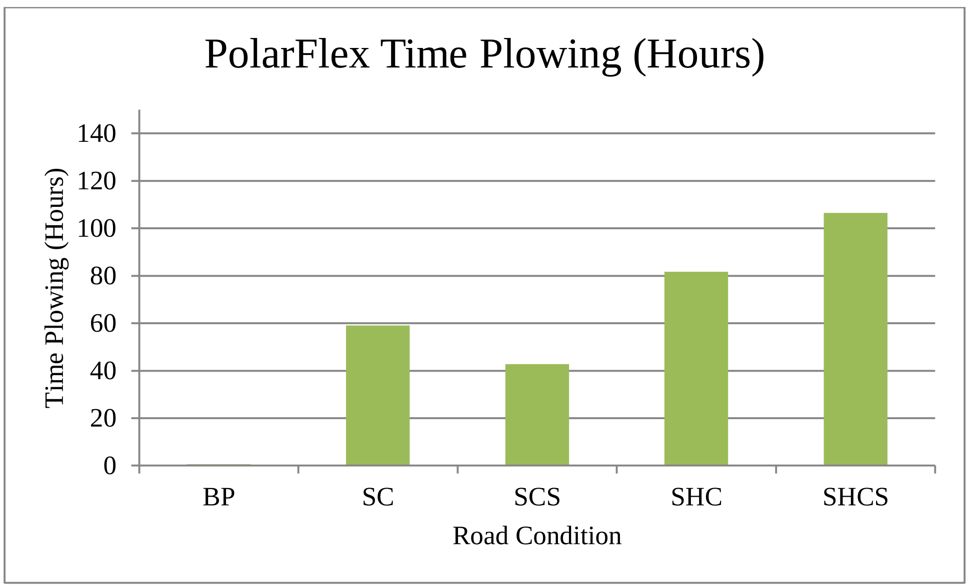

XL Classic Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
Unknown
SC
SCS
SHC
SHCS
Road Condition


Time Plowing (Hours)
Time Plowing (Hours)
350
300
250
200
150
100
50
0
Unknown
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)

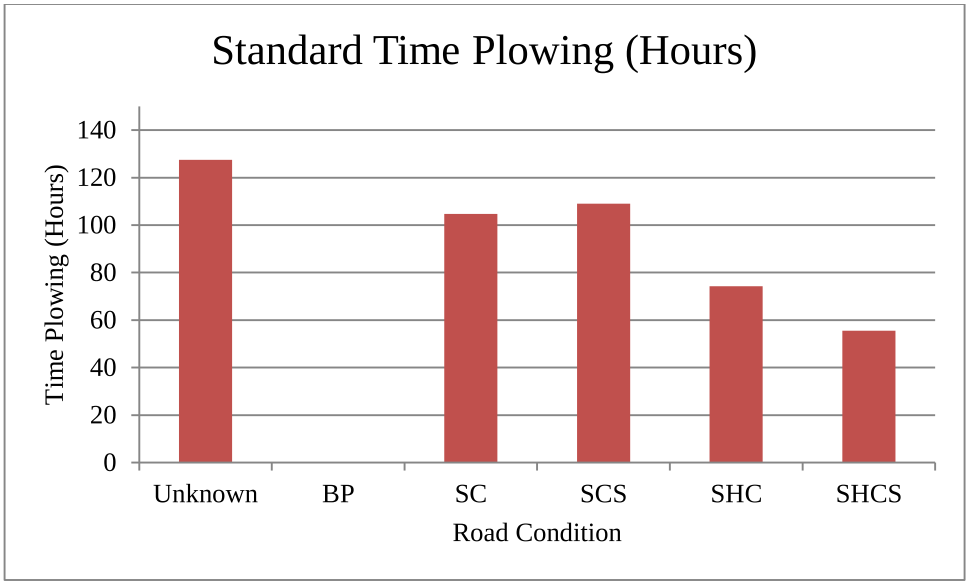

Carbide Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
SC
SCS
SHC
SHCS
Road Condition

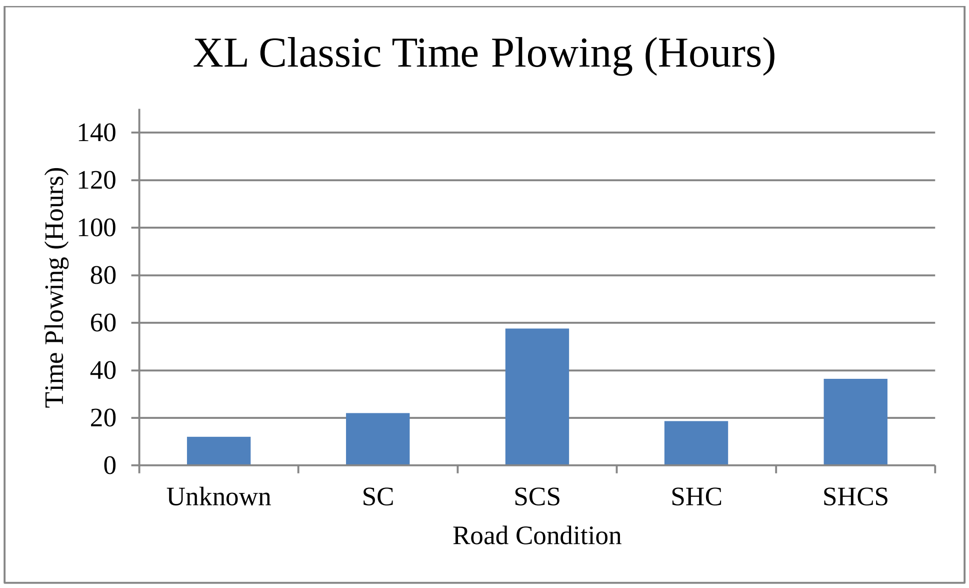


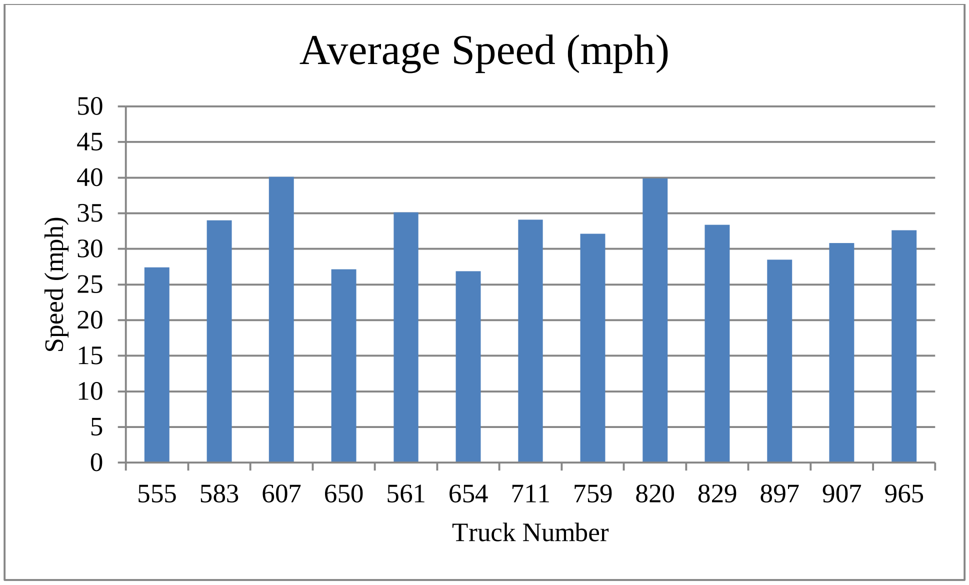
JOMA Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Unknown
BP
SC
SCS
SHC
SHCS
Road Condition

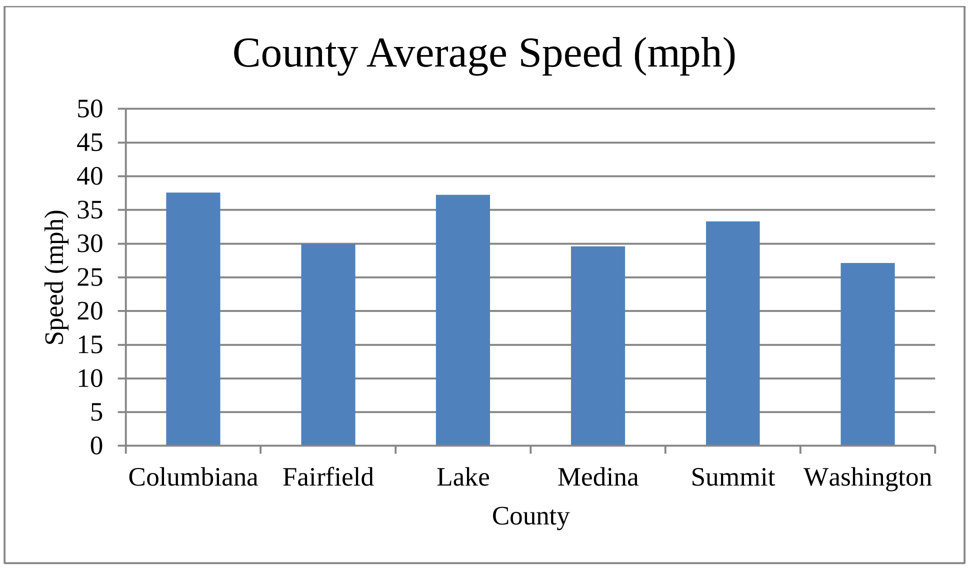


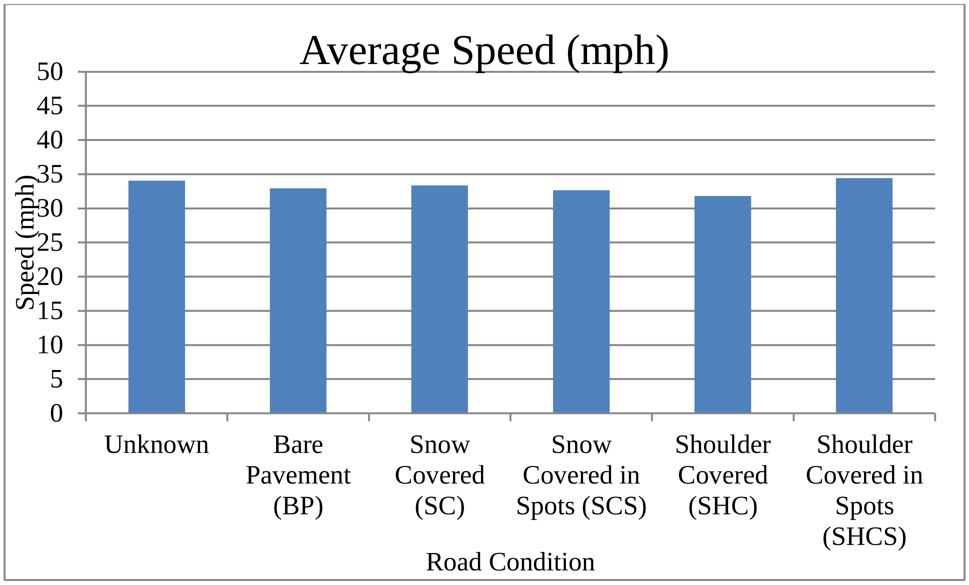
PolarFlex Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition


Standard Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Unknown
BP
SC
SCS
SHC
SHCS
Road Condition

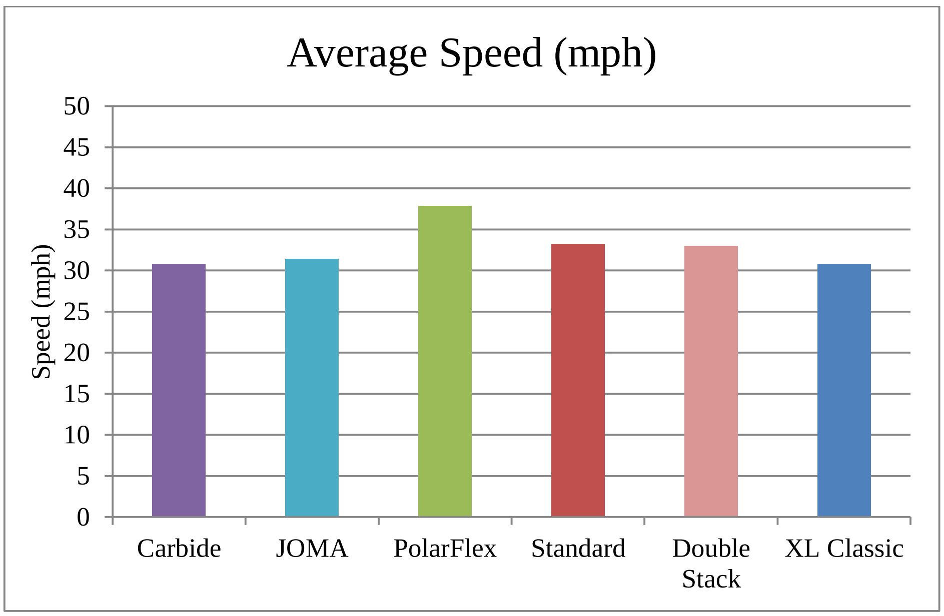

XL Classic Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Unknown
SC
SCS
SHC
SHCS
Road Condition


Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
555
583
607
650
561
654
711
759
820
829
897
907
965
Truck Number

