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PERFORMANCE EVALUATION OF SNOW AND ICE PLOWS

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16. Abstract
Removal of ice and snow from road surfaces is a critical task in the northern tier of the United States, including Illinois. Highways with high levels of traffic are expected to be cleared of snow and ice quickly after each snow storm. This is necessary for maintaining the safety of the public and the efficiency of the highway system. In 2011, the Illinois Department of Transportation (IDOT) initiated a research project to conduct a comprehensive study to evaluate the performance of snow and ice plows. The project targeted several plow performance indicators including blade type, scraping forces, and shock acceleration, among other suggested parameters.

The project involved a literature review, a synthesis of best practices in snow and ice plowing operations, development of a plow and blade performance evaluation procedure, instrumentation of a snow plow and the carrying out of field tests, development of finite element models to synthesize a comprehensive performance database, and documentation of project results.

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EXECUTIVE SUMMARY

The removal of ice and snow from pavement surfaces is a critical operation that affects the safety of the traveling public and the timely delivery of goods and services. In fact, major federal and state highways are expected to remain clear of snow and ice during a storm because those storms have a significant safety and economic impacts Secondary roads are also in need to be cleared in a timely manner to prevent excessive accumulations. Federal, state, and local agencies that are involved in snow and ice removal use a variety of tools, techniques, and materials to achieve their own objectives and guidelines to ensure that their operations are safe, efficient, environmentally responsible, and cost effective. This project was proposed by the Illinois Department of Transportation (IDOT) to better understand the behavior of snow and ice plows, shed some light on the effectiveness of common types of blades, and produce a synthesis of best practices in snow and ice control practices.

The objectives of this Illinois Department of Transportation–funded project were to be achieved by performing the following tasks:

TASK 1. LITERATURE REVIEW AND SYNTHESIS OF BEST PRACTICES

This task included the following activities:

1. Literature review of prior performance evaluations of snow plows. The research team conducted a comprehensive literature search to review and report on methods for evaluating snow and ice plow performance.
2. Literature review of best practices in snow and ice plowing. The research team conducted interviews with agency personnel, DOT engineers, and consultants actively involved in snow and ice plowing. The interviews focused on collecting information related to best practices and standards for: plow selection, blade selection, and installation and maintenance practices. In addition to this, the research team visited with plow and blade manufacturers.
3. Synthesis of Best Practices. The research team summarized the best practices in a well-organized report based on a classification system and criteria that were developed during the survey phase.

TASK 2. DEVELOP A PERFORMANCE EVALUATION PROCEDURE

This task included the following activities:

1. The research team identified controlling parameters for snow and ice plow performance measures based on the literature review and the interviews in Task 1. These parameters included ambient temperature, plowing speed, the stresses at a number of locations on the front plow and carrying structure and the underbody scraper, the positions of the plows, and the use of the blade-saver option.
2. An instrumentation plan was developed to measure plow stresses and collect other pertinent information about the plowing process. The installed instruments included 22 strain gauges (16 on the front plow and carrying structure and 6 on the underbody scraper), two accelerometers on the underbody scraper, and a GPS capable video camera focused on the front plow and road ahead to capture the plowing event including location and truck speed. The instrumentation was designed to be as simple as possible to operate and the field testing plan included the full participation of a graduate research assistant who would ride the plow truck and

manage the data collection activity. The equipment was tested before it was cleared for field measurements in dry runs that were performed to make sure the instrumentation was correctly calibrated and that it was able to handle extreme conditions.

3. The research team performed a number of dry and data collection runs during two snow seasons. During these operations a massive amount of data was collected representing many possible variations in snow and ice plowing parameters.

TASK 3. PERFORM FIELD TESTS

This task was the most important part of the project as the performance evaluation procedure of snow plowing activities was mainly based on data collected during this phase. The research team secured the use of a plow and truck from the Morton, IL, IDOT yard fleet. Initial dry runs and all of the eleven 2012 to 2014 field tests were conducted using a steel blade with trapezoidal carbide inserts. Additional dry runs were conducted at the end of the study and outside of the snow season to investigate the effect of using different types of blades: a PolarFlex blade with trapezoidal carbide inserts and a steel blade with dowel-type carbide insets. The findings from these tests are described in the appropriate sections in this report

TASK 4. DEVELOP FINITE ELEMENT MODELS TO SYNTHESIZE A COMPREHENSIVE PERFORMANCE DATABASE

The research team developed a finite element model of an Alaska front plow and the underbody scraper. The models were used to simulate the behavior of the plows under a variety of predefined loads. Plow stresses obtained from the field tests were then used to calibrate the model. The analyses and ensuing calibrations provide for a method of analyzing and simulating the behavior of complicated systems under uncertain loading conditions.

TASK 5. DOCUMENTATION AND DISSEMINATION OF RESULTS

This report includes a literature review, the results of the best practices in snow and ice plowing interviews, results from the field testing, and a description of the plow finite element modeling effort, including an analysis of the results. The research team also disseminated some of the findings of this research project by making presentations at four conference, contributing with one poster presentation at a TRB annual meeting, and publishing a paper in the proceedings of one of the attended conferences.

PROJECT ACHIEVEMENTS

In this project, the research team achieved the following:

1. Existing information in literature pertaining to best practices in snow and ice control was collected and presented.
2. A survey of best practices in snow and ice control was developed and administered to a number of snow and ice control professionals from around the country. The interviews generated a number of recommendations with respect to effective snow and ice control.
3. A plow instrumentation plan and a data collection strategy were developed and implemented. The instrumentation plan included the use of strain gauges and GPS enabled video cameras to allow for capturing the snow and ice plowing activities in their totalities. The data collection took place during actual snow storms from different weather conditions and patterns allowing for an adequate variability in considered parameters

4. The data collection effort included the use of a video camera to capture the interaction between the plow and the pavement during a dry run.
5. The research team developed a finite element model of an Alaska front plow and an underbody scraper. The models were used to simulate plow behavior and estimate the loads acting on it by matching measured-to-computed stresses.

CONTENTS

FIGURES

TABLES

CHAPTER 1 PROJECT INTRODUCTION

Removal of ice and snow from road surfaces is a critical task in the northern tier states of the United States, including Illinois. Highways with high levels of traffic are expected to be cleared of snow and ice quickly after each snow storm for maintaining the efficiency of the highway system and for safety issues. Studies have shown that accident occurrence and severity both increase with the start of a snow storm. Proper removal of ice and snow can improve road safety by maintaining higher friction levels of the pavement surface.

To improve plowing operations and make them more efficient (perform at higher level), it is necessary to develop a method to measure such efficiency. It is desired that such method be easy to use, reliable, and provide repeatable results. Several performance measures exist in the literature—some purely theoretical and some in use. Also, even within the same agencies, some measures are monitored continuously (friction), some are per storm, and some are per season. Other intervals may include week by week or month by month.

Research by the Iowa Department of Transportation showed that plowing load can be used as a measure of ice plow performance. Those studies showed that the horizontal scraping forces are directly related to the amount of ice scrapped; however, that is not the case for snow plowing. The most common performance measures for winter maintenance during and after a storm, among many others, are the following:

- Bare pavement regain time
- Friction (skid resistance)
- Reduction of crashes
- Duration and frequency of closures
- Customer satisfaction
- Visual precipitation of roadway surface

To establish uniform performance measures, information related to the weather and the pavement surface at the time of plowing operation should be collected. This information should include snow depth, temperature, surface condition (ice/no ice), and snow moisture content. Snow moisture content can be measured by evaluating the “water equivalent of the snow.” In concept, the water equivalent of snow is determined by measuring the depth of the new snow; the new snow is then melted and the resulting water amount is measured.

The main objective of this study was to develop an evaluation procedure for snow and ice plow performance through field testing and finite element modeling techniques. To attain this objective, the research team conducted a comprehensive review of literature to develop a synthesis of best practices in snow and ice plowing and then developed a plow performance evaluation procedure, the main component of which is a plow instrumentation and field data collection strategy. Subsequently, an Illinois Department of Transportation (IDOT) snow and ice removal truck was instrumented to measure stresses at a number of locations on the front and underbody plows and the front plow carrying structure. Data were collected from snow and ice storms that occurred in the Peoria, Illinois, area between November 2011 and February 2014. The research team also developed a finite element model of the plows and carried out interviews with snow and ice removal professionals from around the country to identify best practices in snow and ice control.

This report describes the approach that was used by the research team to achieve project objectives and presents the findings of the research. The report is organized into six chapters, including this introduction. The second chapter presents a comprehensive review of literature of snow and ice plow studies, and it is followed by a survey and synthesis of best practices in snow and ice removal and control. The fourth and fifth chapters describe the field testing effort and the finite element modeling of the plows, respectively. The last chapter contains the conclusions and recommendations from the project.

The phenomenal amount of experimental data that were collected during the last few months of this project provided the team with valuable information that can be used to better understand plow behavior. However, the short time between the most recent snow storms and the time this report was prepared made it difficult to consider the data and incorporate them in the analyses. The research team will continue working with the collected data for the remainder of the project and will publish any possible new findings in appropriate venues.

CHAPTER 2 REVIEW OF LITERATURE

Snow and ice control is a difficult task that is performed in a harsh environment. Moreover, the sheer number of parameters that can affect equipment performance during a snow and ice control operation makes it difficult to establish a viable plan that will capture the effect of all possible parameters. A wealth of information exists dealing with the various aspects of snow and ice control, including a few studies to investigate plow and blade performance and evaluate plowing techniques, but much work remains to be done. This chapter provides a synopsis of the literature dealing with the various methods and techniques used to keep the nation's roads relatively safe during the winter months.

2.1 PRE-TREATMENT TECHNIQUES

Pre-treatment is a vital technique used to maintain roads and to make the plowing process easier for department of transportation (DOT) drivers. Pre-treatment involves many different techniques, but the most crucial are anti-icing and adding abrasives to the roadways. Not only are the techniques important but how often to apply the treatments is imperative to increase effectiveness and decrease cost. This section discusses the use of anti-icing chemicals and abrasives on roadways.

2.1.1 Anti-Icing

Anti-icing is a technique that has been used throughout the United States, but not every DOT has implemented it into their winter operations. As defined by the Federal Highway Association (FHWA), anti-icing is the technique used to prevent the formation or development of bonded snow and ice by applying chemical freeze-point depressants in a timely manner (Ketcham and Minsk 1996). To put it simply, anti-icing chemicals restrict bonds that form between the compacted snow and pavement to make plowing more effective. This technique is important because using it allows state DOTs to reduce materials and labor costs with respect to deicing chemicals (which are applied after a snow has been compacted on the roadways) and plowing. Boselly (2001) found that without the use of anti-icing chemicals, it takes five times the amount of energy to plow through snow and ice after the snow–pavement bond forms. Accordingly, DOTs have made an effort to incorporate anti-icing into their snow and ice control operations (Cuelho et al. 2010).

Like many snow and ice control techniques, anti-icing chemicals are applied based on climatic conditions. Generally, anti-icing chemicals can be applied any time before a snow event, but pavement conditions must allow for the anti-icing chemicals to be effective. As Blackburn et al. (2004) stated, anti-icing chemicals should applied before a snow event and when pavement surface temperatures are above 20°F. This is because temperatures below 20°F (or any temperature below the freezing point) will freeze the chemicals and can adversely affect the roadways by creating a thin layer of ice.

Another parameter that must be taken into account is the level of humidity and the dew point temperature. With a high level of humidity and a low dew point temperature, there is a high potential for black ice to form on the road surface (Ketcham and Minsk 1996). Black ice is created in these conditions because the moisture in the air condenses on the pavement surfaces and freezes.

Blackburn et al. (2004) explained the application of anti-icing chemicals in six steps:

1. Determine the pavement temperature trend before and after the time of treatment. "Nowcasting" is used to determine the pavement temperature. Nowcasting is the use of real-time data collected for a very short period of time.
2. Establish the dilution potential of a chemical treatment. This step is to establish how long the chemical treatment must endure before another treatment is applied to the roadway surface and

the results that will obtained from said treatment. Dilution potential for short-term applications during precipitation can be found in Table A-1 in Appendix A of this report. If precipitation is absent, refer to the dilution potentials Table A-2.

3. Adjust the chemical treatment dilution potential according to various wheel path area conditions. These adjustments can be found in Table A-3.
4. Additional adjustments to the dilution potential may be necessary in accordance with the cycle time of the treatment. This refers to the time between successive applications of the chemical treatment. These adjustments can be found in Table A-4.
5. Make additional adjustments to the dilution potential related to traffic speeds and volumes. An adjustment must be made for speeds greater than 35 mph and traffic volumes greater than 125 vehicles per hour. These adjustments can also be found in Table A-4. No adjustments are necessary for traffic speeds less than 35 mph. A level adjustment of 1 would increase a low level to a medium dilution potential level and a medium level to a high level, whereas an adjustment of 2 would increase a low level to a high level. The final level cannot exceed "high"
6. Make a judgment about whether an ice–pavement bond exists. This is made by observations or data collected by sensors.

The information found in Tables A-1 through A-5 was developed for five anti-icing chemicals: sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), and calcium magnesium acetate (CMA). The application rates for these chemicals can be found in Table A-6. *Note: all the chemicals are normalized to 100 lb/LM (pounds per lane mileage) of dry, solid NaCl.*

Studies have shown that anti-icing reduces costs by a significant amount. In a case study performed on U.S. Highway 12 in Idaho, average labor hours, abrasives used, and accidents were reduced by 62%, 83%, and 83%, respectively, after anti-icing treatment was implemented in 1997 (Breen 2001). Costs were also reduced on average by 10% to 20%, and cost per lane was reduced by 50% (Nixon 2002). These decreased costs are reflected in the reduction of materials, labor hours, and indirect costs such as roadway accidents and corrosion to vehicles and transportation infrastructure (Cuelho et al. 2010).

2.1.2 Abrasives

The main purpose of abrasives is to increase traction on compacted snow. Abrasives consisting of sand or crushed rock are generally necessary when an increase in friction is required at temperatures so low that chemicals take an extended period of time to become effective, and in conditions where snow or ice cannot be easily removed because of strong bonding to the roadway surface (Ketcham and Minsk 1996). These temperatures are in reference to roadway surface temperatures below –10°C (14°F).

The use of abrasives must be strategically implemented because of their limited effective time. Because of traffic flow, abrasives generally do not last very long on the road. As stated by Vaa (2006) and Norem (2009), the improved friction created by abrasives will last for only approximately 50 cars on roads with traffic speeds of 80 km/h (50 mph) and a high percentage of trucks. A way to counter the adverse effects of traffic on the effective time of abrasives is to wet the sand with warm water. This is called the warm-wetted sand method. This method is effective only when road surfaces are below the freezing point, which allows the sand to freeze to the compacted snow (Norem 2009). Use of the warm-wetted sand method causes the abrasives to adhere to the road surface better than if the sand had not been pre-wetted.

Engen (2006) conducted a study to investigate the feasibility of reducing the amount of sand necessary and still obtain the desired friction coefficient. He found that the amount of sand can be reduced from 200 g/m^2 (0.04 lb/ft^2) to 100 g/m^2 (0.02 lb/ft^2). Though a reduced amount of sand can achieve the desired friction coefficient, Engen showed that the sand lost its effectiveness during a snow event.

Weather conditions also greatly impact the effectiveness of abrasives. Figure 1 (Norem 2009) illustrates the appropriate weather conditions for applying abrasives to road surfaces.

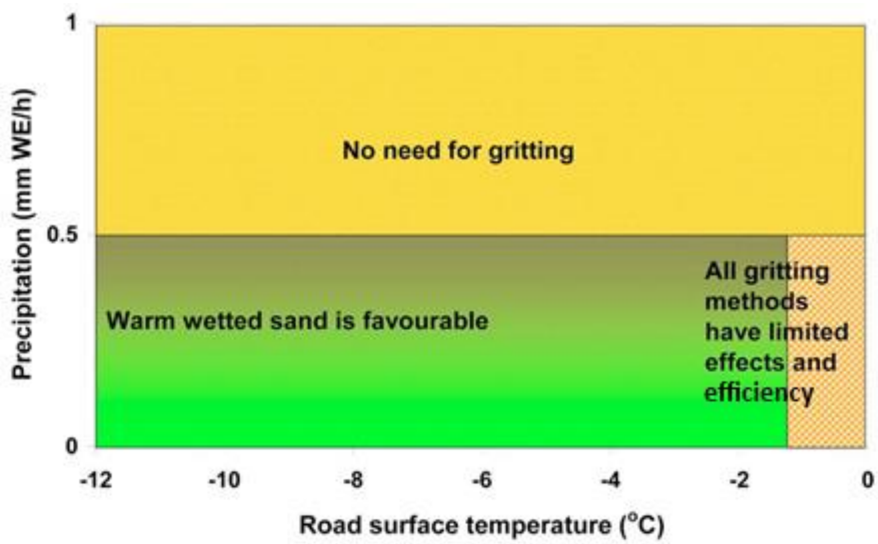


Figure 1. Weather situations where warm-wetted sand is efficient or has limited efficiency (Norem 2009).

This figure shows that warm-wetted sand is effective from 0 to 0.05 mm WE/h (mm of water equivalent per hour) or 0 to 0.002 in. WE/h and –12°C (10°F) to –2°C (28°F). The warm-wetted sand method is the most effective method for temperatures below –8°C (18°F) and is discussed further in Section 2.2.2.

2.2 ROADWAY MAINTENANCE TECHNIQUES

Roadway maintenance is the heart of snow and ice control operations. Current procedures for snow and ice control work, but the goal is to achieve the most effective, environmentally friendly, and inexpensive results. This chapter discusses plowing, deicing, and pre-wetting techniques that make operations run at their highest potential.

Information that must be known is the difference between classic blades and serrated blades, as well as the cutting angle and attack angle. Classic blades are cutting blades that are consistently flat at the blade surface, whereas serrated blades are evenly separated at equivalent widths (Figure 2).