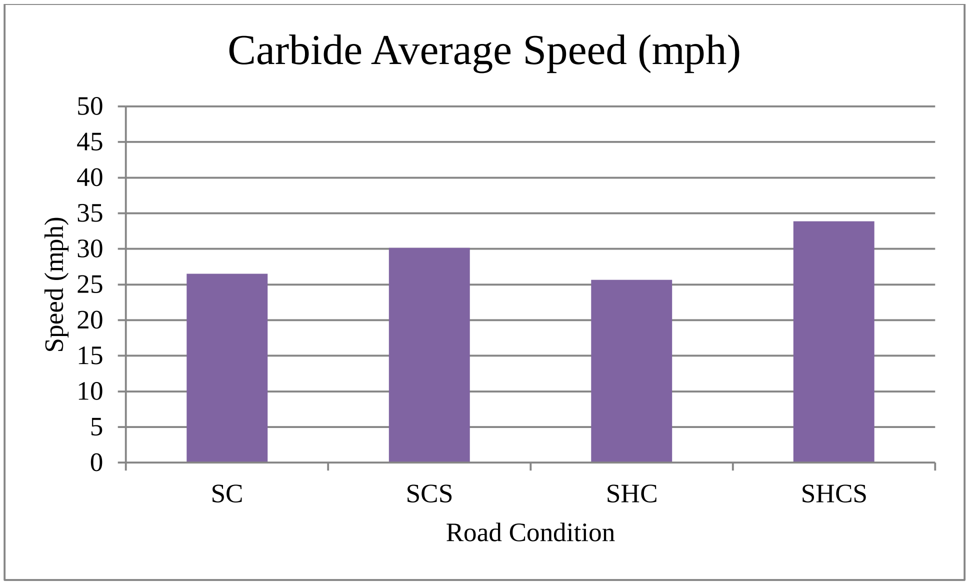

County Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Columbiana
Fairfield
Lake
Medina
Summit
Washington
County

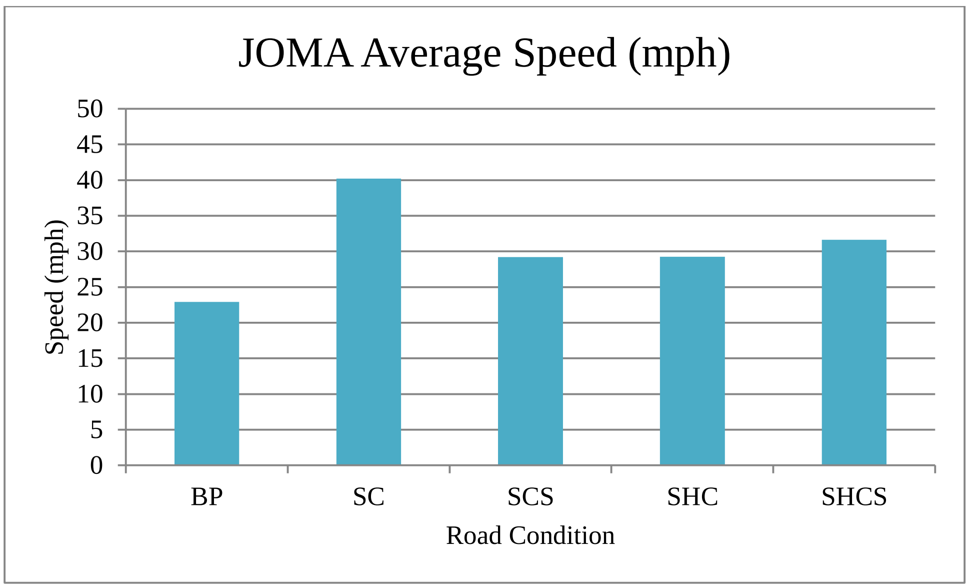


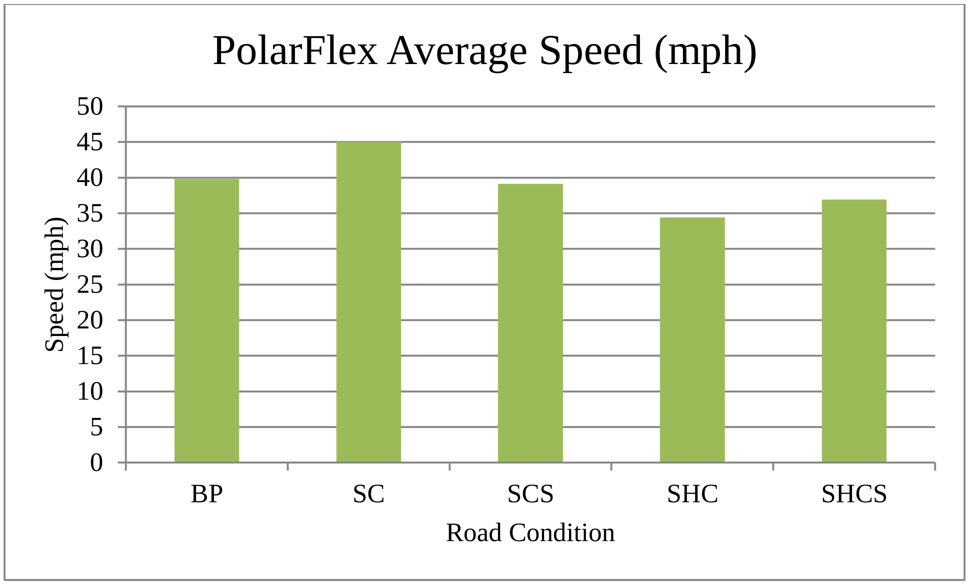
Average Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Speed (mph)
Unknown
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)
Road Condition

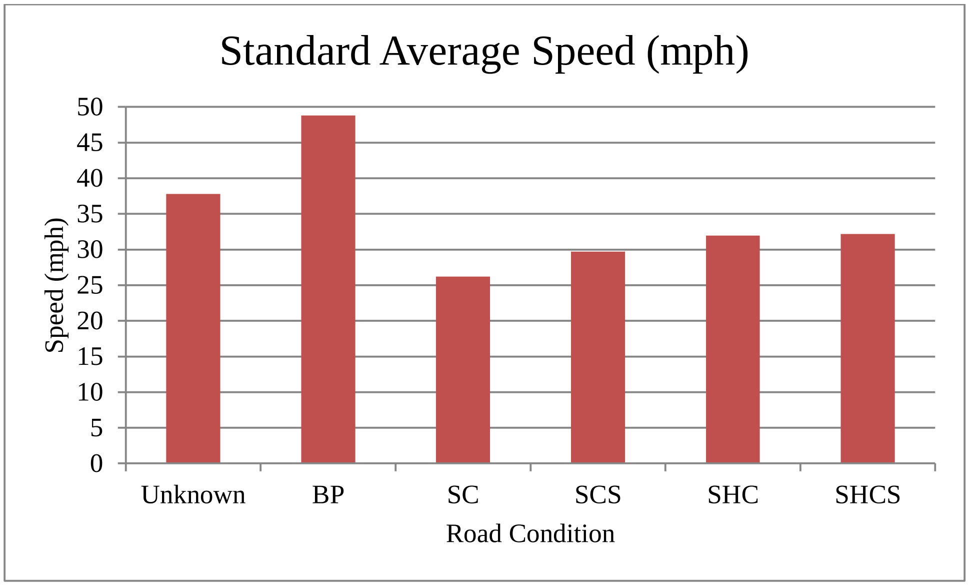


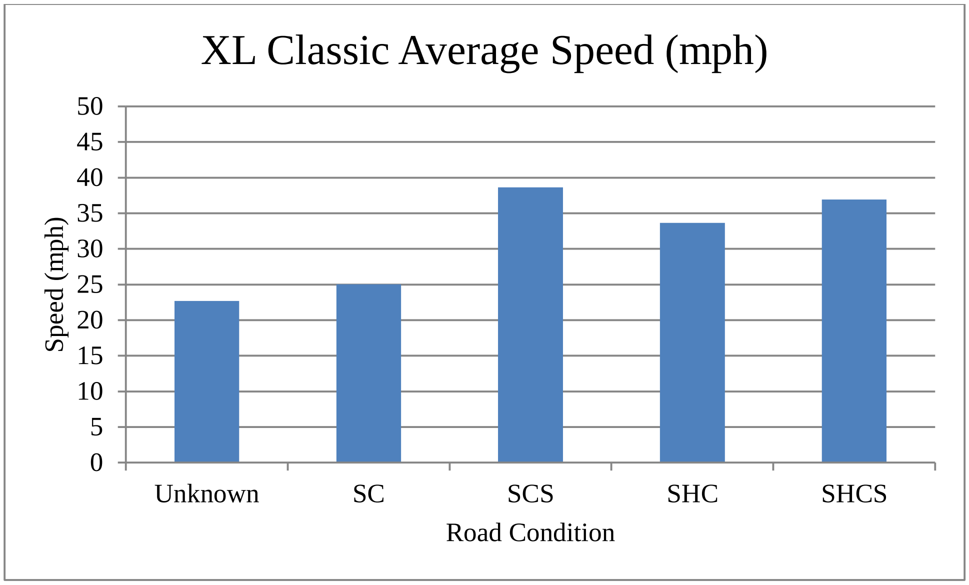
Average Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Speed (mph)
Carbide
JOMA
PolarFlex
Standard
Double Stack
XL Classic


Carbide Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
SC
SCS
SHC
SHCS
Road Condition

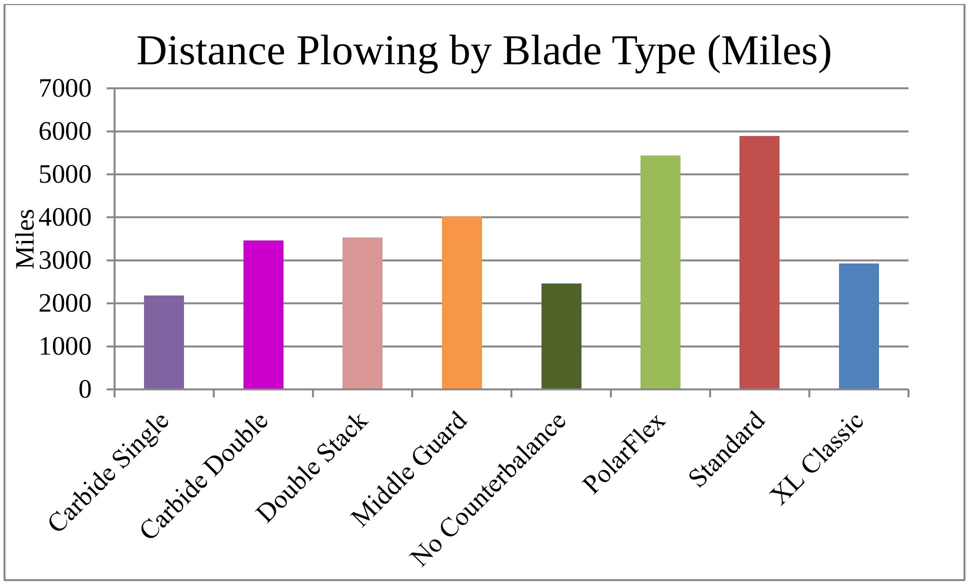

JOMA Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition

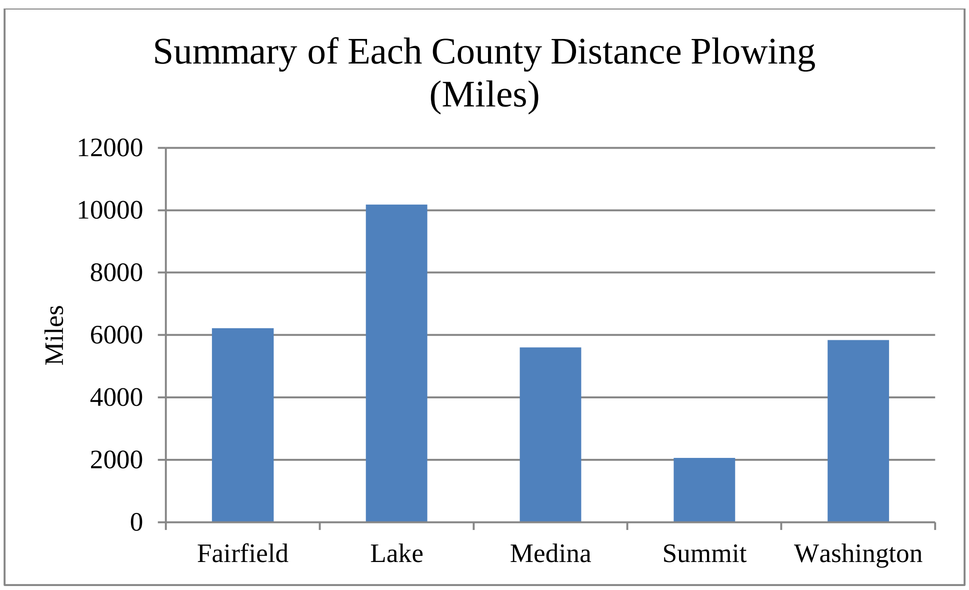

PolarFlex Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition

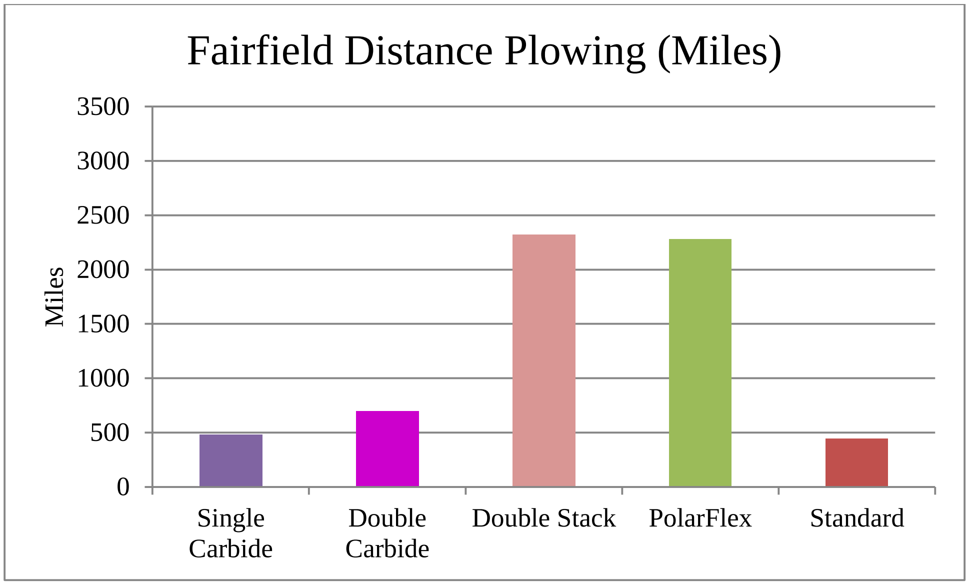

Standard Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Unknown
BP
SC
SCS
SHC
SHCS
Road Condition

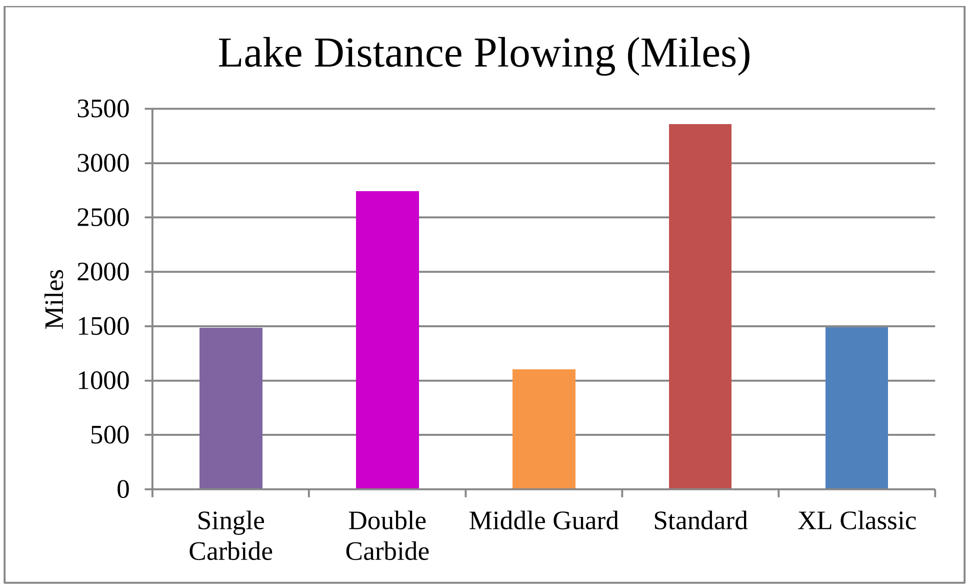

XL Classic Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Unknown
SC
SCS
SHC
SHCS
Road Condition

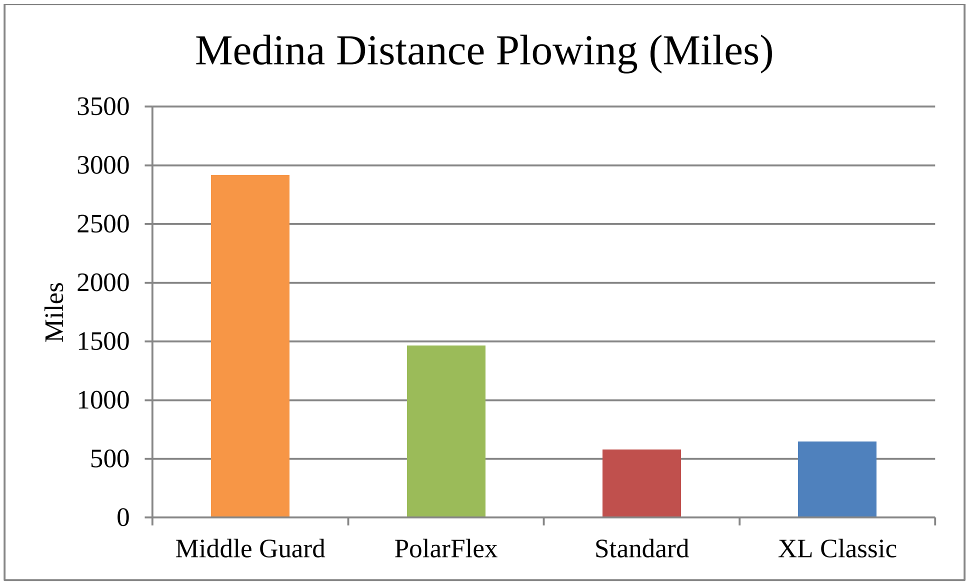
Year Two

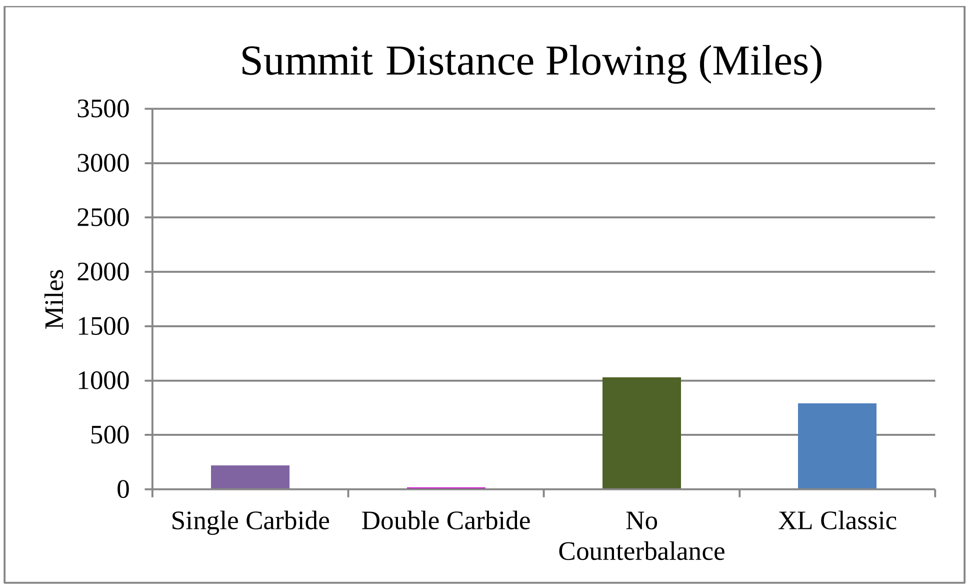

Distance Plowing by Blade Type (Miles)
Miles
7000
6000
5000
4000
3000
2000
1000
0
Carbide Single
Carbide Double
Double Stack
Middle Guard
No Counterbalance
PolarFlex
Standard
XL Classic

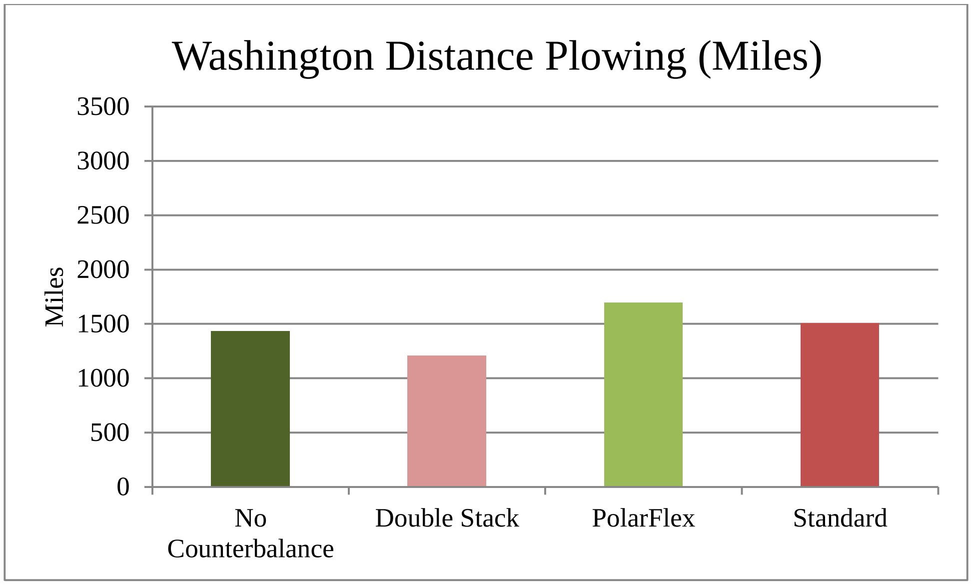

Summary of Each County Distance Plowing (Miles)
Miles
12000
10000
8000
6000
4000
2000
0
Fairfield
Lake
Medina
Summit
Washington

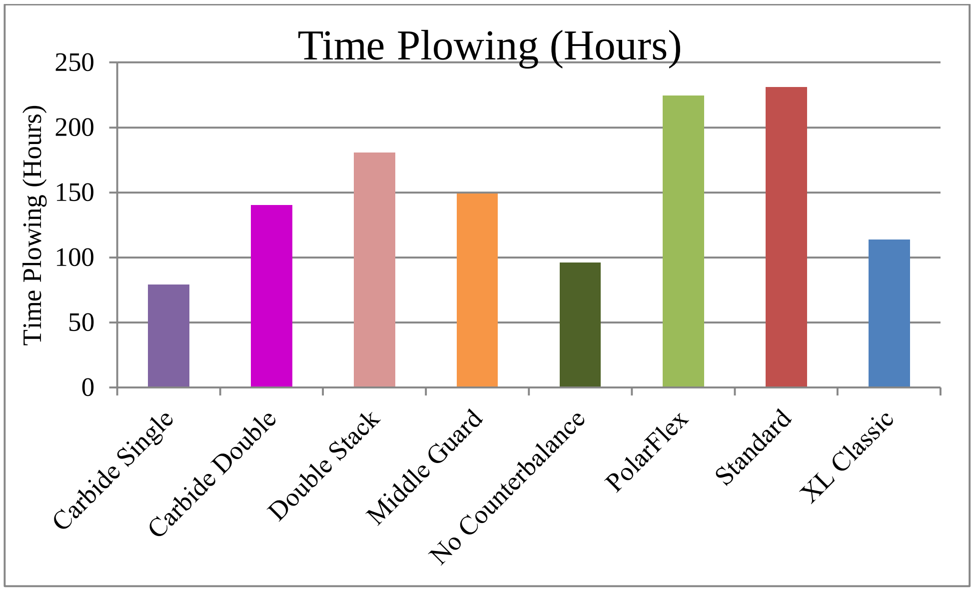

Fairfield Distance Plowing (Miles)
Miles
3500
3000
2500
2000
1500
1000
500
0
Single Carbide
Double Carbide
Double Stack
PolarFlex
Standard

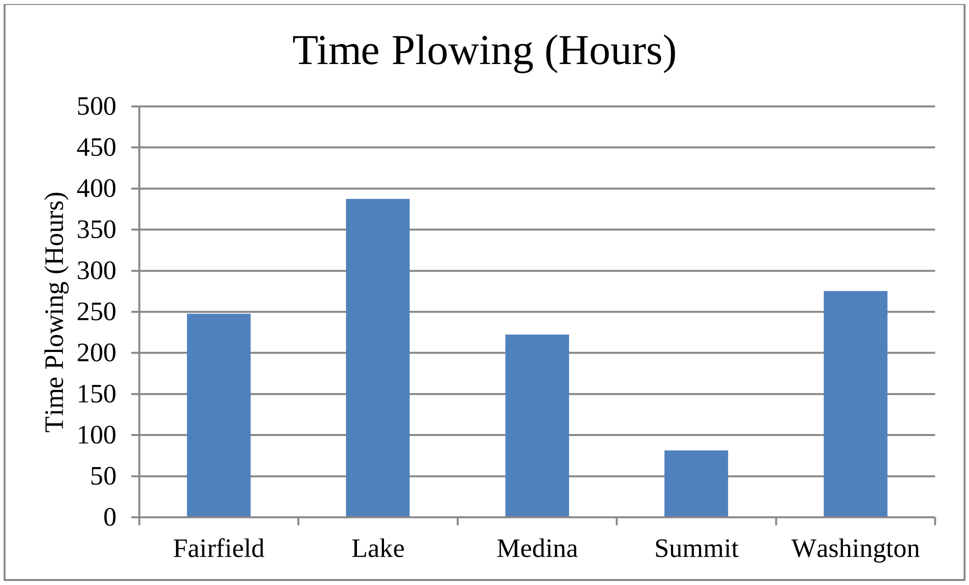

Lake Distance Plowing (Miles)
Miles
3500
3000
2500
2000
1500
1000
500
0
Single Carbide
Double Carbide
Middle Guard
Standard
XL Classic