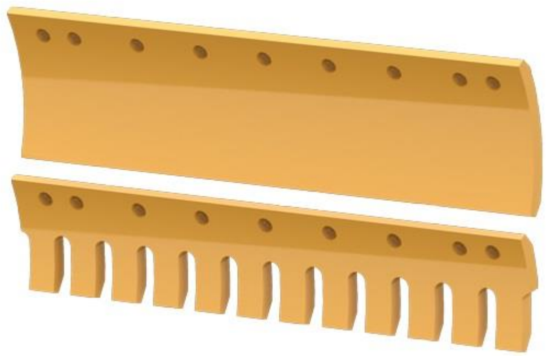


Figure 2. Difference between classic blades and serrated blades.

The difference between the attack angle and cutting angle is the direction from which the angle is being measured. The attack angle is the rotation about the vertical axis, and the cutting angle is the rotation about the horizontal axis (Figure 3).

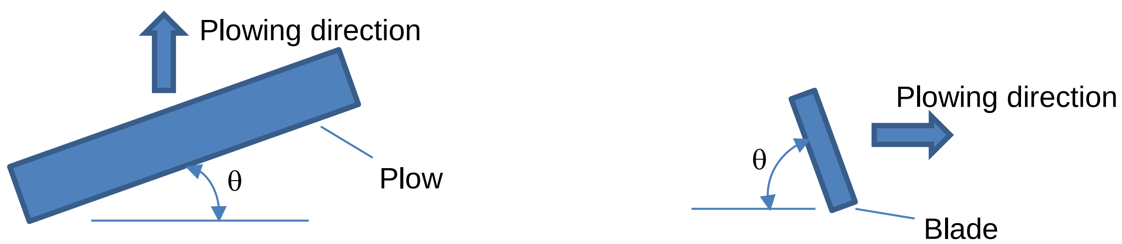


Figure 3. Attack angle (left) and cutting angle (right).

2.2.1 Plowing

Plowing is generally accepted as the most effective technique for snow and ice control. A few studies have been conducted on plowing techniques, but much work remains to be done to better understand the full effects of the harsh environment on the equipment, including blade, plow, and truck.

Nixon (1993); Nixon, Gawronski, and Whelan (1996); Nixon and Potter (1997); and Nixon, Wei, and Whelan (1997), in conjunction with the Iowa Department of Transportation and the Iowa Institute of Hydraulic Research, have worked to make ice scraping on underbody blades and front-mounted plow blades more effective. Front-mounted plows are not the most ideal for ice removal because they cannot be forced down, and they rely on the weight of the plow for its download force (Nixon, Wei, and Whelan 1997). Once snow has been compacted enough, it acts as though it were ice because bonds between the compacted snow and the roadway surface are created.

Nixon and Potter (1997) conducted further research on the use of various types of blades. In their research, they found that the use of serrated blades increases the amount of stress the cutting edge can apply to the ice sheet. The larger stresses result in more ice being scraped from the roadway but also increase the amount of wear on the blade. Nixon and Potter (1997) estimated that the serrated blades had a superior performance in the field because they increased scraping effectiveness by 25% to 67%.

Hansen (1990) conducted a study on the analysis of energy dissipation caused by snow compaction during plowing operations. He found that as a plow displaces snow, a compression wave is created in front of the plow that dissipates energy as the plow continues to move forward. As the plow pushes snow forward, energy is dissipated as the result of compaction of the snow. This creates a "plastic" (non-linear) wave running in front of the plow, which is defined as the compression wave (Hansen 1990).

Hansen used partial differential equations and a constant value for the volumetric rate of deformation to approximate the total energy that dissipates as a result of a compression wave. In his analysis, Hansen assumed values for the plow velocity, plow cutting angle, and initial snow density. His modified model was used to determine a curve with pressure and density as its parameters. Hansen then used a volumetric constitutive law to generate a curve between pressure and density and superimposed it with his modified model. This can be seen in Figure B-1 in Appendix B. Hansen stated that there are conditions where these two curves do not intersect. This occurs when "the initial pressure predicted by the constitutive low is greater than that of the sheet model" (Hansen 1990). Because of this, the critical pressure required to cause compression is never achieved, and the snow acts like a sheet during the displacement process (Hansen 1990).

Hansen's results indicate that energy loss increases as plow speeds increase. It was found that at speeds below 9 m/sec (20 mph), energy dissipation is negligible, but it is significant at higher speeds (Hansen 1990). Three blade cutting angles were tested in Hansen's research (90, 70 and 50 degrees), and it was found that if the cutting angle was set back to 50 degrees, the least amount of energy would dissipate from the plow. This can be seen in Figure 4, which is a result of findings from Figures B-2, B-3, B-4, and B-5 at a snow density of 80 kg/m^3.

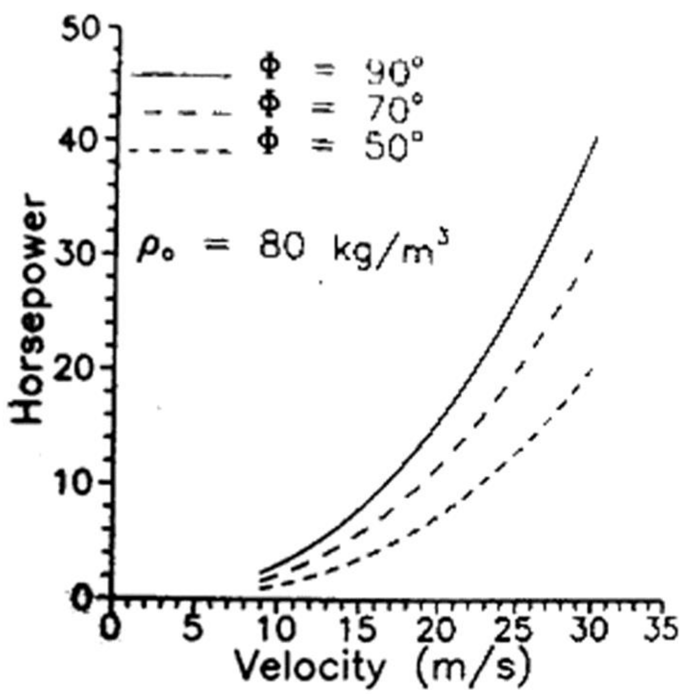


Figure 4. Parametric plot of horsepower consumed by compression versus velocity for various cutting edges (Hansen 1990).

Hansen's results also showed that increase of energy dissipation as velocity and snow density increases. This phenomenon can be seen in Figure 5. With less energy being dissipated from the compression wave, it is potentially possible to plow more snow effectively without wasting energy. With that being said, a cutting angle of 50 degrees creates the least amount of horsepower consumed by the compression wave during snow displacement, but safety issues arise. Proper tripping for the cutting blade may become increasingly difficult as the cutting angle is laid further back (Hansen 1990).

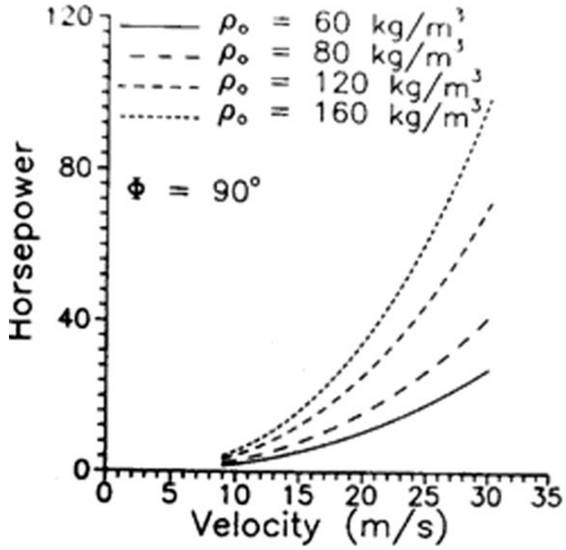


Figure 5. Parametric plot of horsepower consumed by compression versus velocity for various initial densities (Hansen 1990).

2.2.2 Deicing

Deicing is generally confused with anti-icing, but they differ in their main objectives. Anti-icing is used to prevent or decrease the chance of snow bonding to the roadway surface, making it easier to plow, but deicing is used to break the bonds between snow and the roadway surface that are already created (Ketcham and Minsk 1996). Chemicals such as sodium chloride (NaCl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), and potassium acetate (CH_3CO_2K) are widely used as deicing agents (Cuelho et al. 2010). With use of deicing chemicals, it is possible to reduce the amount of abrasives used, provide longer-term effectiveness of abrasives at higher traffic speeds and volumes, and save on fuel consumption when compared with plowing alone (Cuelho et al. 2010).

As with anti-icing agents, it is imperative that deicing agents be applied at specific times and during specific weather conditions. Blackburn et al. (2004) stated that deicing is a suitable solution when pavement temperatures are below 20°F for most weather, site, and traffic conditions. They concluded that it is possible to apply deicing chemicals at temperatures below 20°F, but the amount of chemicals that need to be applied becomes excessive, and the amount of time for the chemicals to become effective is quite long.

Sodium chloride (salt) is the most widely used deicing chemical in snow and ice control operations. Studies conducted in Oslo, Norway, have shown that salt is effective only over a range of certain weather conditions. In one study, two roadways were examined NR161(test road) and NR168 (control). The study took place over 4 years, beginning in winter 2001/2002 and finishing in winter 2004/2005.

As shown in Figure 6, sodium chloride is most effective when road surface temperatures are between –8°C (18°F) and 0°C (32°F) and precipitation amounts are in the range of 0 to 1 mm WE/h (0 to 0.04 in.). For WE/h below –8°C (18°F), salt becomes ineffective. In comparison, the use of abrasives is effective below –8°C (18°F), which makes it the technique most preferred below that temperature.

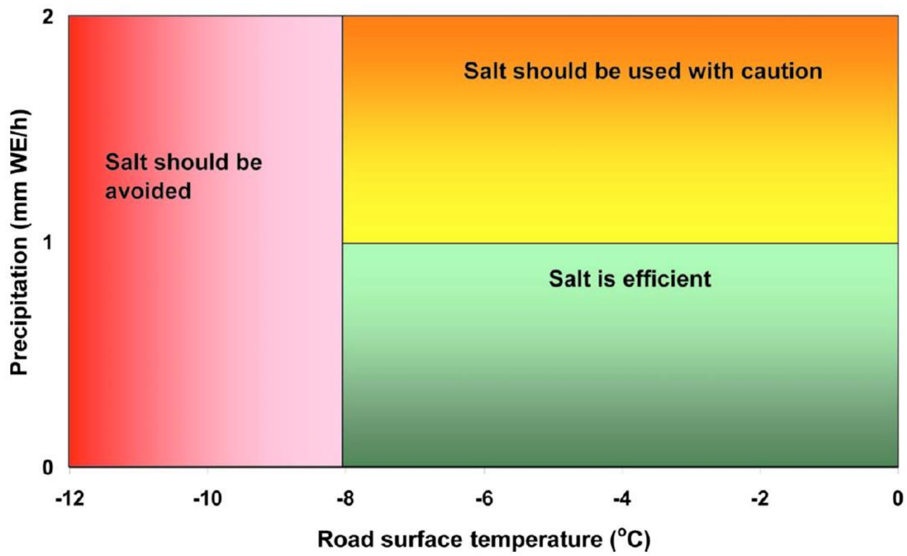


Figure 6. Salt efficiency under various weather conditions (Norem 2009).

2.2.3 Pre-Wetting

Pre-wetting is an innovative technique in which solid chemicals are saturated with liquid before they are applied onto the roadway surface (Conger 2005). This technique can be used for both anti-icing and deicing agents to increase effectiveness. As discussed earlier in this report, pre-wetting is also used for abrasives to make them adhere to the road surface.

The main purpose of pre-wetting is to make solid chemicals adhere to the road surface, much like how warm-wetted abrasives work. This technique makes the solid chemicals more effective and decreases costs incurred in replacing solid chemicals that have been scattered across the road by traffic. O'Keefe and Shi (2004) conducted field testing in Michigan on the effects of pre-wetting salt before applying it. In their studies, 96% of pre-wetted material was retained on the road surface compared with the 70% that was retained without pre-wetting.

Not only does pre-wetting help solid chemicals adhere to the road, it also increases the effectiveness of the agent. In testing, pre-wetted salt is effective at temperatures below 14°F compared with dry salt, which is ineffective at those temperatures (Luker, Rokash, and Leggett 2004). Roosevelt (1997) found that pre-wetted magnesium chloride (MgCl) and calcium chloride (CaCl) melted ice more quickly than dry MgCl and CaCl. These findings show that pre-wetting of anti-icing and deicing chemicals provides better performance than using them dry.

Blackburn et al. (2004) explained proper use of the pre-wetting technique: "10 to 12 gallons of a sodium chloride (NaCl) solution will be sufficient for 1 ton of dry chemical or coarse aggregate." They also stated that some agencies use three times the amount of sodium chloride solution to make the chemicals adhere to the road surface better.

2.3 ADMINISTRATIVE AND MANAGERIAL TECHNIQUES

Proper administrative and managerial procedures are critical factors in snow and ice control. These procedures should ensure that accurate information is collected for making decisions about when and how to handle a snow and ice event. This section discusses the importance of traffic information, roadway weather information systems, and other techniques used throughout the country.

2.3.1 Traffic Information

Though snow and ice control operations are meant to make road travel convenient and safer for the public, vehicles can greatly affect operations. Vehicle tires compact the snow. Vehicles also “abrade it, displace or disperse it,” and “heat from tire friction, engine, and the exhaust system can add measurable heat to the pavement surface” (Ketcham and Minsk 1996). Therefore, it is important to know about traffic flow and volumes before making decisions about snow and ice control.

A major roadway requires much more consideration than a minor roadway in terms of how much chemical should be applied to the roadway and how often trucks should go out to plow. As stated in the FHWA’s *Manual of Practice for an Effective Anti-Icing Program* (Minsk, Blackburn, and Fleege 1996), the most important traffic information for making operational decisions is the variation in the traffic rate over a 24-hr period.

2.3.2 Roadway Weather Information Systems

Roadway weather information systems (RWIS) are vital when making decisions on snow and ice control operations. As defined by FHWA, “Roadway weather information systems are networks of weather data-gathering and road condition monitoring systems and their associated communications, processing, and display facilities which provide decision information to maintenance managers” (Minsk, Blackburn, and Fleege 1996).

Parameters such as pavement temperature, wet or dry conditions, and any indication of a freezing point of a depressant can be obtained through RWIS (Ketcham and Minsk 1996). All of this information is desirable because it will aid in deciding how much chemical to use, when to plow, or even to operate at all.

The most important parameter in RWIS is pavement temperature. As discussed throughout this report, the chemical agents used in anti-icing and deicing are heavily dependent on weather conditions, especially temperature. Air temperature is also important because road surface temperatures follow the trend set by the air temperature.

The Utah Department of Transportation conducted a study on the effectiveness and economic standpoint of their RWIS program. UDOT conducted a literature review to gain knowledge of RWIS’s in use today. They found that though these systems were usable, something more advanced and customizable to the state was needed. By means of its methodology, UDOT discovered its RWIS added value to their operations by improving the annual budget planning process for winter maintenance; decreasing the cost of winter maintenance by reducing labor hours, unnecessary callouts, and materials required; increasing the level of service (LOS) for road users by providing better roads with fewer road closures, delays, and accidents; decreasing incident response time; and decreasing the cost of construction projects through better planning based on storm predictions (Shi et al. 2007). UDOT’s methodology included interviewing engineers and staff, developing indices for cost-benefit analysis and weather, and evaluating their weather and maintenance services.

2.4 EMERGING TECHNOLOGIES IN SNOW AND ICE CONTROL OPERATIONS

Technology is consistently progressing, and it seems counterintuitive not to keep up with current trends in snow and ice control operations. Discussion of these new technologies should not be interpreted as requirements for the state of Illinois; rather, the researchers provide this information as an overview of what is currently available.

2.4.1 In-Place Anti-Icing Systems

In-place anti-icing systems are a new technology that makes it easier for agencies to apply anti-icing chemicals to major roadways but that cannot be attended to by the available personnel. Walderman (2004) describes in place anti-icing systems as systems that apply the optimum amount of chemicals in a timely, localized, and repeated cycles without deployment of typical maintenance equipment and personnel. These systems are generally run by information collected by RWIS. In-place anti-icing systems can be programmed to be used automatically or manually. Automatic systems are also referred to as Fixed Automated Spray Technology (FAST), in which algorithms are used to determine when chemicals need to be applied to the road surface (Cuelho 2010).

In-place anti-icing systems are widely used throughout Europe and are considered a proven technology (Bell, Nixon, and Stowe 2006). This technology has also been implemented and tested in the states of Virginia and New York. Both states discovered that though the systems do not replace plowing operations, they improved vehicle traction and produced a higher LOS than roadways without this system (Cuelho et al. 2010).

2.4.2 Global-Positioning Systems (GPS)

Global positioning systems (GPS) are not a new technology but implementing them in snow and ice control operations is fairly new. Missouri DOT districts have integrated GPS into their trucks not only to track where the drivers are going but also to aid in operations. GPS systems are used in MoDOT operations to track progress of their plows as well as to pinpoint bottlenecks in traffic (Carney 2008). When a bottleneck or any other traffic obstruction occurs on the road, MoDOT drivers can be re-routed, saving time and money in labor hours and equipment use. GPS information can also be used to optimize snow plowing routes.

2.5 CONCLUSION

In this report, the best practices of many agencies have been synthesized as a means to effectively reinforce operations in the state of Illinois. By use of pretreatment, roadway maintenance, and administrative and managerial techniques, snow and ice control operations will become more efficient and effective.

The application of pretreatment agents such as anti-icing chemicals and abrasives can greatly affect plowing operations and overall roadway drivability. With the information provided in this report about roadway maintenance techniques, plows can be used more effectively. This is vital because some IDOT have only plows at their disposal for snow and ice control. If the cutting angle of the front-mounted plow is changed, energy can be used more efficiently, with minimal dissipation caused by compaction.