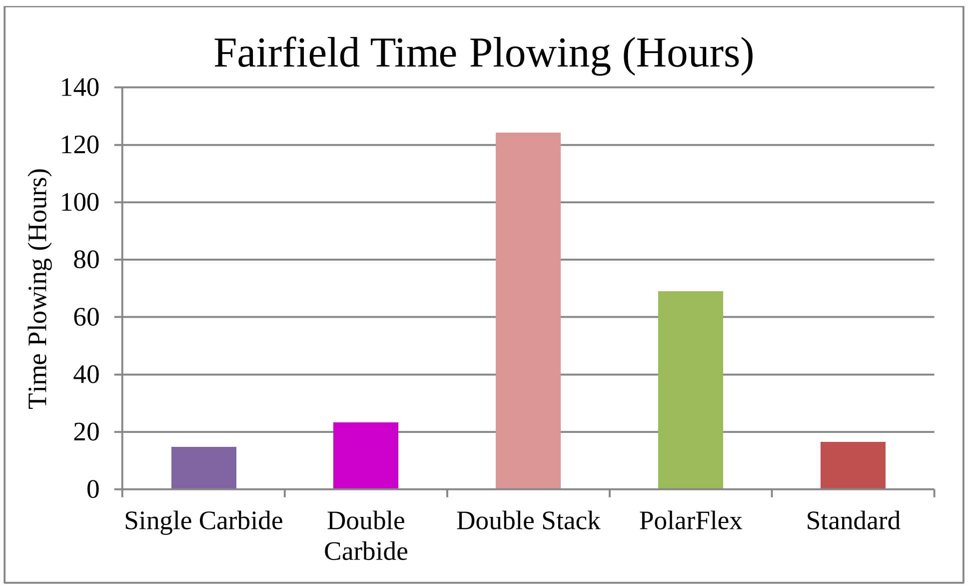

Medina Distance Plowing (Miles)
Miles
3500
3000
2500
2000
1500
1000
500
0
Middle Guard
PolarFlex
Standard
XL Classic

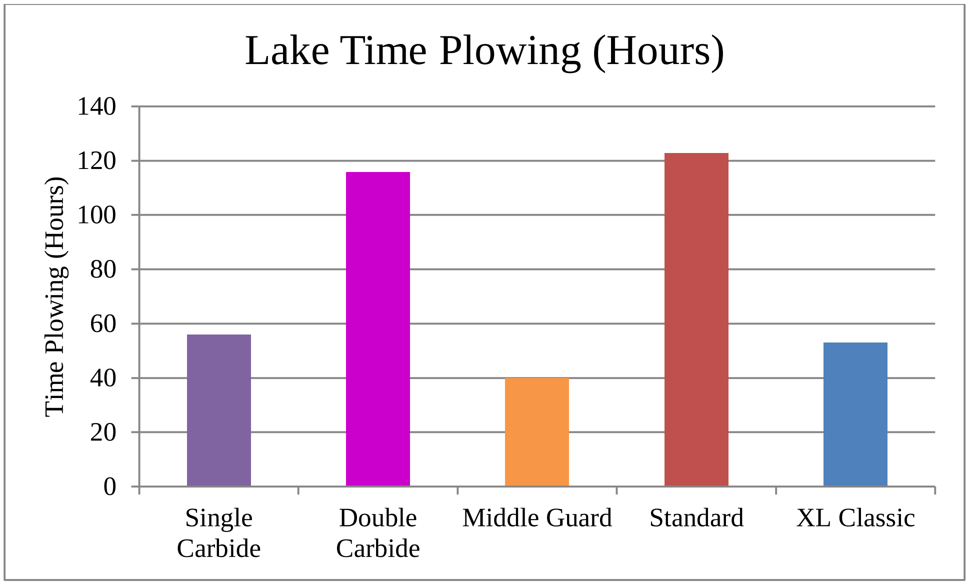

Summit Distance Plowing (Miles)
Miles
3500
3000
2500
2000
1500
1000
500
0
Single Carbide
Double Carbide
No Counterbalance
XL Classic

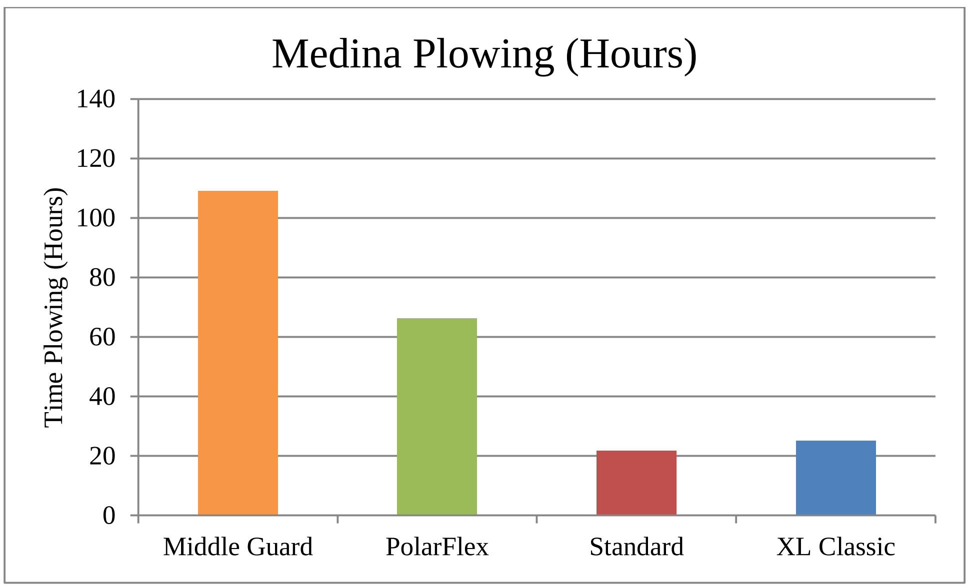

Washington Distance Plowing (Miles)
Miles
3500
3000
2500
2000
1500
1000
500
0
No Counterbalance
Double Stack
PolarFlex
Standard

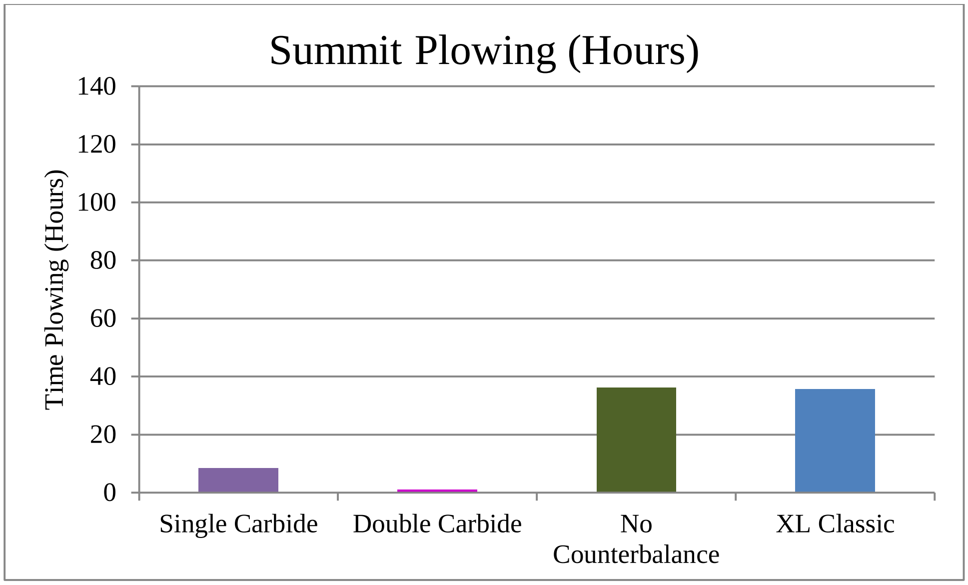

Time Plowing (Hours)
Time Plowing (Hours)
250
200
150
100
50
0
Carbide Single
Carbide Double
Double Stack
Middle Guard
No Counterbalance
PolarFlex
Standard
XL Classic

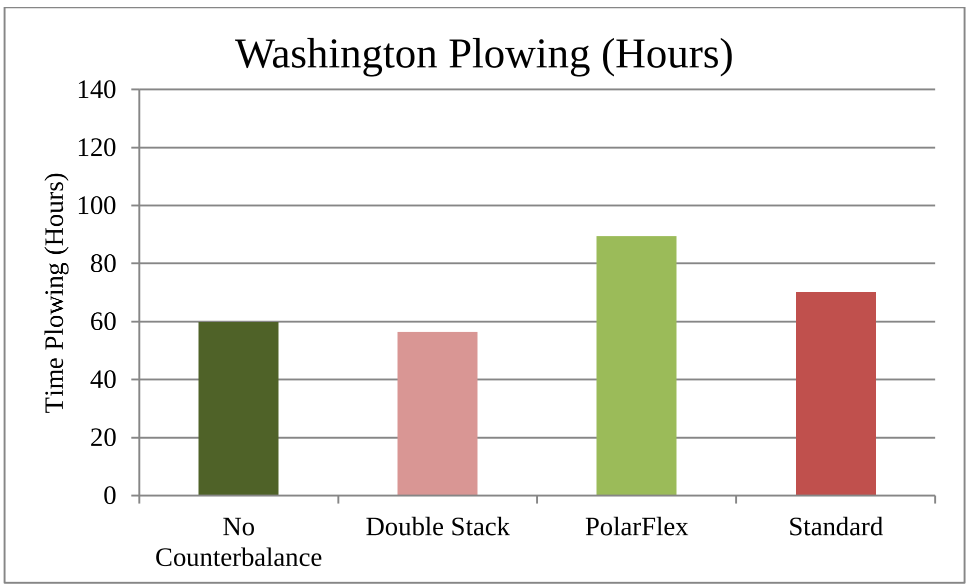

Time Plowing (Hours)
Time Plowing (Hours)
500
450
400
350
300
250
200
150
100
50
0
Fairfield
Lake
Medina
Summit
Washington

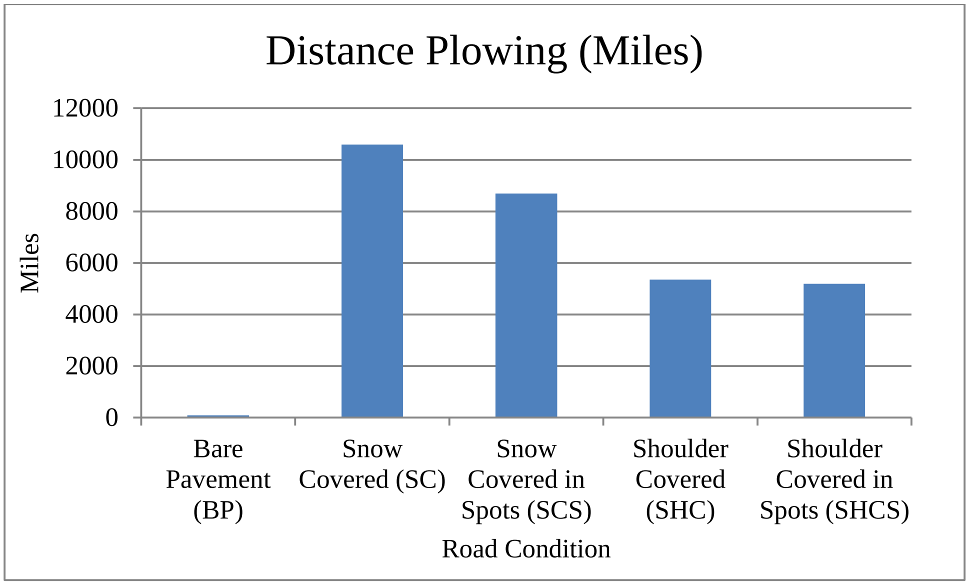

Fairfield Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Single Carbide
Double Carbide
Double Stack
PolarFlex
Standard

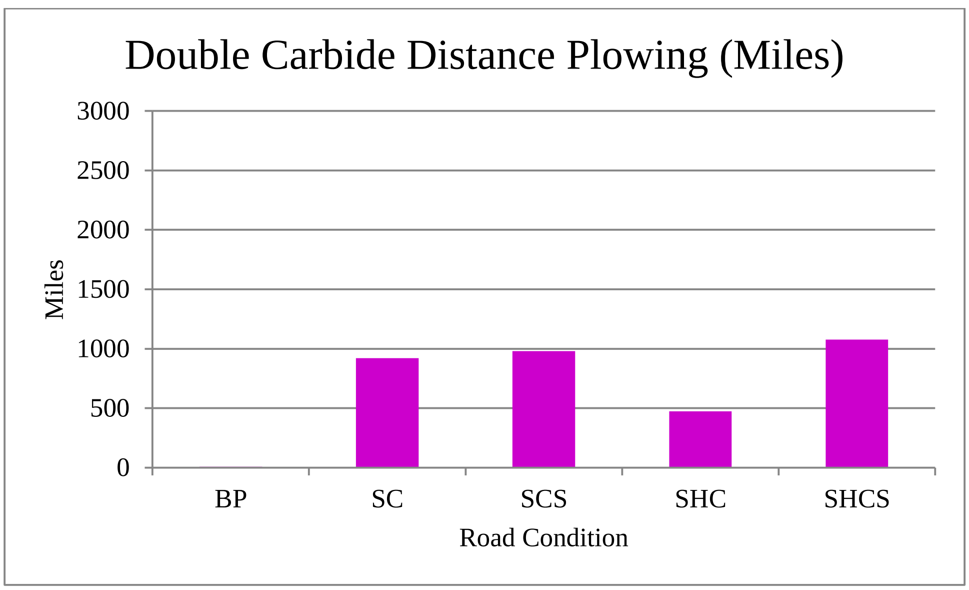

Lake Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Single Carbide
Double Carbide
Middle Guard
Standard
XL Classic