Moreover, snow and ice control operations can run smoothly only if administrative and managerial techniques allow them to Roadway Weather Information Systems (RWIS) allow operations manager to fully understand the snow event and the effects of parameters such as traffic.

CHAPTER 3 BEST PRACTICES IN SNOW AND ICE PLOWING

3.1 INTRODUCTION

To develop a synthesis of best practices in snow and ice control, the research team, in collaboration with the Technical Review Panel (TRP) for this project, developed a questionnaire to use for interviews with practitioners in the field. This section of the report presents the questionnaire and summarizes the results of the interviews.

3.2 INTERVIEW QUESTIONNAIRE

In collaboration with the project's TRP, the researchers developed a questionnaire and met or teleconferenced with professionals from around the country to solicit their input with respect to best practices in snow and ice control operations. The questionnaire targeted six categories, with a number of questions asked under each category. The interviewees were also given an opportunity to add other comments or address other issues that were not covered by the interview. The questions are as follows:

1. **Interviewee Information**

   Name

   Position and affiliation

   Years of experience in snow plowing operations

   Contact Information

2. **General Information about Best Practices**

   What are the characteristics of a successful snow/ice plowing operation?

   What pitfalls to watch out for in snow/ice plowing operations?

   What are the most important parameters in snow/ice plowing operations?

3. **Standards and Guidelines**

   Are there any pre-plowing guidelines that need to be followed?

   Are there any snow/ice plowing guidelines that need to be followed?

   Are there any post-plowing guidelines that need to be followed?

   Are there any safety guidelines that need to be followed?

   Are there any rules of thumb for best practices in snow/ice plowing operations?

   Are there specific practices you use when installing plow blades?

4. **Equipment**

Types of trucks (Comment on where and how best to use)

Types of plows (Comment on where and how best to use)

Types of blades (Comment on where and how best to use)

Equipment inspection guidelines and records

Equipment maintenance guidelines and records

5. **Technology**

What new technology is available in the field (last 3 years)?

IS your DOT using the most recent technology in snow/ice plowing?

Are the plowing trucks adequately equipped in terms of technology?

How often does your DOT replace it plowing trucks? Is this an adequate truck replacement interval?

How often does your DOT replace plows? Is this an adequate plow replacement interval?

How often does your DOT replace blades?

What criteria are used to determine blade replacement?

6. **Personnel and Training**

Are the snow plowing personnel generally competent?

What kind of training are snow/ice plow operators usually exposed to?

What kind of training do snow/ice plow operators receive specifically related to plows and plow blades?

What additional training should snow/ice plowing operators be exposed to?

7. **Additional Notes**

3.3 INTERVIEW RESULTS

Following is a summary of the responses that were obtained by the research team from the interviewees. In some instances, additional questions were asked to clarify original answers.

3.3.1 General Information about Best Practices

What are the characteristics of a successful snow/ice plowing operation?

- There are three characteristics:
  - Obtain the cleanest road in the quickest time without hampering the public's convenience. This is basically the goal of IDOT.
  - No fatalities (due to road condition) means that we did a good job.
  - Get the job done at the most effective cost.
- Dollars—Clear roads with little as possible amount of money spent on expenses.
- Long lasting blades and use little salt as possible.
- Perform the fewest passes as possible.
- How do you know if the road is clear enough?
  - Safe roads with bare pavement and no patches of ice or snow.
  - Do visual inspections.
  - Truck drivers' responsibility.
- APWA or SHARP or Clear Roads Project.
- Public safety.
- Clear roads or black roads.
- Depends on the highway.
- Different municipals handle snow plow operations differently.
- Flexibility, management and field personal operators need to be flexible in terms of changing technology and procedures of operations, and look at new ways of serving the customers.
- Depends on the person driving on the roadway, but quickly and accurately make the roadway mobile to drive again with minimum accidents is the characteristics of a successful operation.
- Cost.
- Low man hours.
- Low salt usage.
- Road condition back to bare pavements within prescribed time (approximately 2.5 hours).
- Safe travel.
- Safety.
- Equipment is ready and drivers are prepared.
- Making sure everything is ready to go and safe to hit the roadways.
- Imperative to get the call out right.
- There are nine districts, and district 1 does it different than other districts.
  - To make a snow call of when people are to come in to work during a snow event, they must wait for an FC-22 from operations manager who is on call to make a decision.
  - To get called before storm hits to be on the roadway, does not always happen. Therefore the calls to bring employees or operators in does not always happen on time. One person makes call for the entire district.

    - Different for the entire district of when it snows and does not due to the lake affect and how big the district is.
    - It is very difficult to get the proper amount of operators on the road in a timely manner.
- Keep the roads safe and clean.
- Maintaining a passable roadway surface during the storm event. Then returning to normal flow and road surface conditions in less than 24 hours after the storm has ended.

What pitfalls to watch out for in snow/ice plowing operations?

- Weather conditions are continuously changing. Even within the same storm you can start with 100% snow and all of a sudden temperature and dew point change and you end up with black ice. It can happen quickly and the driver has to be able to quickly shift his mindset.
- For large enough counties, you can have two different operations running at different parts (one snow, one sleet, …). It makes it hard to manage. Ice is the worst to deal with.
- Equipment reliability.
- Road conditions
- Drivers being familiar with the routes and what to look for on the roadway surfaces.
- Know what angle the plow should be at while running across bridge joints.
- When to raise the plow up for joints at railroad crossings and bridges.
- Obstacles in the roadway like manhole covers and curbs.
- In-experienced drivers do not know what to look out for, but experienced drivers know what to keep an eye on and what to expect on their route.
- Over applying liquids to the roadways to make clean may not be safe.
- Having proper tools to tell you weather conditions is very important.
- Not having the proper procedures in proper area.
- Amount of snow, when to put plow down, when to wing the area to get snow away, taking notice of what to look out for on the route.
- Putting down too much salt or not enough salt.
  Getting out late, get caught off guard, snow sticks to the road way, traffic makes it stick.
- Temperature drops severely all of a sudden, using the wrong chemicals—cause snow and ice to build up on the roadway.
- Roadway hazards—man holes, public, loose plow bolts, frozen load, equipment, there is a lot of variables to look out for to make sure everything is done safely.
- Common sense when it comes to safety.
- Falling temps, wind speed, ground temp, do not have any sensors in their trucks for road temps. Helps determine when to put down the deicer and what type of deicers.
- If you are not prepared in terms of inventory, salt, and whether or not they have enough for the storm.
- Upcoming ice storm and no calcium chloride they are in trouble.
- Do they have enough blades in inventory to last through the storm because they use steel on steel blades?
- Repair parts, breakdowns in the truck, only have one mechanic and may not have him all the time. Some counties have two mechanics.
- Inexperienced drivers.

- Improper call outs for amount of people on duty, some operations managers will not allow yard techs unless there is a full group, micromanaging the team of snow plow operators.
- Want to control the hours and the amount of money, but the real part that needs to be a focus is to worry about safety of the public.
- People expect the roads to be clean completely and same as before the snow storm.
- Change in temperature.
- Night operations are different.
- Blowing/drifting snow.
- Freezing rain.
- Equipment troubles, material shortages, not prepared for the first storm of the season, not ready to meet the weather forecast.

What are the most important parameters in snow/ice plowing operations?

- Pavement temperature—our trucks have sensors. At 32° switch to salt and chemical spraying.
- Dew point—high dew point means ice on pavement is quicker to form.
- Wind can completely change the operation. If there is wind, you want the pavement to be dry. So we need to monitor weather patterns and wind.
- Type of pavement—asphalt holds heat longer so concrete freezes quicker. Also, the permeability of asphalt allows the liquid to dissipate quicker and not freeze.
- Topography affects the amount of snow. There is more snow on higher elevations.
- Road vs. bridge—more likely to have ice on a bridge.
- Day or night.
- ADT.
- Temperature—warmer temps mean the faster and easier it will be to get the snow off the pavement. Time of day—the sun helps melt the snow because the pavement temperature increases.
- Wind—do you treat pavement because snow will build back up in wet areas due to drifting:
    - Do not salt or salt or just keep plowing to keep the roadway clear.
    - When to know to treat and not to treat is the big question.
- Budget, how successful of getting roadway cleaning, temperature dictates type of material and areas.
- The affordability of certain materials, budget.
- Pavement and air temperature.
- Blowing snow plays a factor when air temp is cold and pavement is warmer then snow refreezes to roadway.
- To follow the guidelines.
- Liability is a big issue.
- If they do not follow the guidelines then cause major issues.
- Pavement temp—adjust chemicals for temps, how the chemicals work depends on the temperature.
- Keeping a good brine, apply salt when it is needed, if you see a slush coming off tires then do not apply salt, If you see slush coming off tires that is really good.
- Need to monitor the air temperature closely.

- Pavement temperature is the most important.
- When temperature is between 32-33 degrees Fahrenheit begin treatment, but depends on the weather and wind conditions.
- Equipment—If they have all the equipment to be able to make the repairs and how long a truck is down.
- Inventory—do they have the parts in stock to make the repairs on equipment
- Manpower:
  - Who makes the snow calls to tell when to call in operators? This needs to be done at a team level for that specific yard.
  - Ray is in the largest team district and furthest south of District 1.
  - They have some of the biggest snow routes around 55 miles and average of 35 miles.
  - Very hard to catch up the roadways if they are behind in calling out operators or if the storm hits early.
- Good plow drivers.
- Right equipment.
- Understanding your environment. How has the weather changed the roadway, the subsurface, and the overall approach to a pending storm event? Is the event wet, dry, cold, very cold, strong or weak, fast moving, is it a back in storm, etc.

3.3.2 Standards and Guidelines

Are there any pre-plowing guidelines that need to be followed?

- Maintenance check of truck and plows. Truck: general checks. Plow: structural—we check the springs, the chains and the frame for cracking and then the blade.
- Salt and liquid applicators are tested—both spreader and sprayer.
- Bolts on the blade—check for missing bolts.
- Lights on truck and hoses (check for hydraulic leaks).
- Checking truck after every run to be ready for next storm.
- Blades—bolts are in and tight.
- Have enough carbide blade left to get through the storm for the route.
- Do not want to have to change blade in the middle of the storm.
- Clean truck after every storm and check everything.
- Change the blade and check bolts after every event.
- Do a walk around the truck before leaving yard to plow.
- Pre-trip training and show them how to use equipment.
- Check loose fittings and cutting edges.
- Class 8 truck.
- Walk around the plow to make sure it is safe. Required for a person who has CDL.
- Check to make sure material is on board that is needed, equipment working properly.
- Anti-icing try to get everyone to do it.
- Check anti-icing guidelines.
- Look for bridges and shady spots.
- Get layer down before storm.
- Truck inspection, make sure equipment is ready to go, pre-wet system is ready to go and have plenty of liquids, and chains are set properly for the front body plow to allow an even distribution of weight on the plow. There is usually plenty of time to check the truck before the storms.
- Check the blade to make sure that there is enough left.

- Always check the equipment,
- Winter inspection is the 16th of the month of October. Go through to make sure it is working properly.
- Takes 2 to 3 storms to be 100%, wash the truck and inspect for everything, springs, stress cracks and what not.
- Every truck has a truck file, any repairs done is logged for the truck in a file, what parts been replaced.
- Get trucks and other equipment such as motor grader ready.
- Prepare your trucks for the event, have personnel ready for call out, discuss the routes and priorities.

Are there any snow/ice plowing guidelines that need to be followed?

- We have guidelines set by the department.
- We get snow and ice procedures manual annually that lays out what condition we need to get roads based on their ADT.
- IDOT has a statewide policy.
- How they plow is from center line out for a 2 lane roadway.
- For a four lane road way they left and right on the interstate and in rural areas with small medians plow to the right only.
- There are guidelines and the drivers would be better able to explain those.
- Limit speed of plowing (between 35 and 40 mph on the interstate. Slower speed on other roads).
- Guidelines and policies wrote for what roads are a priority, guidelines followed for everything.
- How to treat, what to apply.
- Procedure and policies must be followed by any state employees and roadways. If any changes done, completed during July to be able to educate the staff.
- Policy is applicable across the state.
- Getting into system ask him later.
- Inspection, make sure all fluid levels are ok in transmission, oil, and windshield washer fluid.
- Check tires for flat tires, bald tires, bolts, curb guards, tailgate settings, spreader settings for liquid and salts.
- Maintenance policy manual that all districts are to follow, they have two of them, they do not have a real copy of the manual but have copies of copies.
- They do not have a computer copy easily available.
- Get major roads open first.
- Get two lanes then get shoulders open.
- This is determined by the foreman to respond to the needs of the system he/she is responsible for.

Are there any post-plowing guidelines that need to be followed?

- Same as the pre-plowing guidelines.
- Clean truck, plows & blades. Drivers need to check plows and blades make sure all bolts are there, make sure enough carbide or enough blades are available to go through the storm.
- Phase 1 during storm.
- Phase 2 after storm—how to go about cleaning the snow from overpass and prevent from covering other roads or railroads. They will be included in the guidelines I am sending.
- Not very good at post storm analysis use GPS systems.
- If there is a fatality really try to focus on a post analysis.
- Wash everything—cleaning is the most important part when inspecting the truck and preventing rust or corrosion.

- Easily find missing parts and bolts while doing a thorough cleaning of the truck.
- Same as what we have from bureau of operations.
- Wash down and do visual inspection of truck.
- Check the salt pile.
- Check what is in the tanks for the calcium.
- Check to make sure that they have more than the minimum amount for salt on hand.
- Drivers need to verify their roads are clean and passable.
- This should be done on a regular basis to improve conflicts that arise during the event.

Are there any safety guidelines that need to be followed?

- Speed—20 miles/hr. on secondary roads. Interstate—30 miles/hr.
- There are guidelines for railroad tracks and bridge joints: Make sure the plow is at an angle w.r.t. the joint.
- We do a two day dry-run before the snow season to check for joints, culverts, turnarounds, obstructions, manholes, curbs, and curb drains.
- Best performance is to not go to fast.
- Do not travel over a certain speed.
  - Interstate—between 35-40mph.
  - 2 lane highway—30-35mph.
  - ***Come up with some speed recommendations***
- Common sense when to check mirrors and blind spots.
- 12-14 foot plow blade so warn public that plows are as wide as the lane width and to get over and slow down.
- Residential business area—need to slow down and not through snow very far.
- Bridges—slow down for safety of throwing snow onto roadways below.
- Experience will help with the route:
  - Keep the person on the same route to gain all familiarities.
- Safety equipment and lighting that must be followed. Second page of standards. Federal guidelines for lighting on trucks.
- Safety measures to look at anything, traffic control. Hats, shoes, and clothes in general.
- Counties have their own safety guidelines that they follow.
- Common sense—make roads safe as possible as fast as possible while doing it effectively and efficiently as we can.
- Bridge decks and overpasses are a very important aspect in keeping the general public safe. Bridges freeze faster due to the air being able to reach all sides of the structure unlike an asphalt roadway.
- How fast the truck is driving for the conditions.
- Spacing between plows and other plow trucks.
- Cannot drive too fast because will flip trucks.
- Monitor temperatures.
- Do not drive too fast.
- Use salt as needed.
- Constant communication between drivers and foreman.
- These are discussed as a crew before the snow season starts and then have follow up safety meetings. Post storm review also points out any safety issues.

Are there any rules of thumb for best practices in snow/ice plowing operations?

- Pretreating before the snow. It takes 4 times the amount of salt to remove ice and snow than it does for preventing it from bonding.
- When wind is blowing above 10 mph, do not use pretreatment on a dry pavement.
- Do not do certain things.
- Know what to look out for like manholes railroads and curbs.
- Look out for reflectors called cat eyes, will tear up the carbide blade, make bolts on blades come loose, and cause vibration in the plow.
- Pre-wetting rock salt on roadway to prevent from bouncing, sodium chloride brine solution to help stick to roadway. Helps longer term for frost and icing. Brine in general helps a lot in snow and ice plowing.
- Using different equipment. Flexible blade for front plow get better durability, coverage and clearage for a flexible blade plow is something that they have recorded and observed. Depends on the areas and how effective they are. Get better mileage, clean better (based on observations) may not be as effective as some areas.
- Currently working—pre-wet salt make it a best practice, MDS system, underbody blades really useful.
- Everything above applies in some shape or form to have a best practice.
- There are many parts that play a key into operating efficiently and effectively.
- When there is blowing snow, do not get pavement wet because it builds snow pack.
- Ice storm throws everything out the window because the approach to be taken changes dramatically to cleaning of the roadways.
- Safety first—loading, plowing, changing blades.
- FC22 tells man power for the yard, but must always upgrade to make sure to cover everything to protect the public safety because they do not want a lawsuit or someone killed.
- The plow drivers are first on the road.
- They need to evaluate the situation and adjust as necessary.
- N/A.

Are there specific practices you use when installing plow blades?

- Cut bolts off with torch, impact wrench to tighten them.
- Set carbide then steel cover blade.
- Takes 2-3 guys to install the blades.
- Use the blade on concrete, do not have any skis for the blade protection line like other places do.
- Safety, use torches to torch bolts off, some people just loosen, make sure equipment is blocked up, some have hoist, some climb underneath.
- Safety is the first concern.
- Varies on available equipment (some people can truck and some cannot….).
- Never change a blade by yourself, always need to have 2 or 3 people to help, must use jack stands.
- Less than two finger rule replace, cracked or broken blades must be replace, blades break during storm a lot.
- Replace carbide bit & blade at the same time.
- Every time this is replaced, new bolts are used.
- Some shops have developed carriers that hold the blades in place and allow the environment to be safer.

3.3.3 Equipment

Types of trucks (comment on where and how best to use)

- Long route: Tandem trucks can carry more salt.
- Depending on snow event and type of plow required, it is not the truck per say—it is the attachments that it has and how much salt it can carry.
- Trucks, basic—single axle dump truck, tandem axle dump truck.
- Basic trucks are single axle and tandem axle dump trucks. Type of truck does not make a difference on plow and blade.
- Tandem trucks can handle the longer routes.
- International trucks are most popular truck in the Midwest. Western Stars, Mac trucks.
- Who has sharpest pencil, size of chassis ¾ ton up to class 8 type truck. Most will be used during summertime and winter, depends how chassis will be used in field.
- Do not exceed gross vehicle weight, make sure chassis is large enough and whether it can fit gross vehicle capacity.
- Weight distribution, national trucking equipment has a program to run and let you know for weights. Iowa and Alaska require this to be looked at.
- Iowa—sometimes go to a lighter gauge material, but it is structurally stronger, go to a Dolmax material to take weight out.
- Alaska, move the equipment around on truck to make fit and work properly.
- Contract with international brand trucks. They spec the trucks and buy from them. Have both single and tandem. Tanker anti-icers for interstate areas.
- Done by county who decided—go with low bid.
- Tandem.
- Single axle.
- 3 ton trucks.
- Bench trucks.
- Would like to see tandem axle six ton for snow plowing, for the long snow plowing distance.
- Summer time a 3 ton truck is ideal for patching and shoulder work.
- Snow and ice operation must use bigger truck.
- When the supervisor go out to check on operators and monitor the roadways, they have to use their pickup trucks with rear wheel drive. This does not make since because these trucks do not have enough weight. They need to have four-wheel drive for the pickup trucks, need to be able to handle the adverse weather. To solve this issue, they get in a bigger truck that weighs more or have to have an operator come pick them up in a six ton truck to drive them around.
- Tandems on all routes (unless restricted by a load limit on a bridge).
- Most of the fleet is now tandem wheels. This is to carry more material and pull the grades on the routs. The front-end in built for the heavier plow blade loads.

Types of plows (comment on where and how best to use)

- High output plows (Alaska) are not good to use in urban areas. They are designed to throw snow away. To be used in rural areas.
- 14 ft plows are not for urban area use.
- Use 12 ft flush in urban and high traffic areas. Output can be controlled better.
- Wing plows are good to use in rural areas and on interstate roads. They get the snow further from the road. Underbody plows can be used for scraping ice or as a secondary plow to make sure roads are cleaner.
- Drivers would know better.
- Standard plow is the reversible for deep snow; one way plows push the snow a little better.

- Alaska plow & the high discharge reversible plow tend to go down on one side before the other and that causes uneven wear on the blade.
- A normal blade change is 1/2 to 1 hour so it is not efficient to switch blade orientation especially that one would end up with an uneven wear.
- Annual snow fall, 41inch plow in Illinois.
- North Dakota, Michigan, Wisconsin—72" tall plow, get bigger trucks too.
- Highway use or city use determines.
- Depends on policy of when to start plowing based on areas.
- One way plow is in a rural application—higher speed and discharge snow further away from snow.
- Reversible rural and metro.
- Scarifying blade then a squeegee blade behind it.
- JOMA flexible blades, a few polar flex blades, and some carbide.
- Underbody plow and mostly right hand wing plows.
- Alaska plows are very good because they have 2 way capability but allow for the primary purpose of getting the snow off the roadway at a further distance.
- 12 foot plows are the ideal plow for getting snow off the roadway.
- They have been getting 11 foot but does not work well for his purpose on the rural roadways.
- Need to have tall plows not small short plows because the operators cannot see them when driving.
- They plow the primary highway routes and routes and interstates.
- Henderson steel plows, 2 way angled plows.
- 4 trucks have mid mount side wings.
- Mostly straight plows with a few sites needing Alaska plows. They want to cast the snow as far off as possible.

Types of blades (comment on where and how best to use)

- Traditional setup—one steel blade for cutting the ice and can be placed in front or behind the carbide plate. Carbide is for wear-ability. Better to use steel in front.
- Steel on steel blade cuts better but wears out faster.
- JOMA blades—rubber blades—give a clearer surface but will wear out quickly on rough surfaces.
- Polar Flex blade—rubber back 1' section carbide—cleans like a JOMA with good wear-ability but cost can be prohibitive.
- I think that there is a blade called snow blaster blade or something like that.
- Reversible plows.
- One way plows—handle more snow, but cannot push snow left and right, only to the right.
    - Do not use one way plows very much.
    - Use the reversible plows more often.
    - Alaskan plow is reversible.
    - Will get more blade wear on one side of the blade come pared to the other side of the blade, the heavier side will wear down faster.
    - Must replace all blades and whole set, not common practice to replace different sections.
    - Will not throw the whole set away, save what may be able to be used.
    - Types of blades:
        - Steel.
        - Carbide.
        - Steel-carbide—cover blade is steel.

    - The under body plow blade uses only a carbide blade.
    - There is carbide insert blades that have a dowel bar type insert perpendicular to the length of the blade.
- Blade Saver on makes a huge difference.
- Blade saver off cause the blade to wear faster.
- Bucyrus blades, carbide blade, Harden blade, ceramic.
- Customer preference here.
- Usually use a carbide blade on the underbody plow.
- JOMA flexible blades, (polar flex & carbide).
- Carbide/steel, rubber blades but cannot use on gravel because it tears the rubber up.
- There is some carbide in the rubber blades.
- Season and half for a carbide/steel blade.
- They use steel blades, they do not use the carbide blades; the carbide ends, they double up on the blades.
- Some other districts have rubber and steel.
- Rubber blades are better on asphalt than on concrete.
- Carbide blade & soft steel blade together as a unit.
- Carbide blades on 12' plows. Looking at purchasing JOMA Blackcat style blades.

Equipment inspection guidelines and records

- Replace blade when blade is less than two fingers (about 1.5 in) away from the bottom of the plow.
- No inspection records, but we record what blades we check out. We have a record of the number of blades used per storm.
- Checksheet.
- Post snow inspection.
- Blade, cutting edge, bolts, hoses, cables, chains.
- 2 fingers to see if need knew carbide blade.
- Set up something to measure all trucks before and after to give rule of thumb of how far to travel before blade wears out.
- Keep track of range and distance traveled for the blade.
- Tell the mechanic what the problem is and write it down and also record what was changed on the truck with new equipment. There is a truck record.
- The post storm inspection is the most important inspection.
- Send trucks to have safety inspection every six months for lights and everything to get safety sticker, winter inspection and summer inspection, recorded into the truck files.
- Every driver is supposed to do a circle of safety before leaving the yard.
- Drivers do "walk around" equipment before heading out.
- Inspect bolts, check blade to make sure it isn't close to mole board (hinged piece of blade).
- There is a truck inspection form that is filled out before every shift change. Repairs will keep a truck from operations.

Equipment maintenance guidelines and records

- Faults are repaired—maintenance & service records for trucks are kept.
- Equipment lists.
- Do not log the miles they drove.
- Get salt rate from the computer.
- Records are kept on truck maintenance and blade changes.

- Manuals, depends on equipment, lubrication varies depending on the product, he will send on manuals.
- Records are housed within Fleet Department database.
- Agile Assets is the software used to track maintenance on equipment. It also tracks hours to send out notices for annuals.

3.3.4 Technology

What new technology is available in the field (last 3 years)?

- Weather monitoring has improved greatly.
- We use the RWIS system.
- Road sensors have improved quite a bit.
- Liquids are on the forefront of snow and ice removal—they have improved quite a bit (brine and especially additives).
- Different types of blades are available.
- Slurry technology.
- Different plow technologies (blade tips).
- Blade saver on truck relieves pressure or downward force.
- There is a fine medium between salt and blades to minimize both the wear and salt consumption.
- Road temp sensors:
  - Not accurate enough.
  - Computer for salt control.
- Clear Roads projects that go over to Europe who has better technology and Japan as well, technology comes with a price.
- There is v box, Henderson, E poke. Puts out smaller amount of material and more liquid.
- Create a system to crush salt and apply liquid to make slurry—Monroe developed this and can be controlled by the driver.
- Front plow with a “scarifier” and squeegee is a new technology, underbody scraper similarly works as well too.
- GPS system and taking it to the next degree. Will be outfitted and gives a lot of data.
- Have a mobile app to tell general public where has been plowed.
- Purchased two tow plows to find out how they work, Eau Clair, Washburn County.
- AVL GPS system tells what they do and what to put down based on weather.
- Meridian in South Dakota, 24 states participate.
- Calibration scales—to calibrate equipment better and prevent the amount of salt to be used.
- Try to make sure what they are out putting do not want to be off by a high percentage.
- ***Talk to FORCE AMERICA ON This question***
- Mid mount plows work great on a 2 lane rural area.
- Pre-wet technology is helped a lot but money plays a high role in this technology.
- The Dicki-Jon system and now the Force America system are a lot better and will help the next generation transition into a job of this nature. Also it is a lot easier to regulate the truck equipment and the speed at which an action is done for a hydraulic function.
- Joystick, but they do not like it because of corrosive nature of chemicals and the electronics.
- The slurry trucks look like an icy when the salt comes out the back, there is a mechanism where it grinds to a fine powder and mixes it with a brine.
- They do have a spray truck to pretreat bridge decks and ramp, will spray before the storm.
- Different types of blades.
- Pavement temperature monitoring.

- Speed controlled salt distribution.
- AVL (Automatic Vehicle Location) in all trucks, MDSS (Maintenance Decision Support System).

Is your DOT using the most recent technology in snow/ice plowing?

- No. This district (4) is starting. Iowa is decades ahead of us in the use of chemicals and the different types of blades.
- Use of GPS to better manage the fleet.
- Not often enough for replacing trucks.
- There is no set standards.
- Go as long as you can.
- Take money they have and replace as many trucks as possible.
- 6000 hrs. no major overhauls on motors:
  - Did not have to rebuild motors or transmission until around 8000 hrs.
- They are using the salt slurry and the salt crusher. The state has not bought plows with the squeegee but some of the counties have.
- Have a little more innovation than other states. Hard to keep up, but try to have the most recent because director pushes for it.
- 600 trucks out of 1100 with AVL technology (Laser Guided Snow Plowing).
- Automatic chains, blades, multi-blade. Minnesota has a research facility and they tell people what they want to be done.
- Counties is better than contracting.
- Yes. IDOT has done a very good job with keeping up on the times for improving the technology. Methods are getting a lot better and so have material uses and applications.
- Yes and no.
- As they can afford it.

- MDSS (Maintenance Decision Support System) not all. AVL (Automatic Vehicle Location) not all.

Are the plowing trucks adequately equipped in terms of technology?

- Yes. We get the job done but we would be more efficient with a better technology: liquids slurries—fleet management GPS.
- We have pavement temperature sensors but the margin of error of 2% can make a difference.
- In my opinion, yes.
- Depends on the truck age and will all be equipped with GPS.
- LOCATION Technology out of Kansas City, MO (LTI)-GPS.
- Have upgraded to tell what is coming out of back end for salt.
- Cirus Control, controls hydraulics and what is coming out of back end. GPS system will tell this information.
- Temperature gauges are not very accurate and we are looking into ways of improving that. Cirus Controls—controls how much water is coming out.
- Laser guided plow, something that will track mist off of tires, fins in back, heated wiper blades, AVL GPS is the biggest.
- Tow plows.
- Very progressive—cannot force people.
- Yes, the trucks are adequately equipped would not be cost effective to do more than what they have.
- They have pavement sensor out at certain locations but would be helpful if the trucks were equipped with temperature sensors.

- Would like to have pavement temps sensors all the trucks and to make a real time decisions of when to apply chemicals,
- No, we do not have ground control salt distribution, temperature monitors or hydraulic sensing plows.
- We think so, might need cameras, but no one has pushed the issue.

How often does your DOT replace it plowing trucks? Is this an adequate truck replacement interval?

- Trucks are replaced when they have 9000 hours.
- Special considerations are made in high maintenance cost.
- 5000 to 6000 hours would be a better interval. At 9000 hours, purchase cost is low but maintenance cost is much higher.
- Get new plow when they get new trucks, 10 yrs.
- Plows hold up a lot better than they did 30 yrs. ago.
- Not often enough. IDOT tries to replace trucks when they have 8,000 hours on them or so, but it is not certain that will happen. 6,000 hours life span for a truck is most efficient.
- Replace every 15 to 16 years right now.
- Need to be able to do it every 12 years.
- Counties 10 to 25 years, pay actual cost of what they do, put new trucks on state and county roads has secondary.
- Tandem trucks need to be replaced more often than what they have been being replaced.
- A single axle 3 ton truck does not need to change because they get replaced often enough.
- Need to look at maintenance cost and the use of the truck for the entire season of both winter and summer.
- Every 8 years but he has trucks that are 19 years old.
- The equipment is aging and costly to maintain.
- They break down a lot during the operations frequently.
- Every 8 years. This is adequate, they make do with this replacement schedule.
- 15+ years; it is what we can afford.

How often does your DOT replace plows? Is this an adequate plow replacement interval?

- Plows go with the trucks. This interval is a little overkill because plows have a higher life expectancy than trucks.
- Blade cracked then replace it, section of carbide broke out then replace it.
- Cover cracked replaced, any sections cracked replace them.
- As a rule of thumb we get a new plow with each new truck and that is reasonable, plows seem to hold up. They are made much better now than they were 30 years ago.
- As long as there is no damage to the plow, it does not need to be replaced. Good quality plows can last up to 20 years.
- Underbody plows are very effective for scraping, Yoma-rubber impregnated.
- Plows come with new trucks. Plows have improved over the years and do not have as many problems as they have had in the past.
- They use to replace 2 to 3 trucks and then get a plow.
- Plows are the best upgrades that they have done in terms of technology. Always have to be on the lookout for hazards in the roadway like manhole covers and expansion joints.
- 1986 plows, they rebuild the plows in the house, sometimes they get plows with their trucks, but they do not always get them depends on the pool of money.
- Every 8 years. Yes this is adequate.
- New plow with new truck. Damaged plows that cannot be repaired are replaced.

How often does your DOT replace blades? What criteria are used to determine blade replacement?

- Two finger rule for steel on steel blades, 3 to 4 per season.
- One finger rule for steel on carbide.
- Blade saver helps the steel on steel quite a bit. Replacement interval is adequate.
- It used to be a 2-finger rule for steel plows.
- With carbide, if visual inspection reveals that there is still a carbide insert along the length of the plow (seen from back) then the blade is still good. If steel cover plate or a piece of carbide breaks out then we go-ahead and change that too.
- City of Milwaukee—put a disc on bolt to know when it needs to be replaced when wearing reaches the disc. Gives it a visual on the front side (like a washer on the cutting edge bolt).
- Do they wash sand blast and paint them again.
- Depends on the roadway and the surface.
- Do not have standard. Change it when it needs to be changed.
- Depends on plow blade when the wear is at.
- Flexible blade different than carbide blade.
- Driver needs to look at blade after the storm and determine how much of the blade is left.
- Factors that play are the route, the roadway, and make sure the plow picks up evenly with the chain.
- 2 finger rule.
- Every year on average based on use.
- 2.9 sets of 12’ blades per truck per year. When the carbide is used up.

3.3.5 Personnel and Training

Are the snow plowing personnel generally competent?

- Yes.
- There is a mix, some are very competent and some not so much so. I do not think they get enough training.
- I think so, generally. We have to train them to be competent and confident for this particular job.
- Clear Roads—putting together training modules—RFP incorporate different learning sessions and what not. Want every operator to have minimum level of competency, have certificate and certification program. Outline from a providence in Canada, add to it and prioritized it as to who should know what.
- Training committee made up of county highways.
- For the most part yes, but there are a few people who do not care. People are for the most part willing to help out each other. There is about 10 percent who do not care and just want their pay check.
- They were in the past, but not anymore, got 16 snowbirds who never plowed snow in their life last year, as people retire, they lost 6 last year and they are not being replaced.
- He will have 47 snow birds and a lot will never have plowed. On the job training is not the way to go. They need to spend more time training before going out. They do set a wing row of salt to be plowed, but do not do it for very long.
- Not very safe, because it is hard to drive during a storm with ice pack snow.
- They bring the new people in who have most experienced first, but least experience come in last.
- Even after one or two storms they do not bring inexperienced drivers to ride along.

- They need to bring inexperienced drivers in sooner so that way they can learn how everything works.
- Matter of money and union rules.
- They cannot skimp on the training. They need to get more acclimated with trucks during weather.
- Yes. Supervisors cannot be in all spots in one time.
- Yes, they received initial truck training (CDL) and then crew foreman complete operations training.

What kind of training are snow/ice plow operators usually exposed to?

- When they are first hired there is rookie training - classroom and hands on (phase I snow and ice training).
- Refresher continuation training every year before season starts.
- Ride along for new people.
- Trainings cover safety and procedures.
- Personnel training depends on the person
- Experience pride in what you do or just do not care
- Need training every year to get everyone up to date and provide reminders
- More that you train the better the results will be made
- Snow plow meeting last approximately 4 hrs
- New driver goes with experienced driver to gain understanding of equipment
- Spend a day or two showing him how equipment works and to become familiar with the route.
- Do not get enough training overall
- We have CBT training (ASHTO computer base training), job shadowing, and hands on, watch all you want, but need to learn and get hands on experience.
- Check AASHTO for videos.
- Every county does what they think they need to do in terms of training.
- They are allowed to get use to the truck controls of loading and dumping, have a three day training period on the equipment. They do learn to operate the plow by moving millings. They did not have any of this when he was hired in. The best training is just gaining experience and becoming comfortable in the operators seat.
- Spend a day and plow salt. Change blades by just telling them how to do it, but learn how to change blades at the yard.
- Need to double them up with experienced operators to train them
- On the job training
- IDOT offers on the job training
- Individual hands on training at the shop level. Initial truck training is classroom style with hands on truck demos.

What kind of training do snow/ice plow operators receive specifically related to plows and plow blades?

- They are taught how to change the blade and that's it.
- Hands on experience getting use to equipment and how to change blades and attach plows. There is always someone showing them and helping them do this. Takes two people to do this. Show them tell them and just go.
- Tell them what to do but learn once they get on the job.
- No training. Plows and blade issues are based on observation and riding.
- Hands on at the shop.