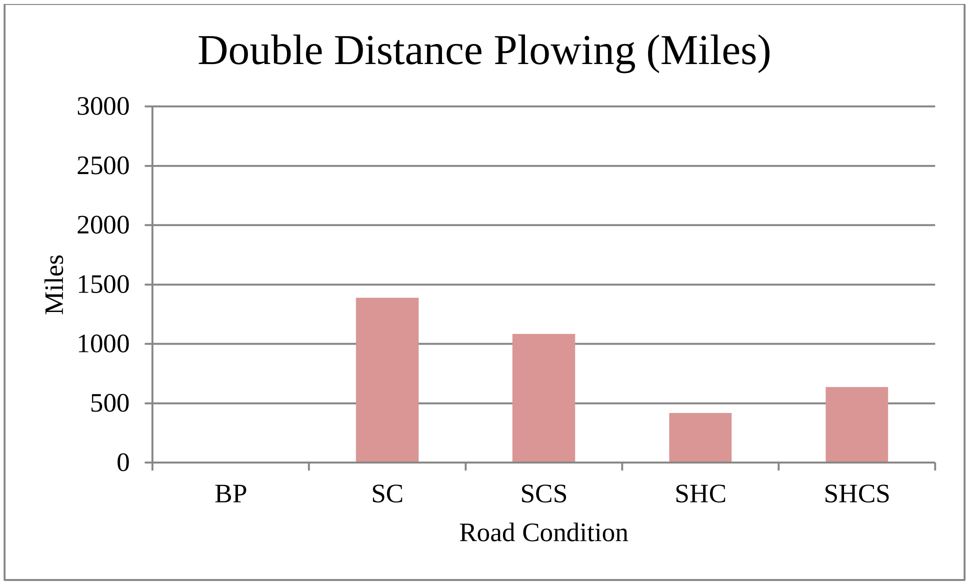

Medina Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Middle Guard
PolarFlex
Standard
XL Classic

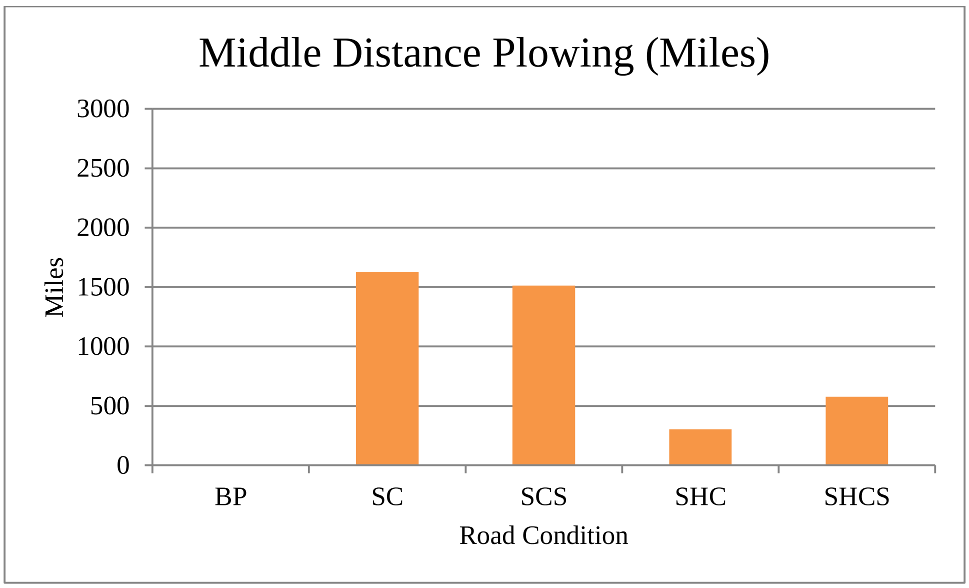

Summit Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
Single Carbide
Double Carbide
No Counterbalance
XL Classic

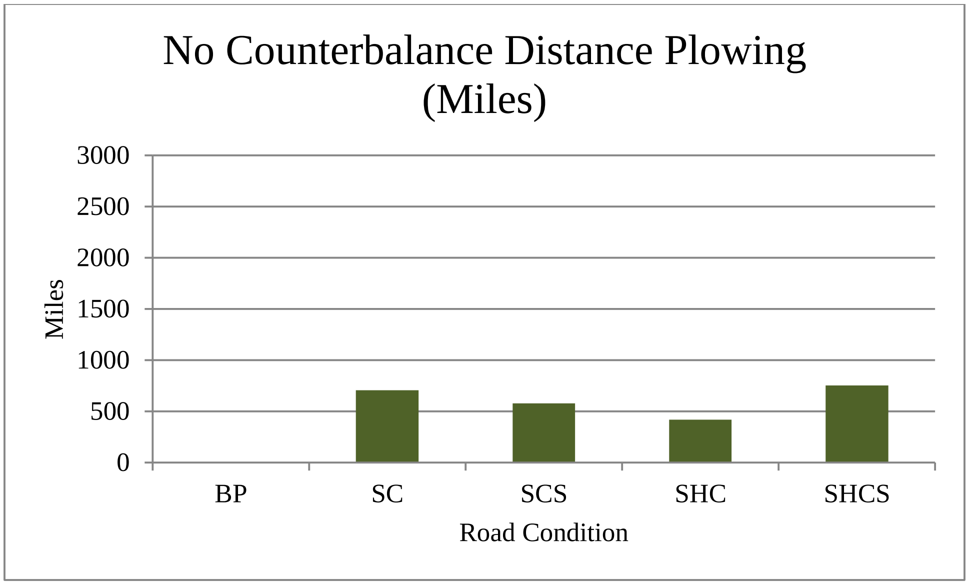

Washington Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
No Counterbalance
Double Stack
PolarFlex
Standard

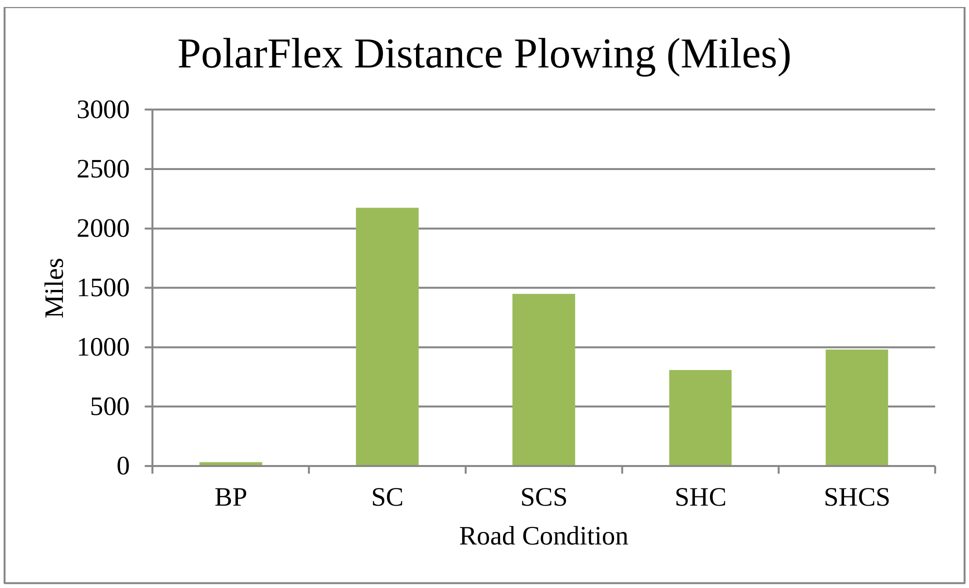

Distance Plowing (Miles)
Miles
12000
10000
8000
6000
4000
2000
0
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)
Road Condition

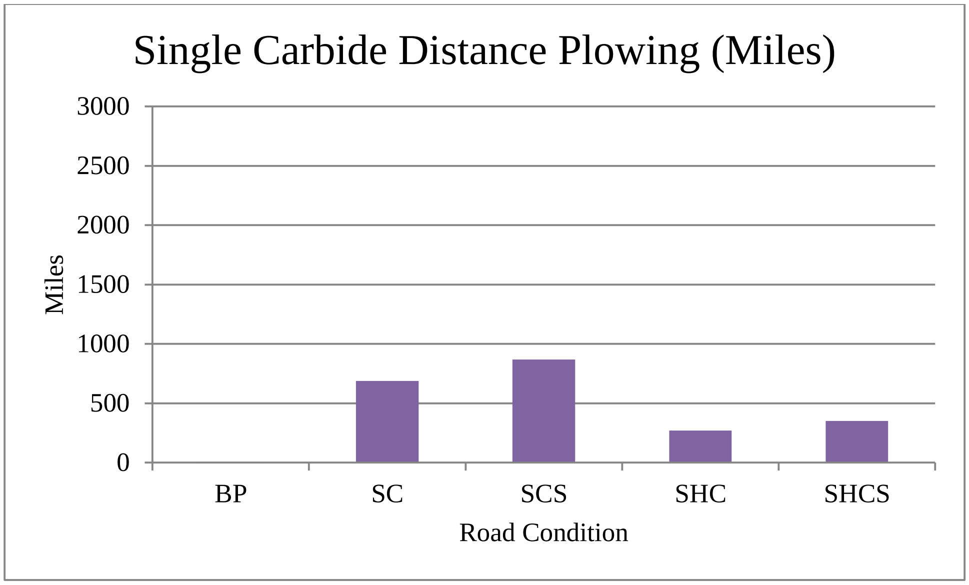

Double Carbide Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
BP
SC
SCS
SHC
SHCS
Road Condition

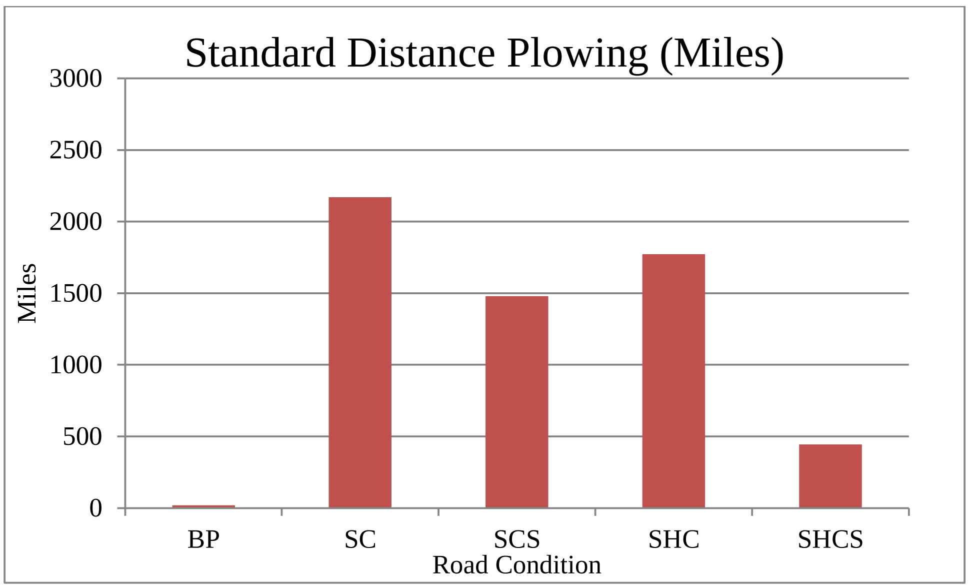

Double Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
BP
SC
SCS
SHC
SHCS
Road Condition

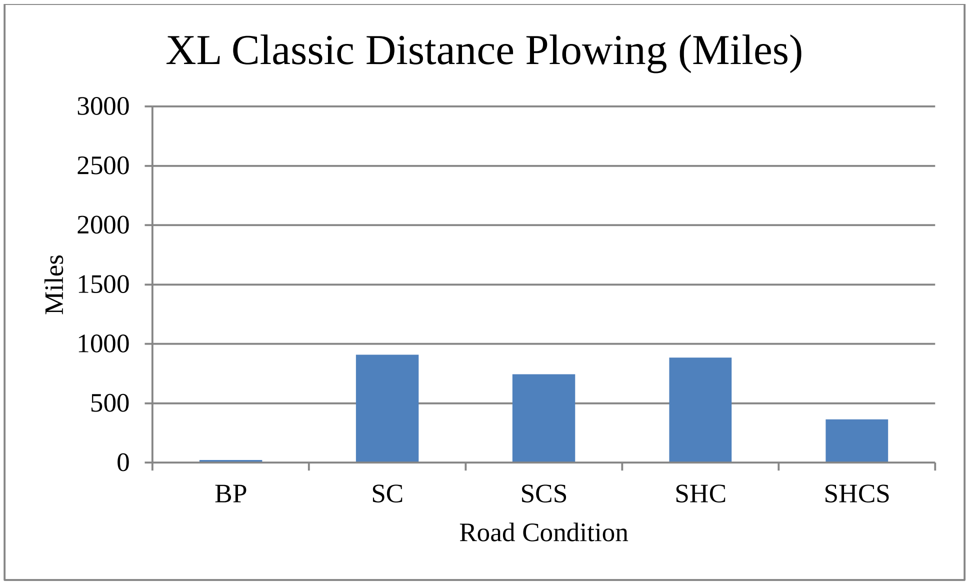

Middle Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
BP
SC
SCS
SHC
SHCS
Road Condition