What additional training should snow/ice plowing operators be exposed to?

- If there is new technology to be used then they should be trained in that and the state is good at that.
- About truck, techniques, when to treat, not to treat and when to plow not to plow, take guys who know and teach everyone who does not know.
- Experience drivers know a lot get them to help.
- Peoria teach to change.
- When to and when not.
- Most want help.
- Do not see experimental blades lasting any longer than what they do right now.
- Educate operators of effectiveness of salt. Teach them about anti-icing brine and pre-treatment. Need operator to know about the effects and compare what you are doing. Management type issues. Help them know what they are doing and impacts that it will have on both the budget and the public.
- It is very important for management staff to educate operators on how effective salt and material is and how much it costs the state to help them understand the impact of what they are doing.
- On the road experience is the best education to becoming a good snowplow operator. Need to be able to have a plan based on weather and if that plan fails know what to do to attack in another way.
- Double them up with experienced to train them.
- Talk to colleagues at other agencies for best practices.
- If affordable simulator training. Classroom truck rodeo style training on an annual basis.

3.3.6 Additional Notes

- Blade saver works great. I did not see a miracle blade yet. The new types of blades that are available are too expensive and do not necessarily last any longer.
- Your position: Deal with policy development. Anything that deals with management to garage level in the shop. Have had experience in the truck. Also deal with government, public, and Legislatures. Act like conduit and everything goes through her office including budgeting.
- Wisconsin model (paying counties to do the job), the operation costs them less.
- Analogy: Salt shaker—wet counter and then dry counter space. Sprinkle salt on the counter then show them what happens when you blow. The salt will act like the snow in this scenario. The salt will not blow off the counter that is wet but will blow off the dry counter space.
- Great analogy for winds snow and roadways.
- Inspecting, knowing truck, and being familiar with routes or just having experience is the most important part of having a successful operation.
- They plow the primary highway routes and routes and interstates.
- IDOT, County, City of Chicago, Tollway have the nice equipment to plow there roads top of the line, new equipment.
- They are the southernmost yard near Joliet and new Lennox, east Moline.
- Everyone does not have the same ability.
- Spend some time watching and observing but then put them in driver seat after 2 storms. Get them more acclimated and feel confident.
- If never plowed a shoulder before and at night may roll truck if truck pulls toward ditch, they do not know how to ease off shoulder.
- Everyone is full of enthusiasm but no experience and then they get hurt. Maybe try to get retired operators to offer to come back and train the operators as a retiree to ride along with trainee. Have them for 6 storms to teach and give knowledge by not depleting resources.

- Needs to transfer knowledge to the new generations of operators. Only way to become an operator is to be a veteran of war.
- They purchase trucks that can be used year round and not just for snow events.
- They recently went to stainless steel auger boxes and beds to extend the truck life.

3.4 SUMMARY OF INTERVIEW RESULTS

1. A successful snow and ice control operation results in the cleanest road in the quickest time without hampering the public's convenience and safety. Measures of success are the absence of fatalities, maintaining a passable roadway surface during the storm event, and returning to normal road surface conditions and flow in less than 24 hours after the storm ends.
2. A successful snow and ice control operation is cost effective and uses as little salt as necessary to reduce the effect on the environment.
3. Management and field operators need to be flexible in terms of adopting the changing technology and procedures of operations.
4. Management and field operators need to make sure equipment is ready and drivers are prepared to respond in a timely manner when the weather condition warrants it.
5. Management and field operators must watch for changing weather conditions. Sometimes a storm may start with 100% snow but a sudden change in temperature and dew point creates favorable conditions for the sudden formation of black ice, necessitating a change in the treatment approach.
6. Snow and ice control operations may be severely hampered by shortages in material, equipment, and personnel. Failure to plan ahead will put the safety of the public at risk.
7. Larger counties may need to have different operations running in different parts (such as one for snow and one for sleet). Such counties need to have the proper equipment and materials ready to be deployed where they are needed in a timely manner.
8. Some of the challenges that may interfere with a successful snow and ice control operation include equipment reliability, physical road condition, and drivers' lack of experience.
9. It is extremely important for drivers to be familiar with the routes they are assigned to clear snow and ice from. Drivers need to be aware of obstacles on the roadway surface, such as manhole covers, curbs, and joints at railroad crossings and bridges. Driver training programs should include route scouting missions before the snow season, and drivers should be assigned to clear the same route throughout the season.
10. The efficiency of ice and snow control operations diminishes when managers focus on reducing hours of operation and use of materials. Operators should be instructed to focus on ensuring the safety of the traveling public first.
11. Over-applying or under-applying salt and other chemicals may create unsafe conditions. Plow operators need to be provided with instructions on when and how much anti-icing or deicing material to apply and also be properly trained to make sure they follow the guidelines.
12. In connection with knowing when and how much anti-icing or deicing material to apply, trucks should be equipped with sensors to measure road temperature.
13. Blowing snow and freezing rain represent challenges that operators need to be well trained and prepared for. For example, anti-icing with liquid chemicals is not recommended during freezing rain or sleet events (NCHRP Report 526).

14. Night operations present additional challenges because visibility is greatly reduced, temperatures are typically lower, and traffic is not as heavy—allowing more snow to accumulate on the pavement. Shifts should be planned in such a way to ensure that drivers remain alert during the operation.
15. The following parameters are the ones that might affect an ice and snow control operation the most:
    a. Pavement temperature: Critical in determining the type of anti-icing or deicing material to use, if any.
    b. Temperature: The warmer it is, the faster and easier it is to get snow off the pavement.
    c. Dew point: The higher the dew point, the quicker and more likely ice is to form on the pavement.
    d. Wind speed and direction: Wind can completely change the operation because it can cause snow drifts and possibly blow the dry chemicals away from the pavement.
    e. Type of pavement: The dark color of asphalt makes it absorb solar radiation and radiate heat better than concrete, which means that concrete is quicker than asphalt to freeze. Moreover, the permeability of asphalt allows the liquids to dissipate faster and not freeze.
    f. Topography and trees: These affect snow distribution and the amount of snow accumulated.
    g. Bridge vs. roadway: Bridges are more likely than roadways to have ice on them as bridges cool much faster because of the air passing under them. The soil underneath provides thermal mass to roads.
    h. Time of day: Night operations are more challenging and require increased alertness. Also, temperature is typically lower during the night, which increases the probability of ice formation.
    i. ADT (or better yet, traffic volume): Affects the priority and timing of snow-clearing operations.
    j. Availability of equipment and parts.
    k. Manpower and management logistics.
    l. Operator training and familiarity with assigned routes.
    m. Plowing speed affects safety and equipment—specifically, blade durability.
16. Pre-plowing guidelines: Perform a quick inspection of the equipment (truck and plow) and ensure adequate quantities of anti-icing and deicing materials. Make sure there is enough of the blade left to avoid having to change it during the storm. It may also be worthwhile to mention here that a more thorough inspection of the equipment is necessary after the current operation is completed to make sure the equipment is ready for the next storm.
17. Make procedure manuals and guidelines for application of chemicals and plowing available to operators to ensure they are familiar with the procedures and guidelines and are able to follow the instructions as required and applicable. These guidelines usually include what chemicals to apply under what conditions, how much to use, and how to plow.
18. When plowing on an interstate highway using the front plow, speed may be as high as 30 to 40 mph. A lower speed should be used on secondary roads. The operator must consider weather and traffic conditions and use an appropriate and safe speed.

19. The underbody scraper is harder on the pavement, so a lower speed of 20 to 30 mph should be used.
20. Monitor temperature and general weather conditions on a regular basis.
21. Keep communications open with the foreman and report any incidents immediately.
22. Plow drivers are first on the road; therefore, they are the best positioned to evaluate the situation and adjust the snow-clearing operation as necessary to ensure successful results.
23. Some general rules to observe while plowing:
    a. If conditions are favorable, pretreat the roadway before the snow starts to fall. It could take up to four times the amount of salt to remove ice and snow than it does to prevent it from bonding in the first place.
    b. When wind is blowing above 10 mph, do not use solid pretreatment on a dry pavement.
    c. When there is blowing snow, do not get pavement wet because it will build snow packs.
    d. Pre-wetting rock salt before spreading it on a dry roadway will prevent it from bouncing. A sodium chloride brine solution will help salt stick to roadway.
    e. Look out for reflectors (“cat eyes”) because hitting them will tear up the carbide, cause vibrations in the plow, and may cause bolts that are holding the blade to come loose. Raised pavement markers can also be knocked loose and become a dangerous projectile. They tear up the carbide by acting as a ramp and causing the blade to bounce. This problem is worse for blades with trapezoidal carbide. The material used to hold the carbide in the blade fractures, and the carbide is lost in chunks.
    f. Change blades when less than the width of two fingers is left on them.
24. Completely clean and adequately inspect trucks and plows after the plowing event. Inspect tires, bolts, lights, springs, spreaders, curb guards, liquid tanks, truck fluids, etc. All maintenance must be performed if due.
25. Best practices for installing plow blades:
    a. Make safety your number one concern. Immediately replace cracked or otherwise broken blade.
    b. Blades should be replaced by at least two people—and preferably three. Always use jack stands or a hoist.
    c. It is usually safer and more efficient to torch off old bolts.
    d. Always use new bolts with each blade replacement.
    e. Use an impact wrench to tighten bolts and secure blade in place. The impact wrench should be such that it does not over torque the bolts. An inexpensive 1/2-in. drive unit is better in this application than a 3/4-in. air impact wrench. Torque sticks or torque wrenches are ideal.
    f. Replace the carbide bits and the blade at the same time. Set the carbide and then install the steel blade.
    g. Shops should develop carriers to hold the blades in place and allow for a safer installation operation. Two- or three-piece blades reduce the weight that staff has to deal with. The smaller size of two- or three-piece blade segments may also be necessary if blades are heat treated. This is because the segments can grow; the longer they are, the greater the variability and the harder it is to maintain tolerance for holes.

26. Supervisors should be provided with pickup trucks that are safe to use in snow. Supervisors sometimes have to go out to check road conditions and assist operators or check on snow-clearing progress. Rear-wheel-drive pick-up trucks are not adequate for performing these tasks, and supervisors often end up having to be driven around in a snow plow truck to be able to do their work.
27. Plow trucks should have a capacity adequate to carry the required amount of material, both solid and liquid, for treating the assigned route.
28. High-output plows, such as the Alaskan plow, should be used in rural areas only. In urban areas, 12-ft-long flush plows are best.
29. Steel blades cut ice better than carbide blades, but they also wear out faster. The best setup is to use a steel blade in front of a carbide-reinforced plate. The steel blade ensures cutting adequacy, while the carbide ensures durability.
30. High-performance blade systems that use multiple materials, such as JOMA or PolarFlex, provide improved performance. Some materials are less expensive but may wear out quicker.
31. Use a hydraulic system that limits the down force on the blade when available. It does make a difference.
32. One-way plows can handle more snow and may be more efficient in clearing large areas such as parking lots and interstate highways. Reversible blades are more efficient for clearing roadways because they can be used to push the snow away to the left or right of the road.
33. Some plows, such as the Alaskan plow, cause uneven wear on the blades. It is common practice to replace the whole blade set—not just sections of it.
34. A safety inspection should be conducted on trucks every six months.
35. Drivers must perform a walk-around inspection of their trucks every time before they head out. They must also be trained on how to look for problems such as loose bolts and cracked blades.
36. Keep adequate truck maintenance and inspection records.
37. Keep adequate blade replacement records.
38. Technology is improving and can be integrated to make snow and ice control operations more efficient. This includes GPS, weather-monitoring systems, road temperature sensors, computerized salt control and slurry technology, automatic vehicle location (AVL), a maintenance decision support system (MDSS), and mobile apps to keep the public informed about road conditions.
39. Guidelines for truck replacement must be developed. These guidelines must take into consideration any value added by new technology in addition to comparing maintenance to replacement costs. Plows do not need to be replaced as long as they are still structurally adequate and safe to use.
40. Initial and continual training must be required of all truck operators. Hands-on training is necessary, and job shadowing or riding along during an actual snow- and ice-clearing operation is highly recommended. The Clear Roads Project and AASHTO offer a number of training manuals and videos that can be incorporated in a comprehensive training program.
41. Training programs must be updated on a regular basis to incorporate new information and the use of new technology.

CHAPTER 4 FIELD STUDY

4.1 SCOPE AND OBJECTIVES

The foundation of all field testing procedures is to develop an instrumentation plan to collect usable data to analyze. This chapter describes the procedure that was used to instrument a plow truck to collect information to use to possibly attain a better understanding of plow behavior under real plowing conditions. The project team developed a plan for installing a data collection system for a front-mounted plow and an underbody scraper mounted on an IDOT truck. This was achieved by performing the following tasks:

- Development of the data collection system
- Selection of sensors and a data acquisition system
- Calibration of the sensors
- Instrumentation of the snow plows
- Performing dry runs to test the system
- Collecting plow-related data during actual snow storms

The following figures show images of the truck that was instrumented for data analysis and collection. In Figure 7, an Alaskan front-mounted plow is attached to a tandem dump truck. In Figure 8, the carrier structure for the Alaskan front-mounted plow can be seen. There are two shock absorbing springs and a hydraulic arm to raise and lower the plow. Figure 9 shows the setup of the blades that were used during collection of data during the dry runs.

Figure 7. Front-mounted Alaskan plow on tandem dump truck.

Figure 8. Carrier structure of front-mounted Alaskan plow.

Figure 9. Steel blade with carbide insert and curb guard.

4.2 INSTRUMENTATION

The carrier structure and the front-body snow plow were instrumented using 16 piezo strain sensors from OES Technologies, Inc. (Figure 10). These sensors were selected for their compact size, ease of installation, and protective steel casing. The strain data that the sensors produced were collected with an LRG-5325 multifunctional data logger from Measurement Computing.

Figure 10. Piezo strain sensor.

The underbody plow was instrumented with six piezo strain sensors mounted across the backside of the moldboard and two accelerometers attached to the backside of the plow. The locations of the accelerometers were at the midpoint on each half of the plow. The accelerometers were mounted inside lengths of square tubing, and the ends of the tubes were covered with silicone to prevent any moisture from reaching the accelerometers. These two accelerometers were used to determine whether the plow is up or down and the plow cutting angle.

The strain sensors and conditioning modules were powered with a Power Stream SR700 12- to 24-v DC/DC power converter. A battery backup system was plugged into a DC/AC power inverter and used to power the data acquisition system. This was done to make sure the data acquisition system did not reinitialize every time the truck engine stop during any single data collection event.

Several other materials were purchased from a local hardware store: rubber shrink-wrap to protect the connection of the cable to sensors from moisture, silicone sealant to protect the contact pads of the strain sensors from moisture, and ¾-in.-diameter liquid tight conduit, which was used to protect the cables from adverse weather conditions.

In addition to using strain sensors, it was decided to instrument the truck with a GPS and two video cameras to capture the front and rear views of the snow plowing operation. A GoPro camera was mounted on the rear of the truck to capture the pavement after it had been cleaned of snow and ice. The camera comes with a waterproof case made of polycarbonate and stainless steel to protect it from the harsh elements of the winter. A special mounting attachment was purchased with the camera so that it could be attached to a custom bracket welded to the back of the IDOT truck. An advanced vehicle black box two-channel driving video recorder (model SCI-DR200, marketed by Spy Chest, Inc.) was mounted inside the cab of the truck on the windshield. This video camera captures both an inside and a forward view of the truck. The camera also records the truck's speed, GPS location, and, when desired, internal audio of the truck. The camera has infrared illuminators for night recording. The exterior camera shoots a view of 130 degrees, and the interior camera shoots a view of 125 degrees. Figure 11 provides sample snapshots of the rear and front views captured by the cameras.

(a) Rear view camera (b) Front view camera

Figure 11. External view cameras.

4.2.1 Wiring Technique and Assembly

The wiring technique used to construct the strain gauge assembly was designed to be as simple as possible. Sensors were connected to conditioning modules that were in turn connected to the data logger. The data logger was marked with a “CH” to signify the single-ended analog channels into which the sensor conditioners were hardwired. The AGND channel on the data logger was used as a ground for the sensors. For consistency, the orange wires were used to hardwire the conditioners into the single-ended analog channels and green wires were used to ground the conditioners into the AGND channels. This assembly is shown in Figure 12.

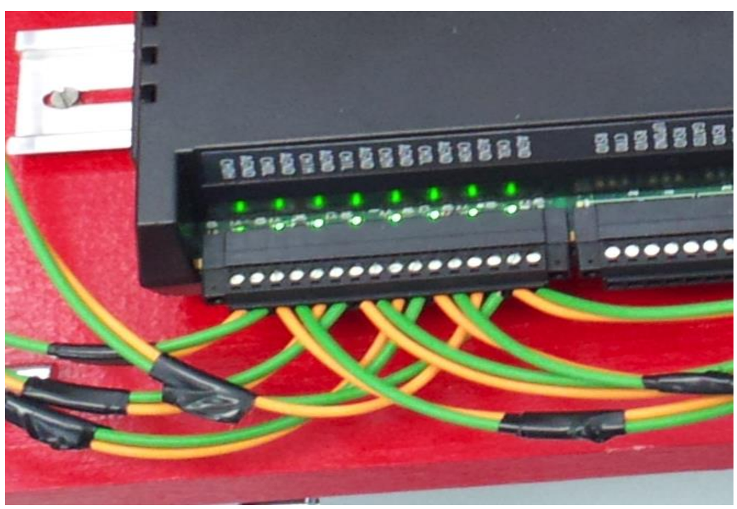


Figure 12. Single-ended analog channel and AGND channel.

To further simplify the wiring assembly, the conditioned sensors were separated into groups of four. Each set of four was connected in parallel to the SR700 power converter that was hardwired to the truck battery to supply the power. A parallel connection between three sets of conditioning modules is shown in Figure 13.