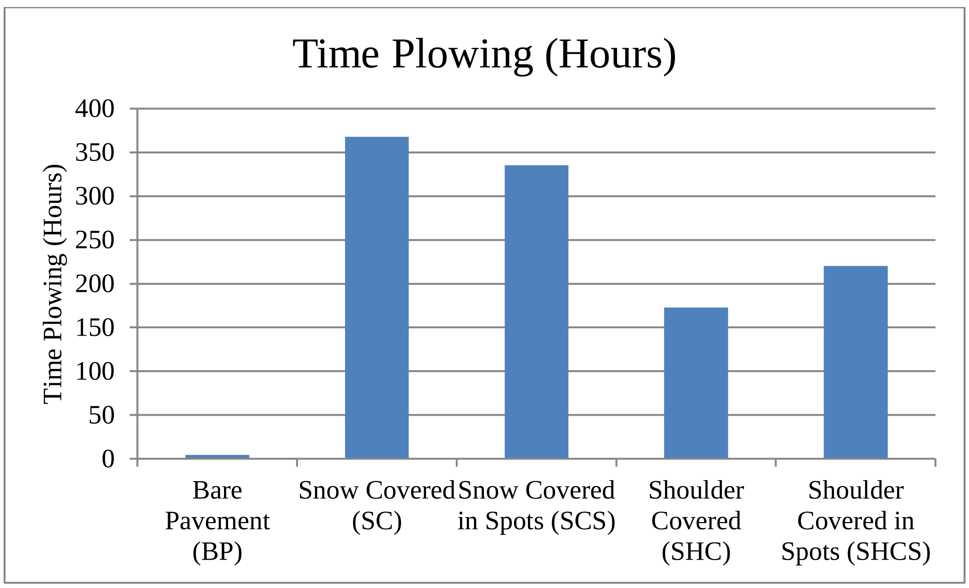

No Counterbalance Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
BP
SC
SCS
SHC
SHCS
Road Condition

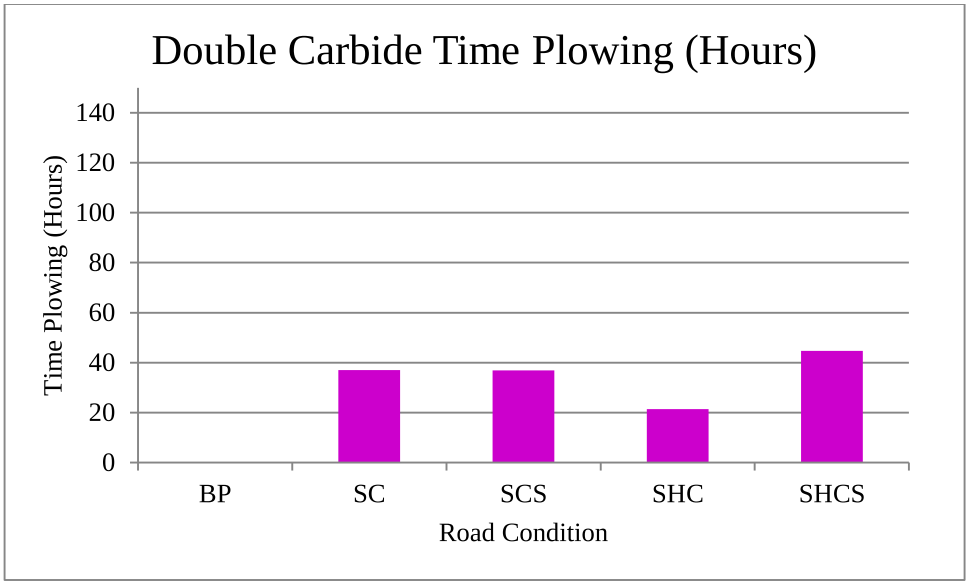

PolarFlex Distance Plowing (Miles)
Miles
3000
2500
2000
1500
1000
500
0
BP
SC
SCS
SHC
SHCS
Road Condition

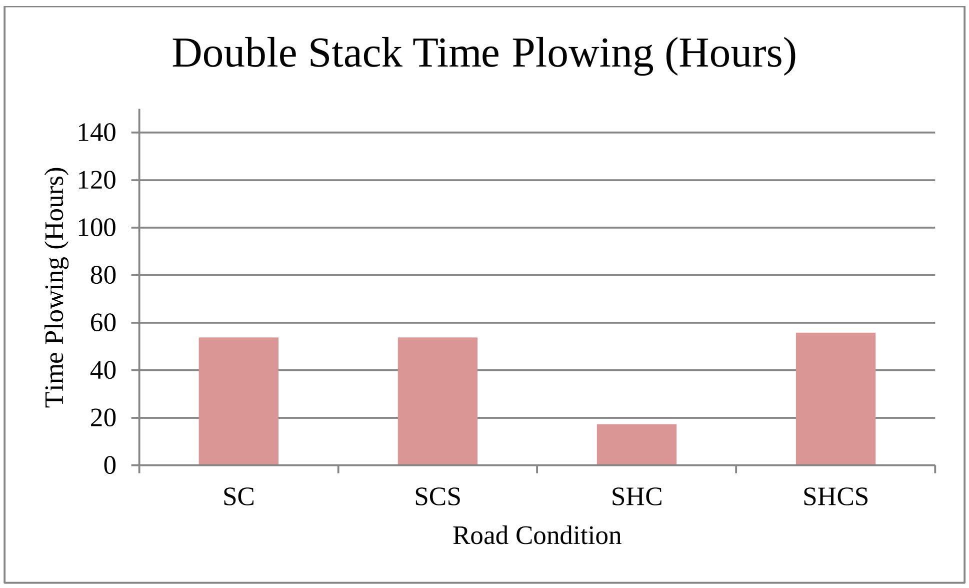

Single Carbide Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
BP
SC
SCS
SHC
SHCS
Road Condition

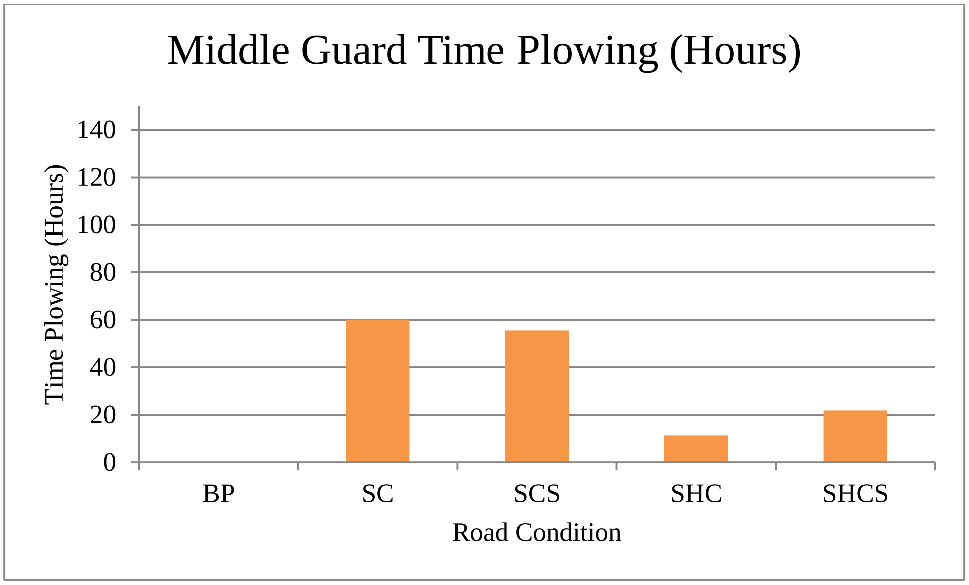

Standard Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
BP
SC
SCS
SHC
SHCS
Road Condition

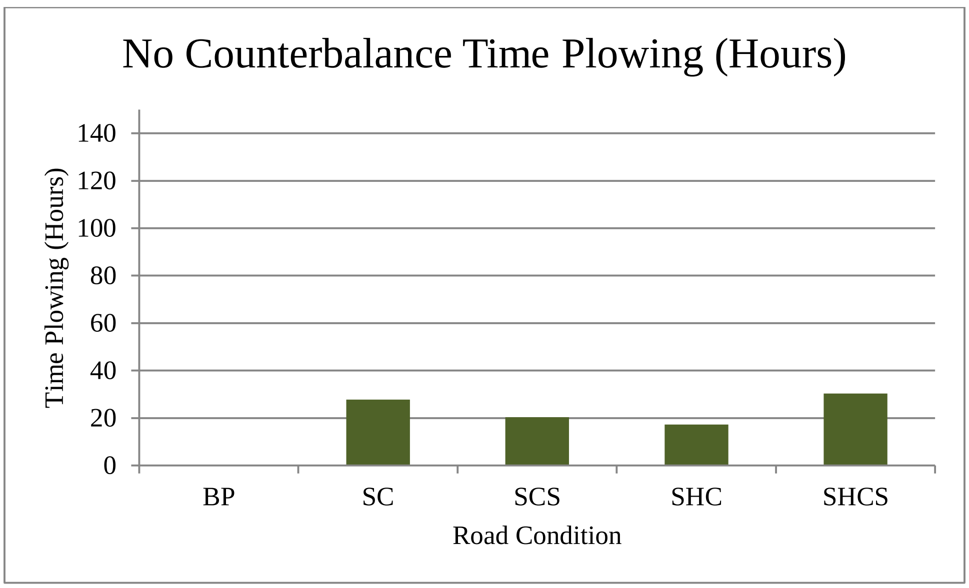

XL Classic Distance Plowing (Miles)
3000
2500
2000
1500
1000
500
0
Miles
BP
SC
SCS
SHC
SHCS
Road Condition

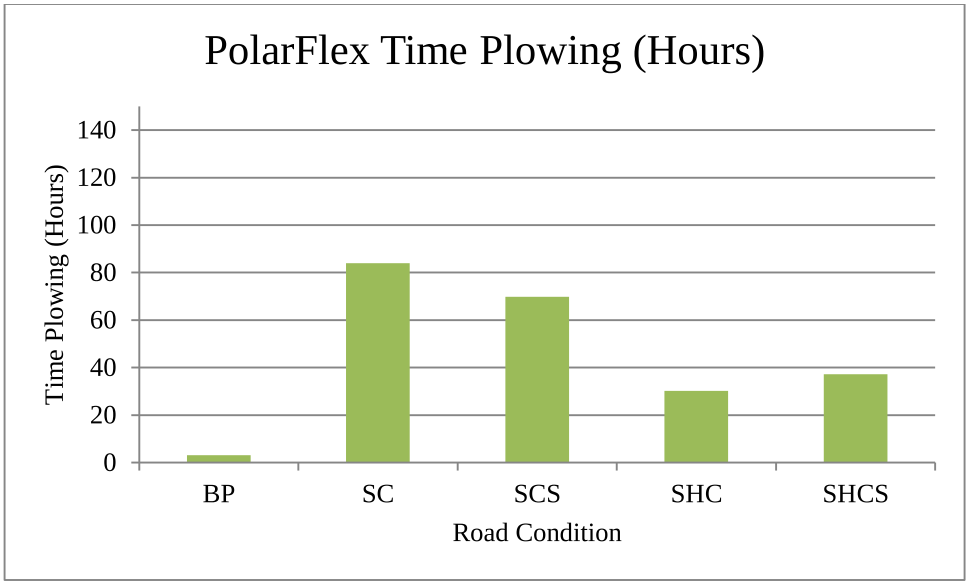

Time Plowing (Hours)
400
350
300
250
200
150
100
50
0
Time Plowing (Hours)
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)

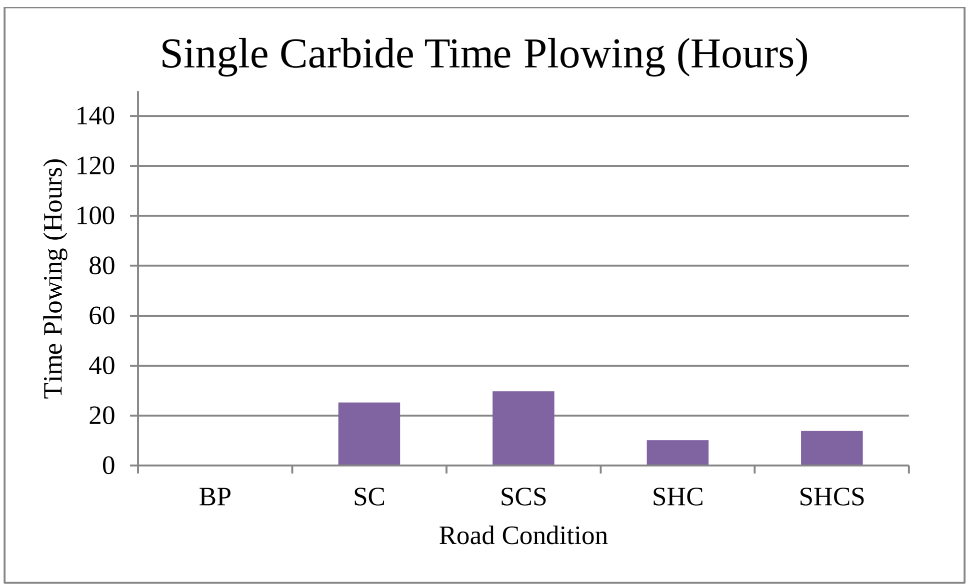

Double Carbide Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

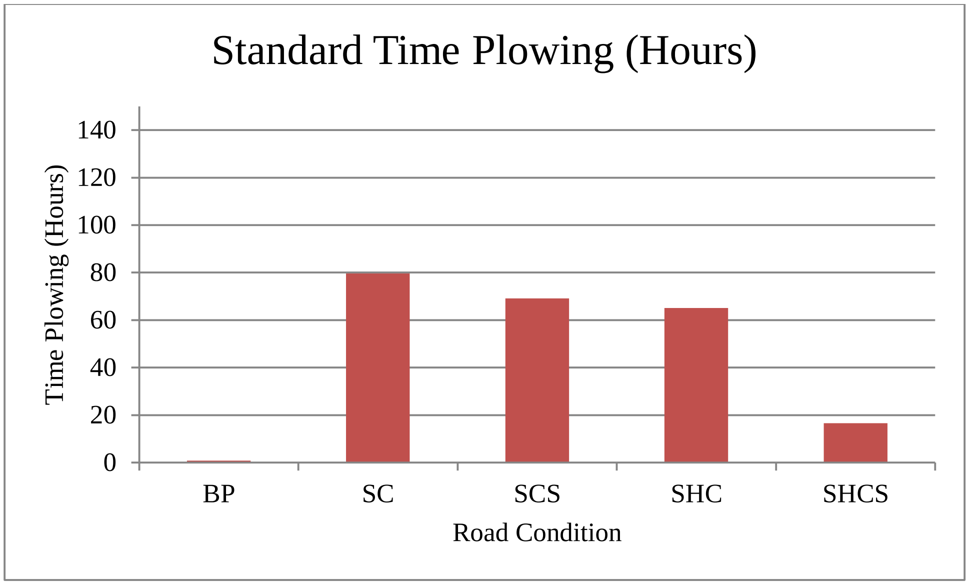

Double Stack Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
SC
SCS
SHC
SHCS
Road Condition