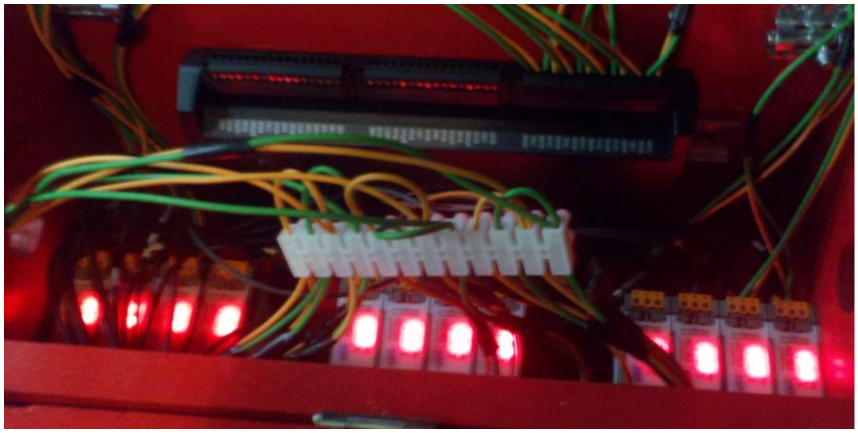


Figure 13. Parallel connection between three sets of conditioning modules.

As shown in Figure 14, the control modules and data logger were installed in a wooden box to keep the assembly compact for ease of transportation and installation, reduce vibrations, and protect the equipment from damage.

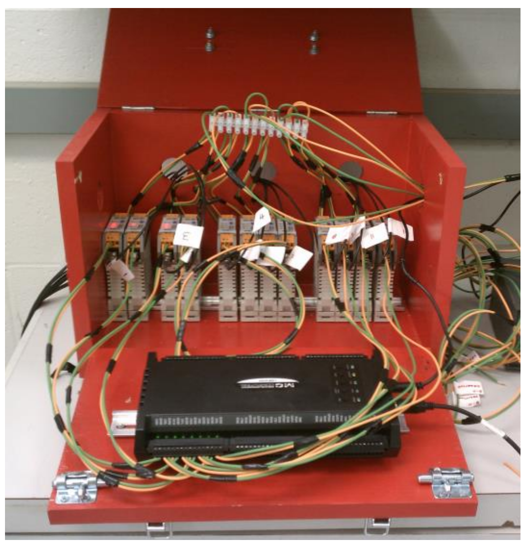


Figure 14. Box containing data conditioning modules and data logger.

The power converter was wired to the auxiliary switch on the panel of switches in the truck cab so that during operations outside of the winter season, the truck could function without powering the instruments. The power converter is shown in Figure 15.

Figure 15. Connection to power converter.

4.2.2 Strain Gauge Calibration

Strain gauge calibration factors were obtained from the manufacturer as 35 mV/microstrain; however, an attempt to verify this calibration factor at the lab was inconclusive. A W8 × 10 steel section, shown in Figure 16, was used for the attempted calibration. A hole was drilled into the steel section with a 3/16-in. drill bit and threaded with a 6 × 1.00-mm tap. This setup allowed the strain sensor to be mounted to the steel section. Each strain sensor was mounted to the steel section and loaded at a constant rate for 5 minutes, with load readings taken approximately every 15 seconds. However, the compression testing machine that was used to load the specimen did not allow for direct electronic recording of the applied load, which had to be written down by hand. This made the correlation between the electronically recorded voltage reading and the handwritten load impossible to achieve. A load cell was later obtained so that strain gauge calibration could be performed once the gauges are removed from the truck.

Figure 16. Steel section assembly used for attempted calibration.

4.2.3 Installation

The same process for drilling and tapping the hole on the W8 × 10 steel section was used throughout the plow and carrier structure. Eight strain sensors were installed onto the carrier structure, and eight sensors were installed on the plow itself, as illustrated in the schematic shown in Figure 17. The strain gauges that were installed on the carrier structure were placed in the longitudinal direction of the elements they were attached to. This setup allows for measuring the axial stress, which is the most likely critical stress, in each of these elements. The four pairs of strain gauges that were attached to the plow consisted of one horizontal strain gauge and one vertical strain gauge at each location to measure stresses in both directions and potentially gain a better understanding of the behavior of the plow under service.

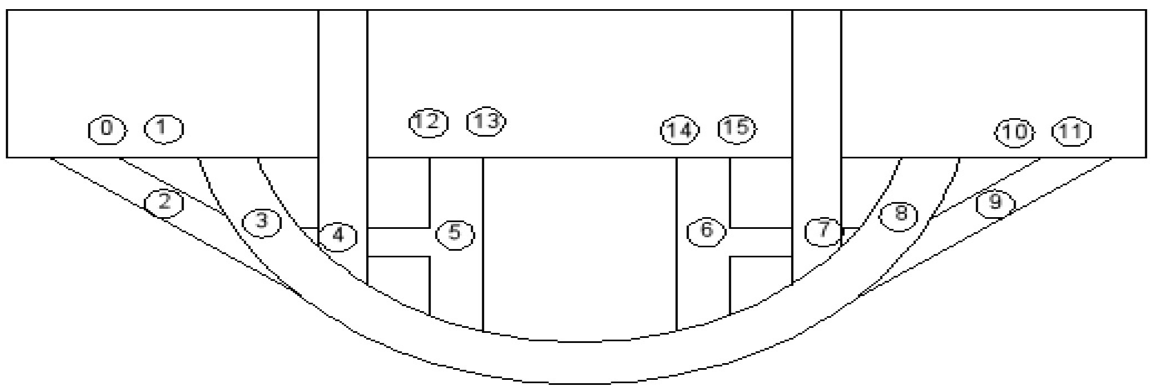


Figure 17. Location of strain sensors on front plow.

Figure 18 is an example of how strain gauges were installed. Each member was sanded down to bare steel to allow for direct contact between the pads on the strain gauge to the member. The strain sensors were connected with the 3-ft SMA male to 10-32 male lead cables that were then connected to the 24-ft SMA male to SMA female extension cables.

Figure 18. Member preparation and strain gauge installation.

The extension cables were then cut and reconnected to a special plug (Deutsch 23-pin connector provided by the IDOT Morton facility) for a quick disconnect in case it was needed. Figure 19 is an image of the quick-disconnect plug. The cables were then run from the plug into a 3/4-in.-diameter liquid-tight, flexible conduit that fed into the engine bay of the truck and into the cab as shown in Figure 20. For all the intermediate connections that are exposed to adverse weather conditions, dielectric grease was applied to prevent moisture from entering the connections.

Figure 19. Plug connection.

Figure 20. Conduit fed into truck engine bay.

The cables exited the conduit in the cab of the truck, and the SMA male ends were connected to their respective condition modules. Figure 21 shows the conduit feeding the cables to the data collection box. The power supply for the condition modules and the procedure in which the condition modules were hardwired into the data logger was done exactly as stated in the wiring technique and assembly section of this report.

Figure 21. Conduit fed into data collection box.

The underbody scraper that was used for this study is a Monroe Scraper MS4410 and is shown in Figure 22. The moldboard is 1 in. thick by 15 in. tall by 10 ft wide. The underbody scraper can be operated while turned to the right or the left in the down position.

Six strain gauges were mounted across the backside of the scraper moldboard; their locations are shown by circled numbers in Figure 23. Three strain gauges run parallel to the blade edge (1, 2, and 4), and three strain gauges run perpendicular to the blade edge (0, 3, and 5). Orienting the strain gauges in this manner allowed for collection of strains in two directions on the plow. Figure 24 is a photo of the installed strain gauges. Two accelerometers were attached to the backside of the plow at the midpoint on each half of the plow. The accelerometers were used to determine if the plow is up or down. The locations of the accelerometers are indicated by numbers in rectangles in Figure 23.

Figure 22. Monroe MS4410 underbody scraper.

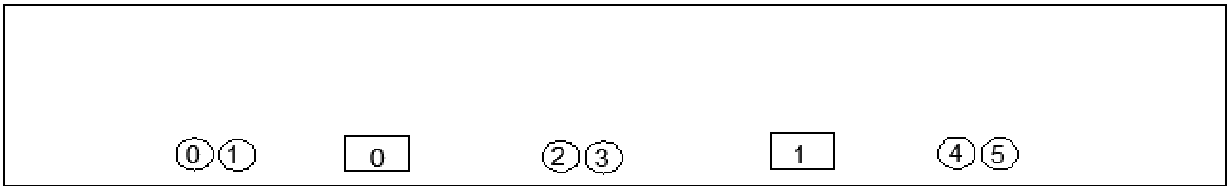


Figure 23. Underbody scraper strain gauge and accelerometer locations.

Figure 24. Strain gauges installed on the back of the underbody scraper.

After all of the sensors and cables were installed, protective measures were taken to ensure that the cables and sensors could endure the adverse weather conditions. The cables exiting the liquid-tight, flexible conduit toward the plow were protected by standard plastic conduit. These cables were also secured to the carrier structure using zip ties. By doing this, the cables are clear from the possible danger of being pinched during operations. Figure 25 shows how protective measures were used to protect the cables to the OES strain gauges.

Figure 25. Strain gauge protection.

4.2.4 Accelerometer Calibration

The angles measured by the accelerometers are used to determine whether the underbody scraper is up or down. The accelerometers were wired directly to the data acquisition system, and calibration factors provided by the manufacturer were used to convert voltage to angles. Prior to actual field testing, angle readings from the accelerometers were taken and compared with the actual angles of the scraper measured using a smart level with the scraper in one of two possible positions: up (Figure 26) or down (Figure 27). The results are shown in Table 1.

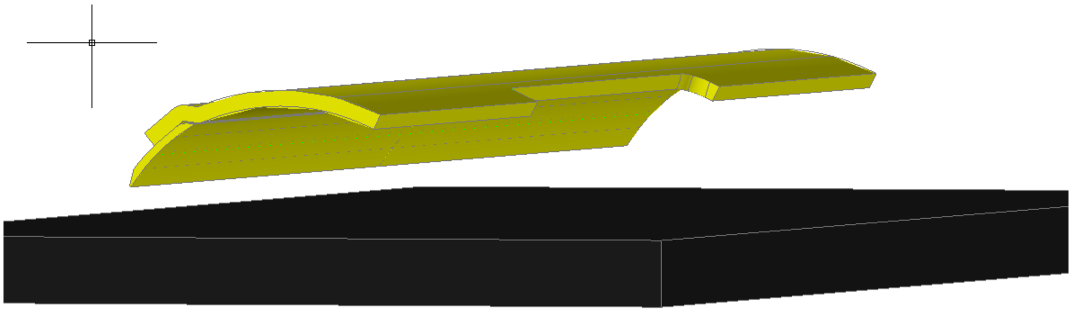


Figure 26. Underbody scraper in the up position.

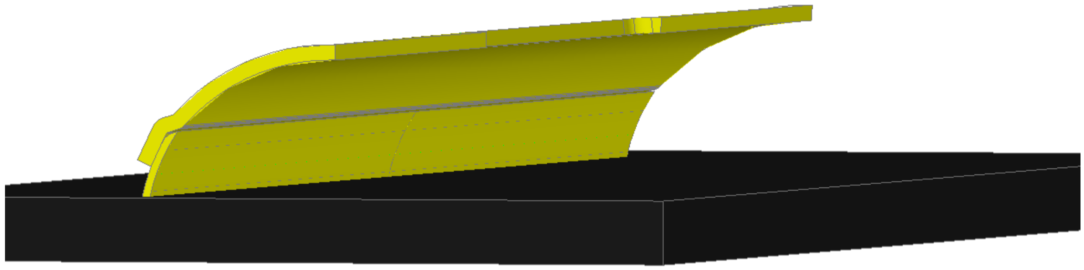


Figure 27. Underbody scraper in the down position.

Table 1. Calibration Verification for Underbody Scraper Accelerometer

	Plow angles (degrees)				
	Plow oriented to the left		Plow oriented to the right		
Plow position	**Accelerometer 0**	**Accelerometer 1**	**Accelerometer 0**	**Accelerometer 1**	**Average angle (degrees)**
Plow up (measured)	2.6	4.7	3.8	6.1	4.3
Plow up (from data)	7.49	6.29	7.68	6.41	6.97
Plow down (measured)	50.1	52.1	51.0	52.4	51.4
Plow down (from data)	51.03	52.84	52.01	52.79	52.17

4.3 FIELD TESTING—INITIAL DRY RUNS

To evaluate the instrumentation and data collection system before full-field implementation during the winter season, plowing of dry pavement surfaces was carried out for an asphalt pavement surface, a concrete pavement, and dry soil on a concrete pavement surface. The testing for the dry run on pavement surface consisted of four conditions, with each condition having two trial runs, while the dry-soil plowing dry run consisted of two conditions. Table 2 summarizes the six conditions. The average truck speed for each trial is also listed. When the blade saver is off, the effect of gravity places the entire weight of the plow on the pavement surface. With the blade-saver option on, the carrier structure hydraulically relieves some of the pressure from the plow to decrease wear on the blade. This is also expected to produce fewer stresses in the blade and the body of the plow. The evaluations took place in Morton, Illinois. Each dry-run trial ran a distance of approximately 300 ft, and the truck was then brought back to the IDOT Morton facility.

The blade saver used on the front-mounted plow is a Monroe Plow SAV hydraulic control valve system. This system is designed to reduce the normal force acting on the cutting edge of any snow plow with respect to the roadway surface. According to the Monroe Hydraulic & Controls sales team, in order to apply a constant up-lifting force on the plow lifting cylinder, the valves on the Plow SAV use an

adjustable-pressure reducing cartridge. When the valve of the Plow SAV is electrically activated by the flip of a switch in the truck cab, the plow lift cylinder becomes pressurized at a percentage of the amount of force required to lift the plow off of the cutting edge, and some of the weight becomes transferred to the front axle on the truck chassis. Because the Plow SAV pressure-reducing valve can be adjusted, the amount of weight on the cutting edge of the plow can be easily adjusted to fit the equipment on a specific truck. When the plow is being transported or not in use, the blade-saver valve is turned off to provide the plow lift cylinder with full pressure to raise the plow off the pavement.
For the researchers to gain an understanding of the blade saver, the Alaskan front-mounted plow was weighed on a scale. The weight of the normal force acting on the blade edge from the plow was decreased by slightly more than approximately 25% (2890 to 2130 lb). The use of the Plow SAV function increases the life of the blades while reducing the wear and tear on the truck.

Table 2. Dry Run and Dry-Soil Run Conditions

Pavement type	Blade saver	Truck speed (mph)
Dry run on asphalt (Illinois Route 150)	On	30
		35
	Off	35
		35
Dry run on concrete (Courtland Street)	On	20
		30
	Off	30
		28
Soil dry run on concrete (IDOT Yard, Morton)	On	5
		6
	Off	6
		6

Dry runs on a concrete pavement surface covered with soil were conducted. It was expected that data collected in this test would resemble snow plowing data to a certain extent. This test took place at the Morton truck facility. The data collected were used to compare the effect of the blade-saver option and to evaluate the instrumentation and data collection system and its functionality. Figure 28 provides an overall look at the process. Figures 28(a) and 28(b) shows the rear and front views, respectively; Figure 28(c) shows the truck during the dry-soil plowing operation, and Figure 28(d) shows the complete layout of the soil run.

(a) (b) (c) (d)

Figure 28. Dry-soil runs: (a) rear GoPro camera view of concrete, (b) front camera view—soil run on concrete pavement, (c) plowing with the Alaskan plow during soil run, (d) complete layout of soil run.

4.3.1 Results and Analysis

After the data collected during the dry runs were retrieved, it was clear that all the sensors were operational and collecting data. The data collected was then used to examine the effect of the blade-saver option, pavement type, and dry-soil runs (saver on and off). Figure 29 shows the effect of the blade saver on concrete pavement. The figure shows that higher stresses developed when the blade-saver option was off compared with when it was on. A similar trend was observed for asphalt pavements. The effect of pavement type is illustrated in Figure 30. The data were obtained with the blade-saver option on. The figure shows that plowing on the concrete pavement resulted in higher stresses developing within the plow. The same trend was observed when the blade-saver option was off. Two cases of the dry-soil run results are shown in Figure 31: blade saver on, and blade saver off. The figure shows that the blade-saver-off option resulted in higher stresses developing within the plow.

It is important to mention that each figure shows the results for one gauge only; the other gauges showed similar trends but different magnitudes of stresses. In all these figures, the continuous line is a smoothing line obtained by applying a moving average filter to the collected data.

(Note: the stresses shown are negative, which means that the higher stresses are shown on the lower side of each graph.)

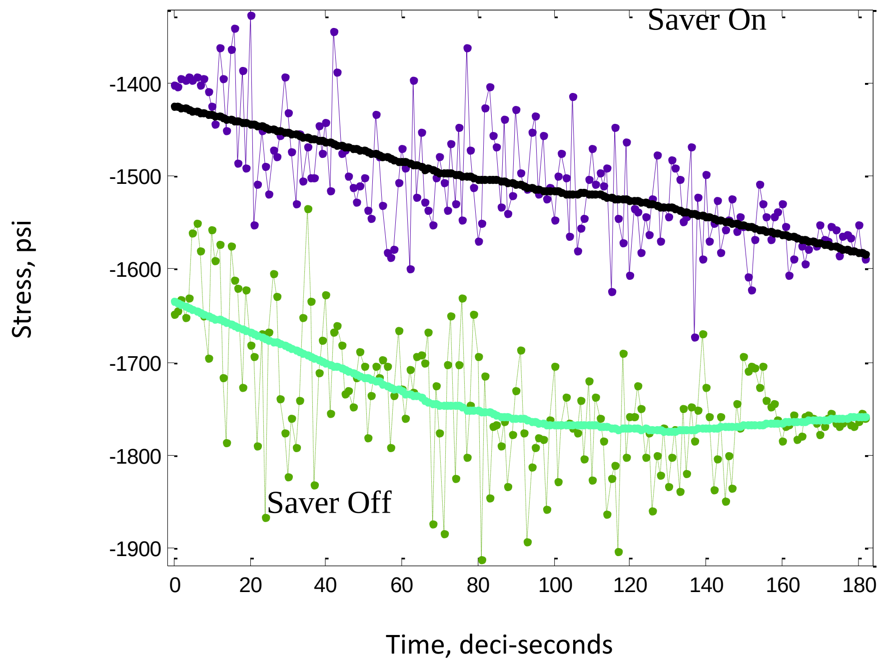


Figure 29. Effect of blade saver on concrete pavement (dry run).