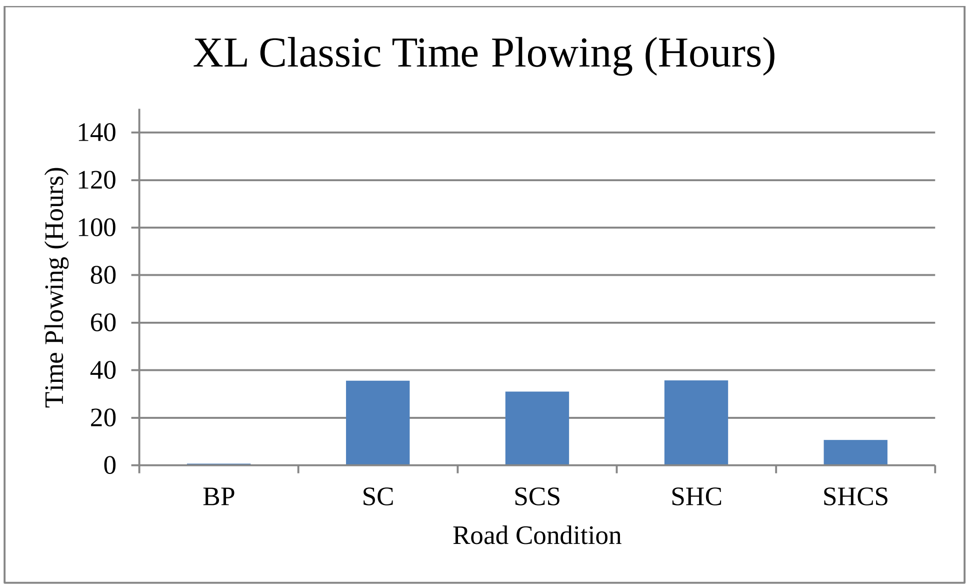

Middle Guard Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

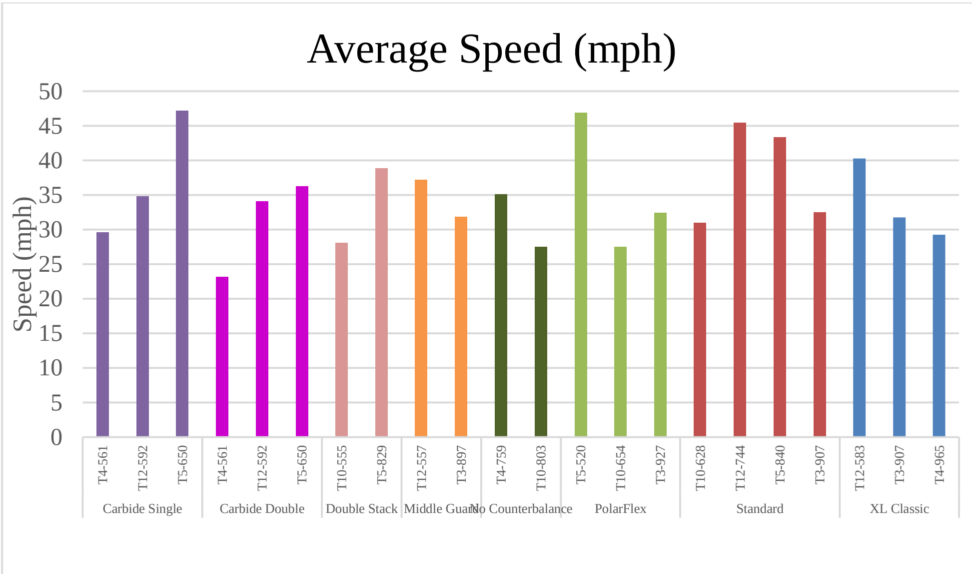

No Counterbalance Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

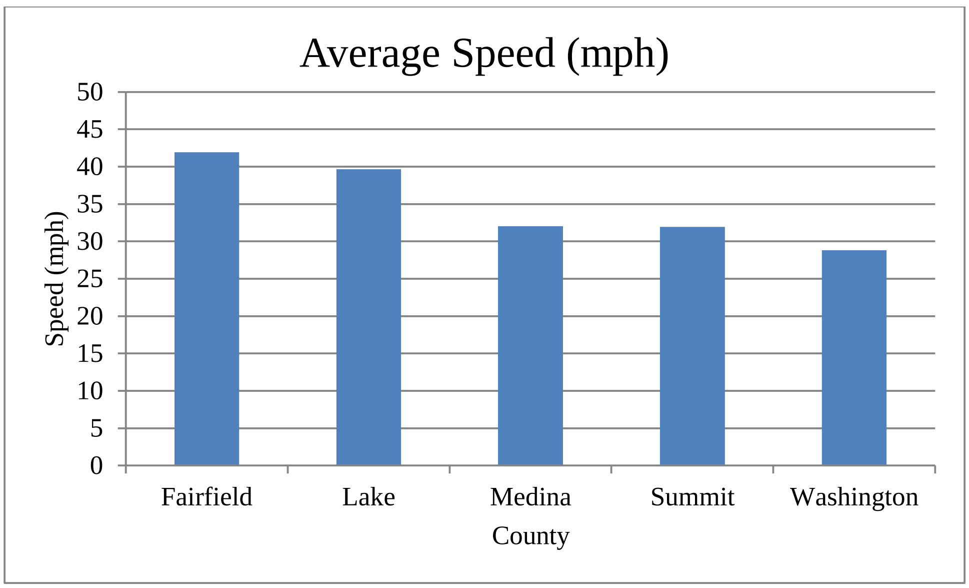

PolarFlex Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

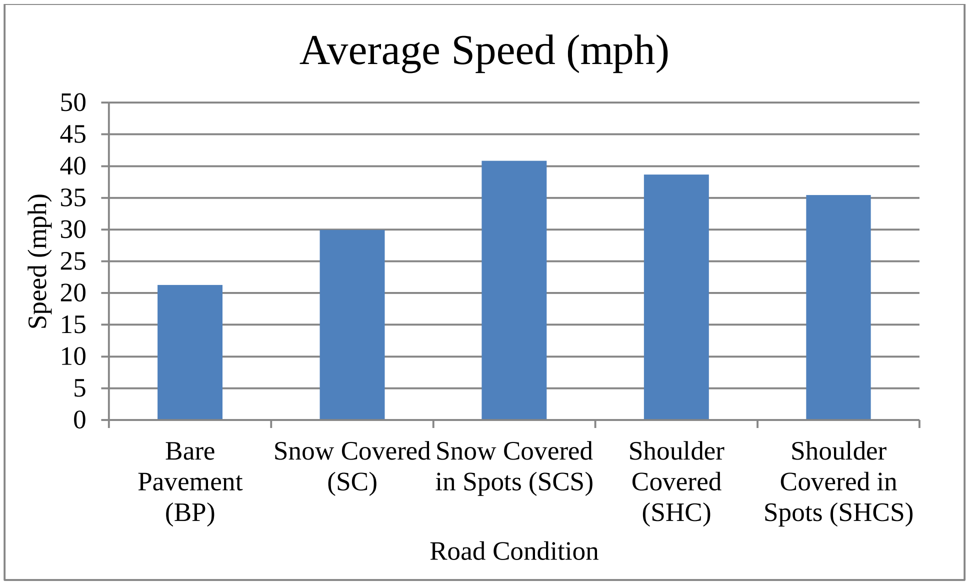

Single Carbide Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

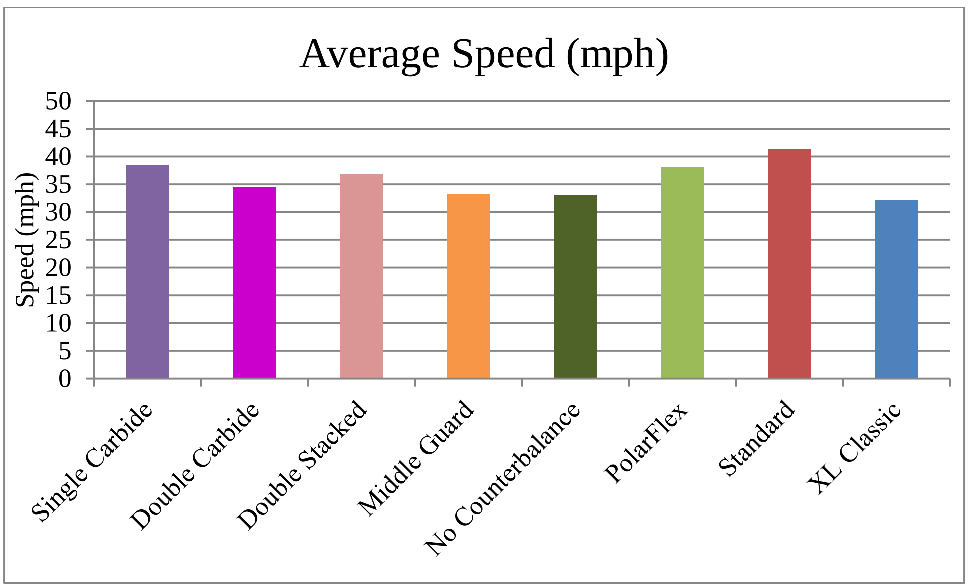

Standard Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

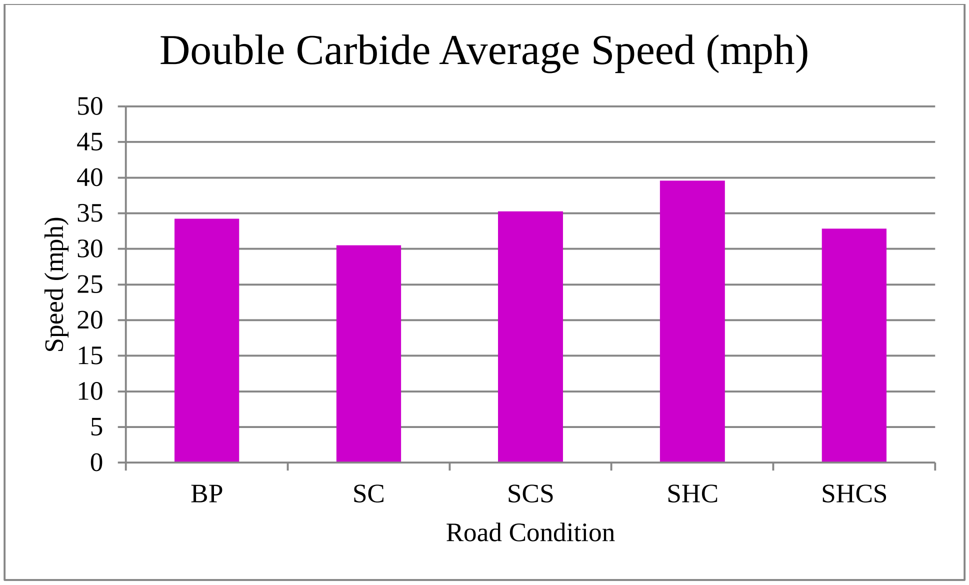

XL Classic Time Plowing (Hours)
Time Plowing (Hours)
140
120
100
80
60
40
20
0
BP
SC
SCS
SHC
SHCS
Road Condition

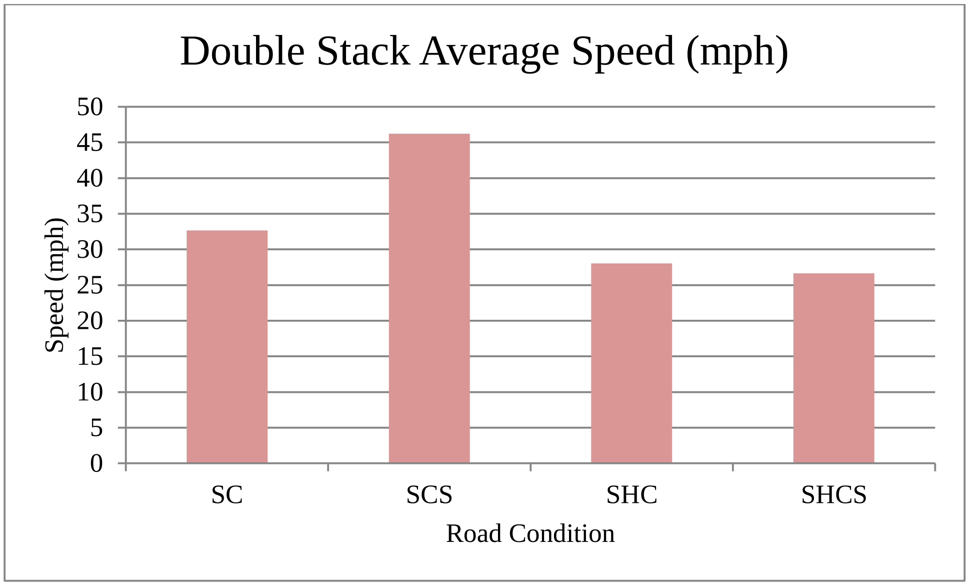

Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
T4-561
T12-592
T5-650
T4-561
T12-592
T5-650
T10-555
T5-829
T12-557
T3-897
T4-759
T10-803
T5-520
T10-654
T3-927
T10-628
T12-744
T5-840
T3-907
T12-583
T3-907
T4-965
Carbide Single
Carbide Double
Double Stack
Middle Guard
No Counterbalance
PolarFlex
Standard
XL Classic

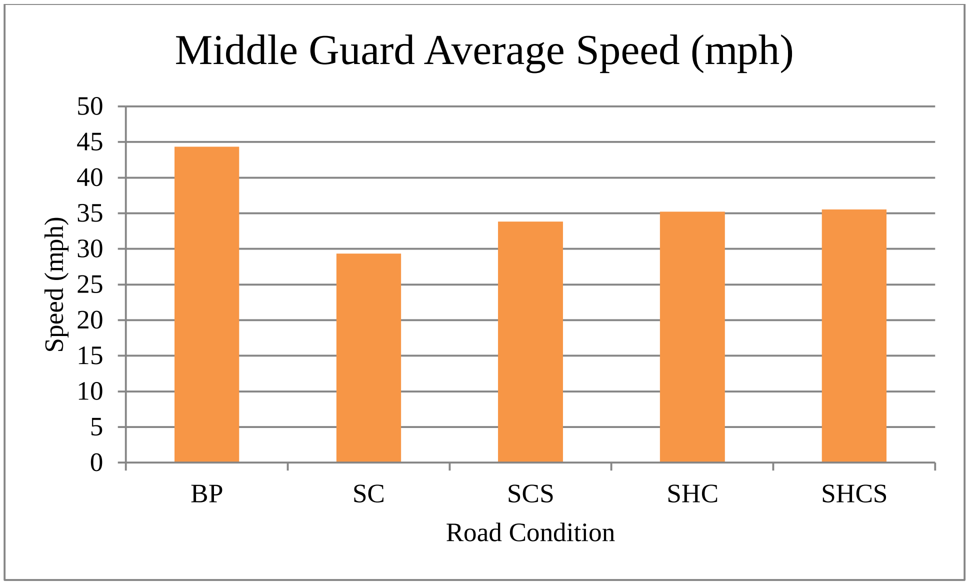

Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Fairfield
Lake
Medina
Summit
Washington
County

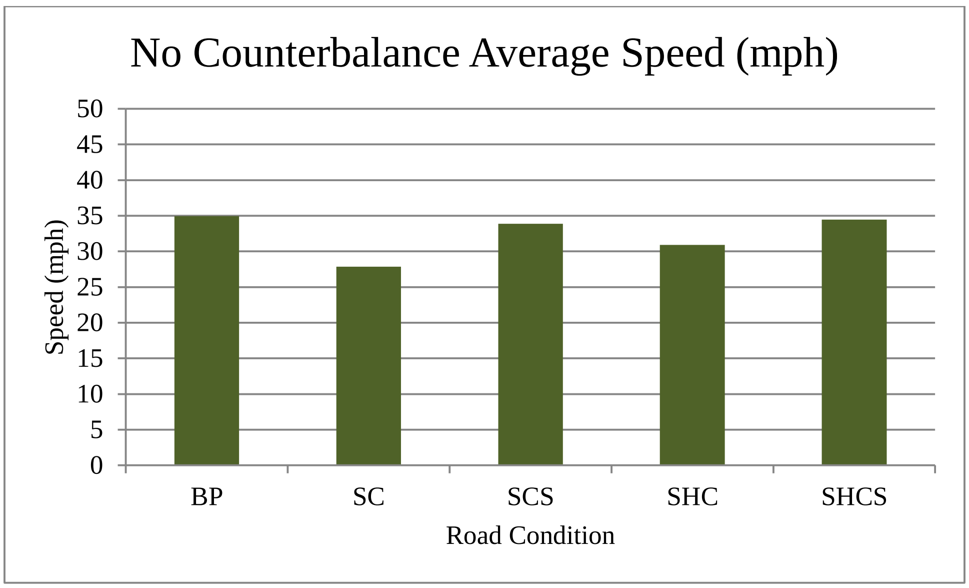

Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Bare Pavement (BP)
Snow Covered (SC)
Snow Covered in Spots (SCS)
Shoulder Covered (SHC)
Shoulder Covered in Spots (SHCS)
Road Condition

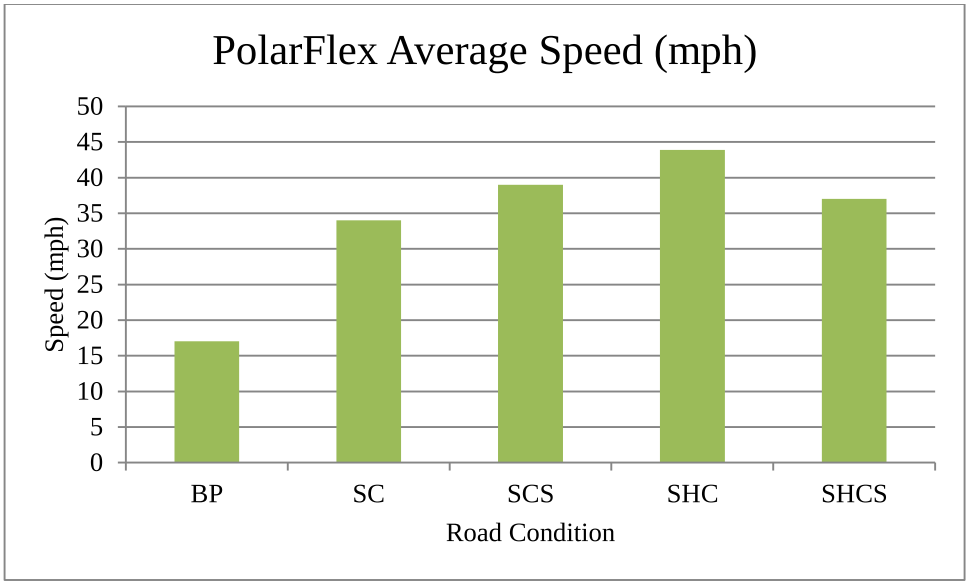

Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
Single Carbide
Double Carbide
Double Stacked
Middle Guard
No Counterbalance
PolarFlex
Standard
XL Classic

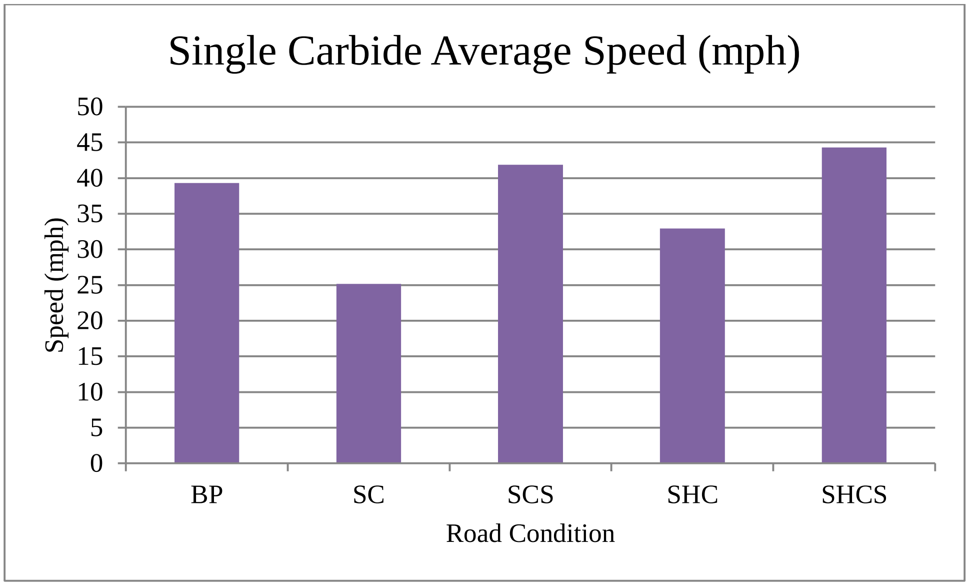

Double Carbide Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition

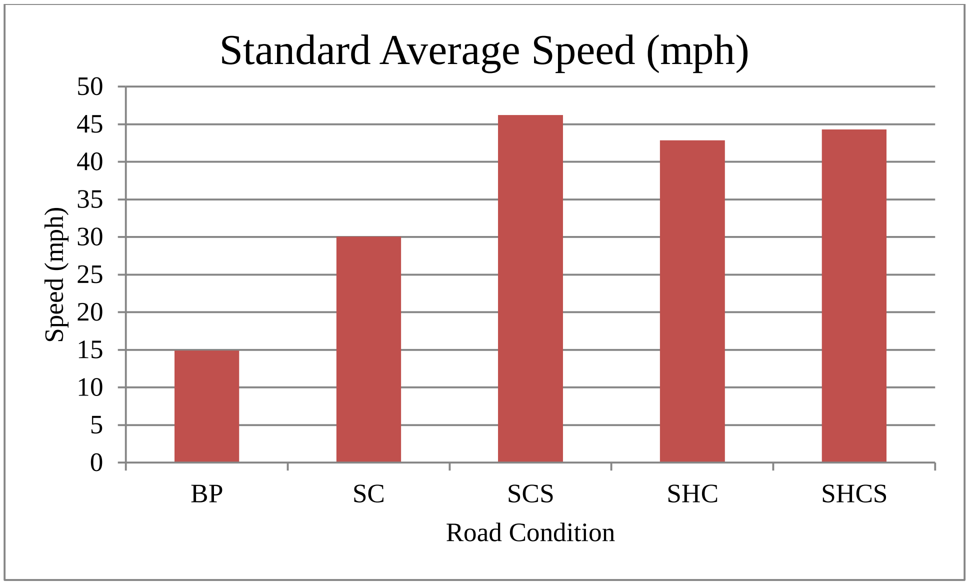

Double Stack Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
SC
SCS
SHC
SHCS
Road Condition

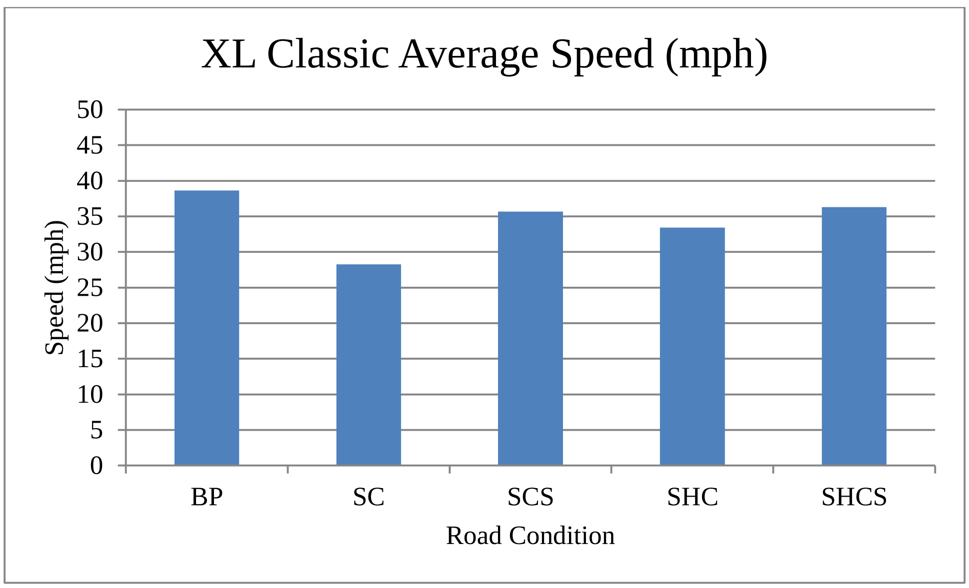

Middle Guard Average Speed (mph)
Speed (mph)
0
5
10
15
20
25
30
35
40
45
50
BP
SC
SCS
SHC
SHCS
Road Condition


No Counterbalance Average Speed (mph)
Speed (mph)
0
5
10
15
20
25
30
35
40
45
50
BP
SC
SCS
SHC
SHCS
Road Condition


PolarFlex Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition


Single Carbide Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition


Standard Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition


XL Classic Average Speed (mph)
Speed (mph)
50
45
40
35
30
25
20
15
10
5
0
BP
SC
SCS
SHC
SHCS
Road Condition