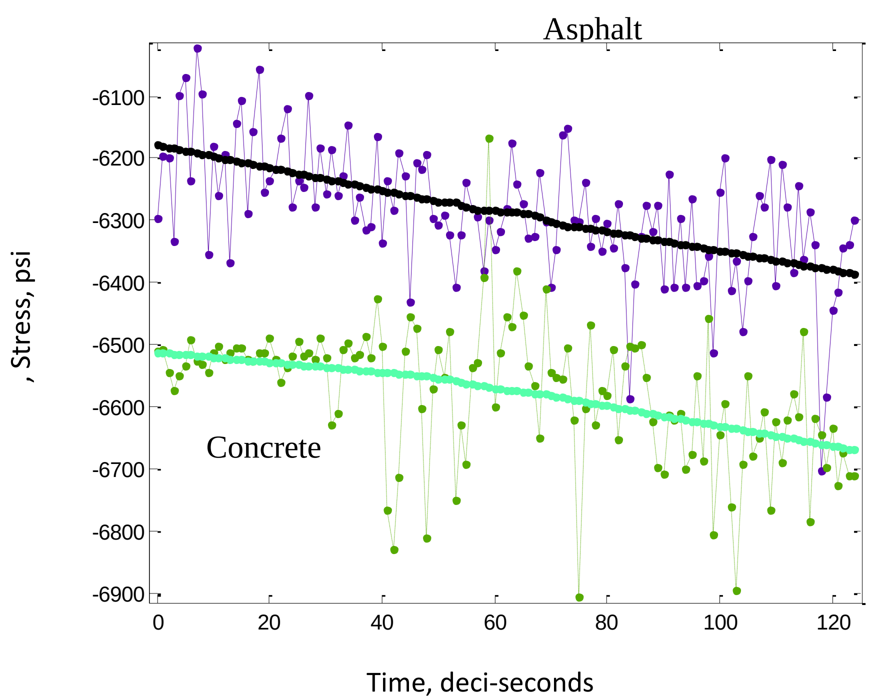


Figure 30. Effect of pavement type (dry run).

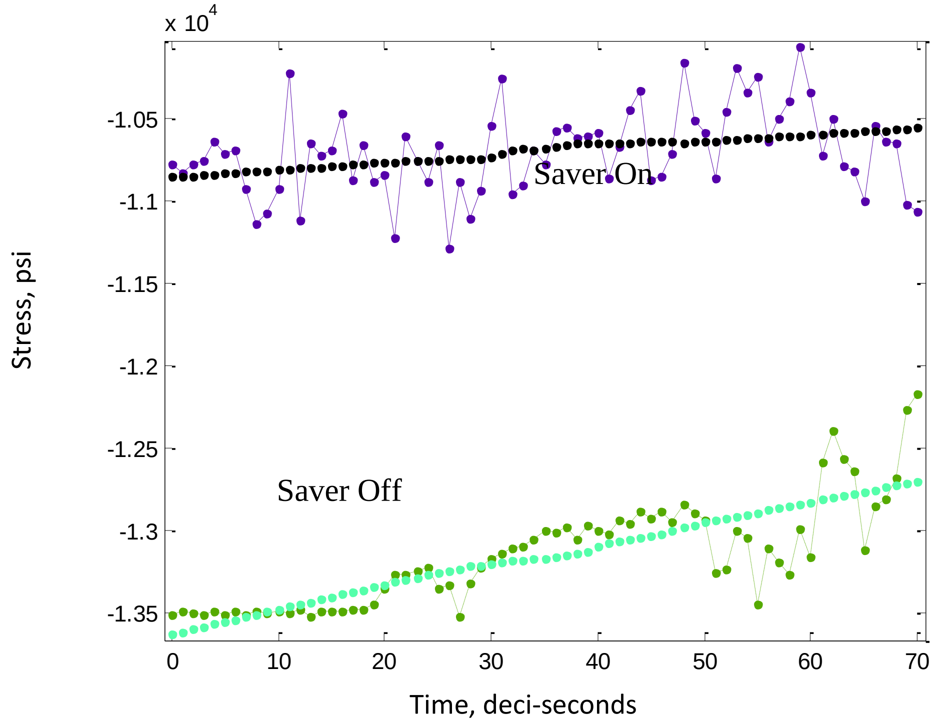


Figure 31. Effect of blade saver (soil dry run).

4.4 FIELD TESTING—SNOW STORMS

Field testing was conducted during 11 snow storms that took place during the 2012, 2013, and 2014 snow seasons per the schedule shown in Table 3.

Table 3. Field Testing Schedule

No.	Date	Start time	Min. temp °F	Mean temp °F	Max. temp °F	Snow in.	Snow depth in.	Wind speed mph	Dew point °F
1	12/20/2012	6:45 PM	22	37	51	4.50	0.00	15	34
2	12/31/2012	2:48 PM	20	28	36	1.00	0.00	8	23
3	2/1/2013	11:48 PM	1	11	21	0.30	—	11	3
4	2/21/2013	6:58 PM	14	22	29	1.20	0.00	12	20
5	2/26/2013	8:19 AM	32	34	36	3.90	0.00	16	30
6	3/5/2013 (*)	7:20 AM	28	32	35	2.80	3.00	10	28
7	12/13/2013	7:40 PM	17	28	39	2.80	—	5	24
8	1/1/2014	7:36 PM	15	20	24	1.70	—	12	16
9	1/4/2014	7:11 PM	21	29	36	2.40	1.00	12	21
10	1/31/2014	8:01 PM	18	20	21	3.10	3.00	5	13
11	2/4/2014	9:58 PM	8	15	22	2.00	5.00	10	12

*No data were collected because there was no activity as a result of light snow or equipment malfunction.

The instrumentation was inspected in preparation for each snow plowing event, and the status of each sensor was recorded before and after the plowing. The results of the inspection were recorded on a form such as the one shown in Figure 32.

BRADLEY UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION
ITC Project R27-94 – Evaluation of Snow Plow Performance
Equipment Check List Front Body Plow

Date:	12/31/2012
Inspectors:	Drew Dragoo
Truck #:	62
Plow Brand:	Valk Alaskan Plow
Blade Type/Material:	Steel/Steel

Strain Gauge Modules Check						
	Before Plowing			After Plowing		
#	Turns On	Records Data	Explanation	Still On	Records Data	Explanation
0	✔			✔		
1		no	Did not Turn on		no	Did not Turn on
2	✔			✔		
3	✔			✔		
4	✔			✔		
5	✔			✔		
6	✔			✔		
7	✔			✔		
8	✔			✔		
9	✔			✔		
10	✔			✔		
11	✔			✔		
12	✔			✔		
13	✔			✔		
14	✔			✔		
15	✔			✔		

Special Notes

Figure 32. Sample form: Effect of blade saver (soil dry run).

In addition, blade measurements were taken before and after the plowing to monitor blade wear and tear. A sample of the form used for recording these measurements is shown in Figure 33.

During the first snow storm, the front plow was used predominantly to remove the 1 to 2 in. of snow that accumulated on the roadway. The underbody plow was used for a very short period of time because the snow and ice came off the road fairly easy with both a salt brine mix and the front plow. The operator used the underbody scraper only on portions of the roadway where ice was packed and the driving lanes were covered. The underbody scraper is used primarily for clearing snow and ice-packed roadways that cannot be cleared without the extra downward force on the blade to scrape the roadway clean. While a speed of 25 mph to 40 mph is adequate when the front plow is being used, the underbody scraper must be operated at a significantly lower speed, 10 to 25 mph, to prevent damage to the truck and the roadway.

BRADLEY UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION

ITC Project R27-94 – Evaluation of Snow Plow Performance

Visual Inspection of Snow Plow Front Plow Blade

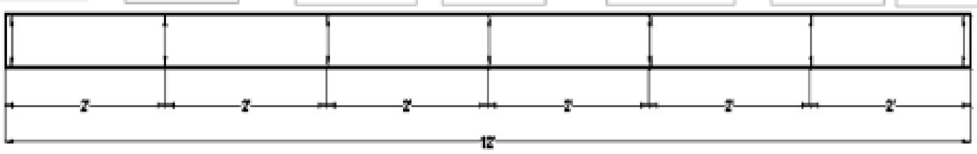
Date:	12/31/2012
Inspectors:	Drew Dragoo
Truck #:	62
Plow Brand:	Valk Alaskan
Blade Type/Material:	Steel/Steel-Double Steel

Before Plowing- Front Plow Blade

Step 1: Measure the wear of the blade at the 7 points. Measure the height and thickness of blade. Look at the plow and blade to find any fractures or preexisting cracks. Mark on the diagram of where the existing fractures and preexisting cracks exist. Take Notes and pictures if necessary.

Driver | Passenger

7-1/2" | 7-1/4" | 7-1/16" | 7" | 7-3/16" | 7-1/4" | 7-1/4"



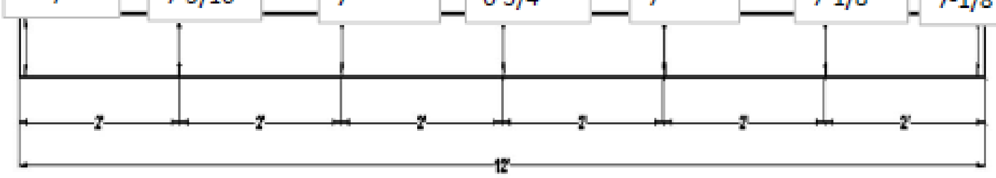
Notes:

After Plowing- Front Plow Blade

Step 2: Measure the wear of the blade at the 7 points. Measure the height and thickness of blade. Mark on the diagram where the fractures and cracks are located. Look at the plow and blade to find any new fractures or cracks. Take Notes and pictures if necessary.

Driver | Passenger

7-3/16" | 7-3/16" | 7" | 6-3/4" | 7" | 7-1/8" | 7-1/8"



Notes:

Figure 33. Sample visual blade inspection form.

4.4 FIELD TESTING—FINAL DRY RUNS

Two final dry runs were performed to obtain more-reliable data for calibrating the finite element model and to compare the behavior of two types of blades on different pavements. The two blade types that were considered were of a PolarFlex blade with longitudinal carbide inserts and a steel blade with dowel-type carbide inserts.

The runs were performed on an asphalt pavement and a concrete pavement for each type of blade. A GoPro camera was installed on the truck directly behind the front plow to catch the plow in action when it was down on the pavement. Plow stresses were collected during all four runs, which were performed over a 4-day period.

Figures 34 and 35 show the plow with a PolarFlex blade on asphalt and concrete pavements, respectively. An examination of the GoPro video showed that the blade hugs the asphalt pavement better than it does the concrete pavement. Moreover, the video showed that this blade produces a lot of sparks, indicating that blade material is being lost.

Figure 34. PolarFlex blade on asphalt pavement.

Figure 35. PolarFlex blade on concrete pavement.

Figures 36 and 37 are snapshots from the video of a plow with a rigid steel blade that has dowel-type carbide inserts used on asphalt pavement and concrete pavement, respectively. The video consistently showed a sizeable gap between the blade and the pavement when this type of blade was used. This was true for both the asphalt and the concrete pavements. Moreover, sparks were very scarce when this type of blade was used, but dust can easily be seen at the points of contact of the blade with the pavement. This indicates that this type of blade causes material to be removed from the pavement.

Stress data were collected for both the front plow and the underbody scraper. Furthermore, the researchers took note of when the blade saver was on and when it was off to synchronize that information with the collected data. As of the date of writing this report, the researchers had not been able to adequately examine the stress data that were collected during these dry runs or use any of them for calibrating the finite element models.

Figure 36. Carbide insert blade on asphalt pavement.

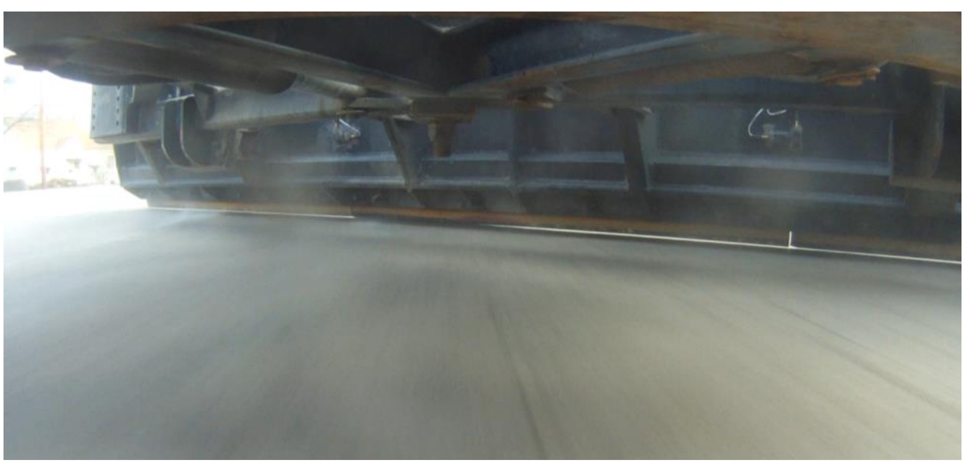


Figure 37. Carbide insert blade on concrete pavement.

4.5 SAMPLING OF FIELD TESTING RESULTS—STRESSES

Stresses measured on the front plow and carrier structures were generally not very high and typically did not exceed 10,000 psi in compression or 5,000 in tension. For the underbody scraper, the stresses varied from about 1000 psi in compression to near 10,000 psi in tension. Table 4 shows the minimum, maximum, average, and median stress values for the different sensors on the front plow, and Table 5 shows the same parameters for the carrier structure. Table 6 shows these same stress parameters for the underbody scraper. The shaded values represent minimum and maximum stress values.

Table 4. Minimum, Maximum, Average, and Median Stresses and Stress Standard Deviation for Front Plow During 12/31/2012 Snow Storm

Sensor	0	1	12	13	14	15	10	11
Minimum stress	-3861	4804	-1191	-4687	-5761	-1915	-801	-8065
Maximum Stress	975	4875	-96	-4133	-5539	288	731	1031
Average stress	-69	4859	-562	-4415	-5633	-272	-218	-5575
Median stress	-48	4859	-551	-4411	-5636	-281	-228	-5562
Standard Deviation	178	3	43	26	13	75	111	219

Table 5. Minimum, Maximum, Average, and Median Stresses and Stress Standard Deviation for Plow Carrier Structure During 12/31/2012 Snow Storm

Sensor	2	3	3	5	6	7	8	9
Minimum stress	-7992	-3295	-3499	-7395	-8139	-8196	-8016	-8107
Maximum Stress	-4794	-418	655	-3043	-1573	923	-1450	-2795
Average stress	-5606	-1590	-1379	-5520	-5455	56	-5294	-4884
Median stress	-5597	-1599	-1370	-5582	-5510	852	-5331	-4847
Standard Deviation	182	309	102	478	849	2553	623	262

Table 6. Minimum, Maximum, Average, and Median Stresses and Stress Standard Deviation for Underbody Scraper During 11/19/2012 Snow Storm

Sensor	2	3	3	5	6	7	8	9
Minimum stress	-7992	-3295	-3499	-7395	-8139	-8196	-8016	-8107
Maximum Stress	-4794	-418	655	-3043	-1573	923	-1450	-2795
Average stress	-5606	-1590	-1379	-5520	-5455	56	-5294	-4884
Median stress	-5597	-1599	-1370	-5582	-5510	852	-5331	-4847
Standard Deviation	182	309	102	478	849	2553	623	262

CHAPTER 5 FINITE ELEMENT ANALYSIS

5.1. SCOPE AND OBJECTIVES

The objective of this chapter is to present the characteristics of the finite element (FE) models developed to analyze the snow plow. Two FE models of the front plow and the underbody scrapper were developed to study the effect of the snow load on the different components of the plows and to identify the location of the critical stresses. Following the validation of the FE models by comparing the strains measured in the field with those obtained from the FE models, the models will be used to determine the locations of the critical stresses in the plows and conduct a parametric study of the effect of crucial design parameters on the performance of the snow plow. All FE models were developed using the commercial software Abaqus/CAE.

5.2 FINITE ELEMENT MODELS

5.2.1 Finite Element Model for Front Plow

5.2.1.1 Geometry

The entire geometry of the front plow is depicted in Figure 38. The 3D models were developed using the Autodesk software AutoCAD and then imported into the Autodesk software Inventor to ensure accuracy of each of the components of the front plow. The components of the front plow were drawn according to the exact dimensions of the actual plow parts.

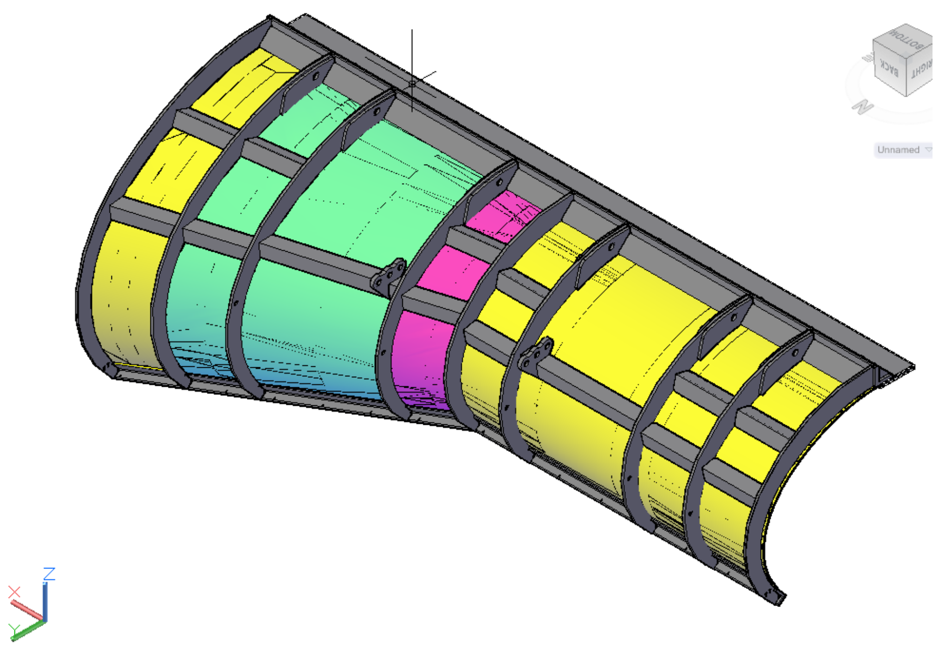


Figure 38. 3D front plow model.

5.2.1.2 Node and Element Numbering

The front plow FE model consisted of 23,018 nodes and 10,264 elements. The node and element numbers were automatically generated by Abaqus. Figure 39 shows a portion of the front plow with the element numbering.

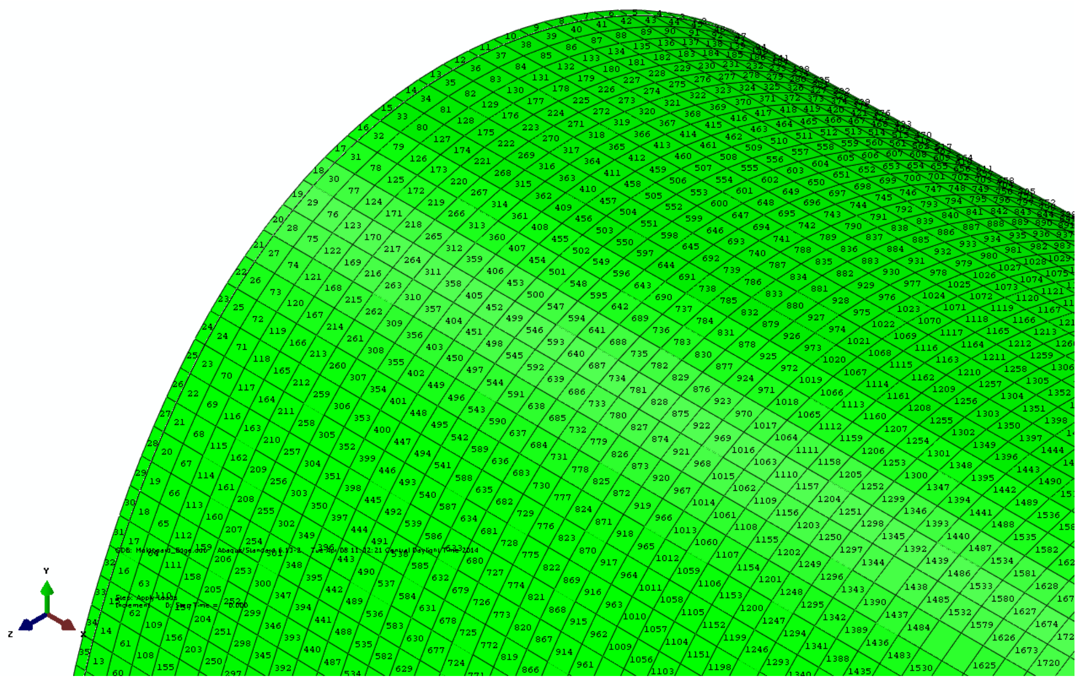


Figure 39. A portion of the front plow showing the element numbering.

The 3D model was imported into Abaqus using the “import part” command and was assembled using the “assembly module” of Abaqus. The components were positioned and oriented in their correct directions and combined to produce the actual 3D shape of the front plow. The eight-noded, linear-brick, reduced-integration (C3D8R) element shown in Figure 40 was used to model the different components of the front plow. Solid brick elements were used to account for the continuity of the front plow and its components.

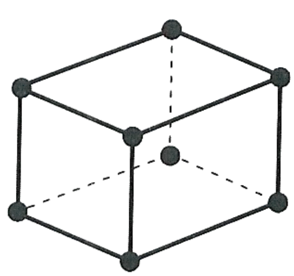


Figure 40. Eight-noded reduced integration element (C3D8R).

5.2.1.3 Front Plow Boundary Conditions

Fixed boundary conditions were imposed at the middle of the moldboard on this model, simulating the connection between the moldboard and truck as shown in Figure 41. This support condition represents the worst-case scenario on the plow, even though the plow has tripping mechanism springs once a certain load is reached.

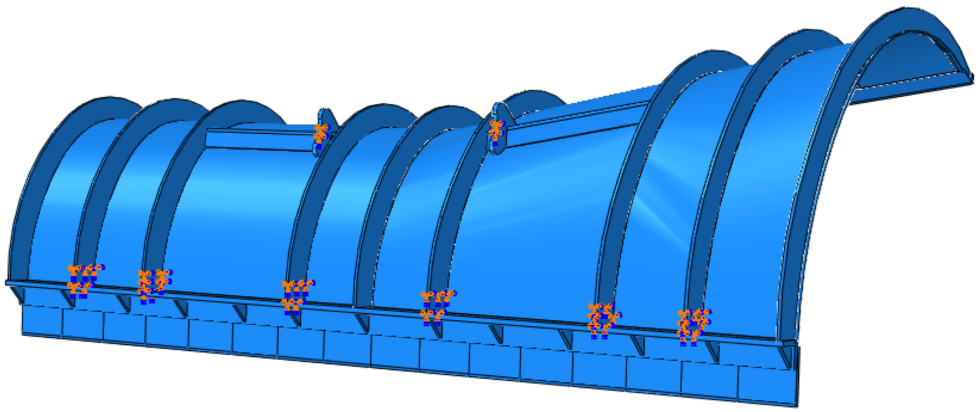


Figure 41. Boundary conditions applied to front plow.

5.2.1.4 Front Plow Model Loading

In an attempt to take all possible plow loadings into consideration, five loading configurations were applied to the FE model:

1. a vertical blade edge pressure to simulate the normal force the pavement exerts on the plow during a snow and ice plowing operation (Figure 42)
2. a friction loading to simulate the interaction of the self-weight of the snow plow and the pavement surface across the bottom edge of the blade (Figure 43)
3. a uniform blade pressure to model the snow build-up that occurs across the blade (Figure 44)
4. a uniform moldboard pressure to model the snow traveling up the plow to be launched onto the shoulder (Figure 45)
5. a concentrated force to represent the plow hitting a pavement reflector, pothole, manhole cover, or grate (Figure 46).

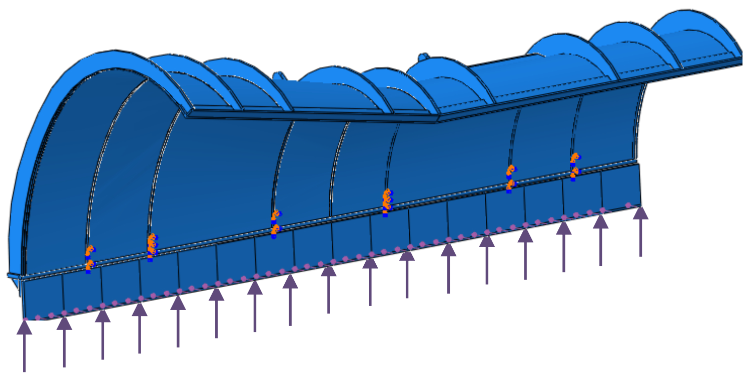


Figure 42. Front plow blade subjected to vertical edge pressure.

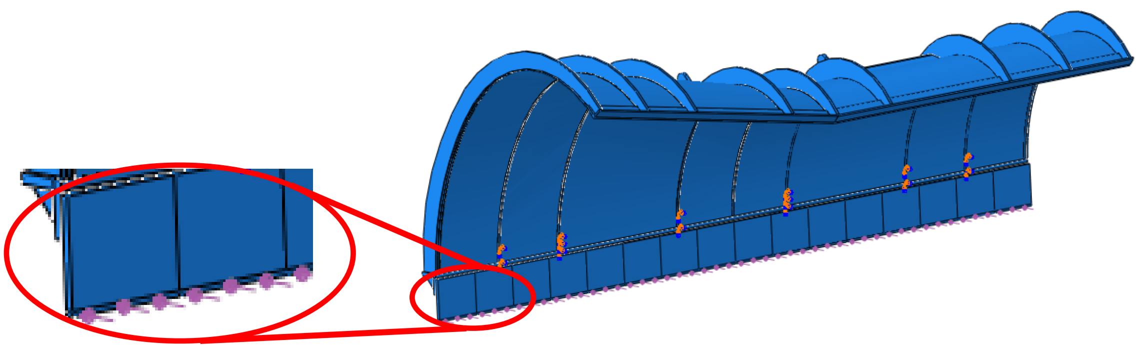


Figure 43. Front plow blade subjected to friction loading.

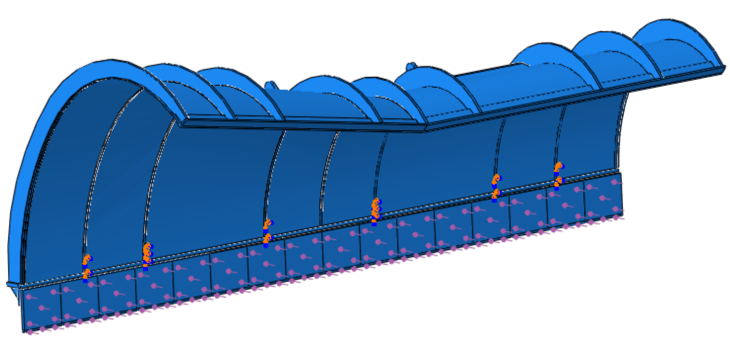


Figure 44. Front plow blade subjected to uniform blade pressure.

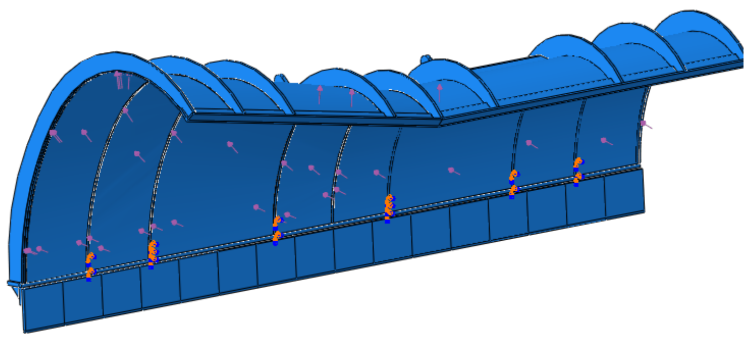


Figure 45. Front plow blade subjected to uniform moldboard pressure.

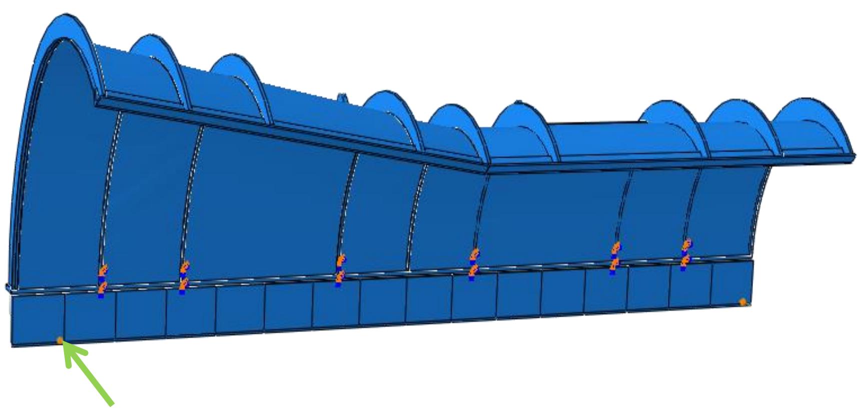


Figure 46. Front plow blade subjected to concentrated load.

5.2.1.5 Constraints

The front-mounted Alaskan plow is 100% welded together. Tie constraints are used to represent the welded connections between parts, including the moldboard and the supporting ribs and between the moldboard and the top and bottom angles.

5.2.1.6 Meshing

Structured and sweeping mesh techniques were adopted for the components of the front plow. This approach was used to produce a mesh with as close to rectangular elements as possible. Figure 47 shows the meshing that was adopted for the front plow model in Abaqus.

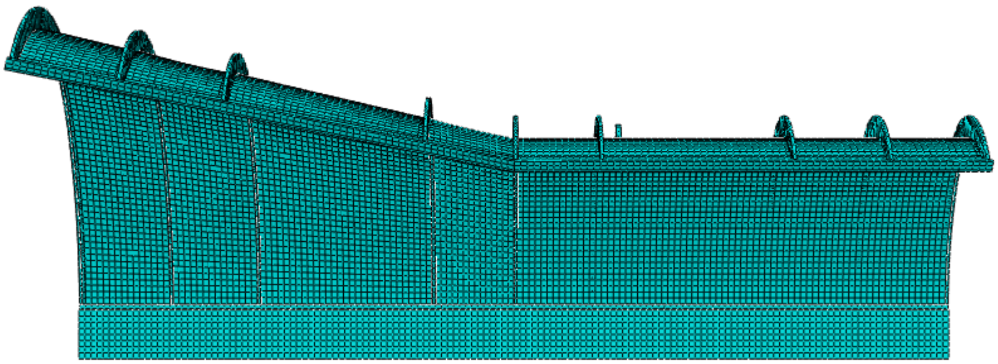


Figure 47. Meshing of the front plow.

5.2.1.7 Results of Analyses

The results of the analyses of the plow under the effect of the loads described above are presented in Table 7 for specific sensor locations on the plow. The stresses, which are given in psi, were obtained from the finite element model by averaging the stresses around the node closest to the sensor location.

Table 7. Computed Stresses (psi) at Various Locations of Front Plow

Sensor location	Plow self-weight	10 psi vertical blade edge pressure	10 psi blade edge friction	10 psi blade pressure	10 psi moldboard pressure	10 lb force applied at sensor 0 blade corner	10 lb force applied at sensor 11 blade corner
0V	–927.413	–20.2	143.6	1029.55	1892.68	2.195	0.0809
1H	4338.25	–9.44	12.4	167.09	–274.305	1.975	–0.044
12V	718.9	–9.34	57.8	450.101	2621.38	0.595	0.0224
13H	682.97	–1.27	55.9042	338.65	203.149	1.291	0.155
14H	4655.14	–2.09	85.20	582.143	–1213.7	0.197	1.69
15V	997.80	–10.40	41.02	232.098	2748.01	0.00613	0.364
10H	7876.16	–7.87	18.63	177.041	–1050.37	–0.065	10.701
11V	–1764.52	–25.90	162.47	1204.77	2698.19	0.1108	2.684

5.2.2 Finite Element Model for Underbody Scraper

To satisfy the objectives for this portion of the study, a 3D finite element analysis (FEA) of the full-scale underbody scraper was developed using Abaqus version 6.13-1. The first stage of the computer analysis of the underbody scraper involved subjecting the scraper to static loads to simulate the stress and strains by comparing the results with those obtained from the field testing and calibrating the computer model. The objective was to use the calibrated FE model to carry out simulations incorporating various loading conditions to optimize the model and to enhance performance of the scraper.

A 3D AutoCAD model of the underbody scraper was provided by the manufacturer, Monroe Trucking and Equipment. The underbody scraper was simplified by not including the holes for mounting the carrier structure to the moldboard. This allowed for analysis of the parts of interest without having to deal with a complicated model. Although the model was edited from the original AutoCAD model to have less complex features, it is the authors' opinion that the model still provides a good representation of how the underbody scraper reacts under various loadings.

5.2.2.1 Assembly and Meshing

The main parts included in the underbody scraper model are the moldboard and the blades. The AutoCAD model was opened in Autodesk Inventor Fusion, which allowed the model to be checked to make sure that the solid 3D parts were in the correct position before importing the file into Abaqus. After the parts were edited and modified in AutoCAD, the model was imported into Abaqus as parts. Once the parts were loaded in Abaqus, they were assembled to complete the underbody scraper model. It is important that the parts were assembled properly in the correct location. This was ensured by closely comparing the Abaqus model to the original 3D model after it was assembled in Abaqus. Figure 48 shows the AutoCAD 3D model of the scraper, and Figure 49 shows the simplified model in Abaqus.

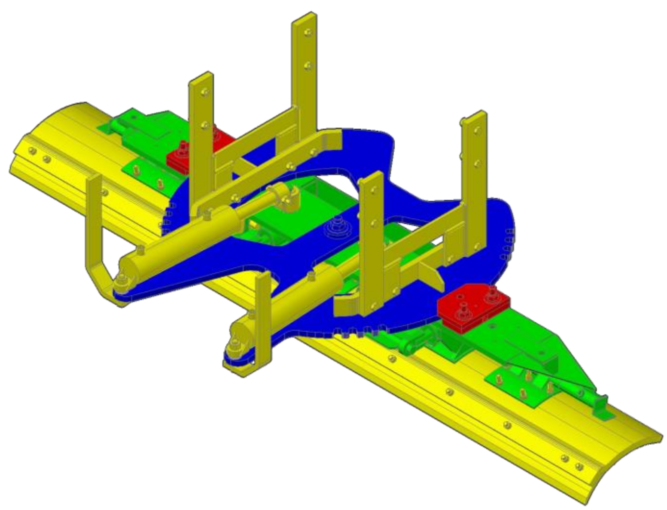


Figure 48. Underbody scraper, AutoCAD model.

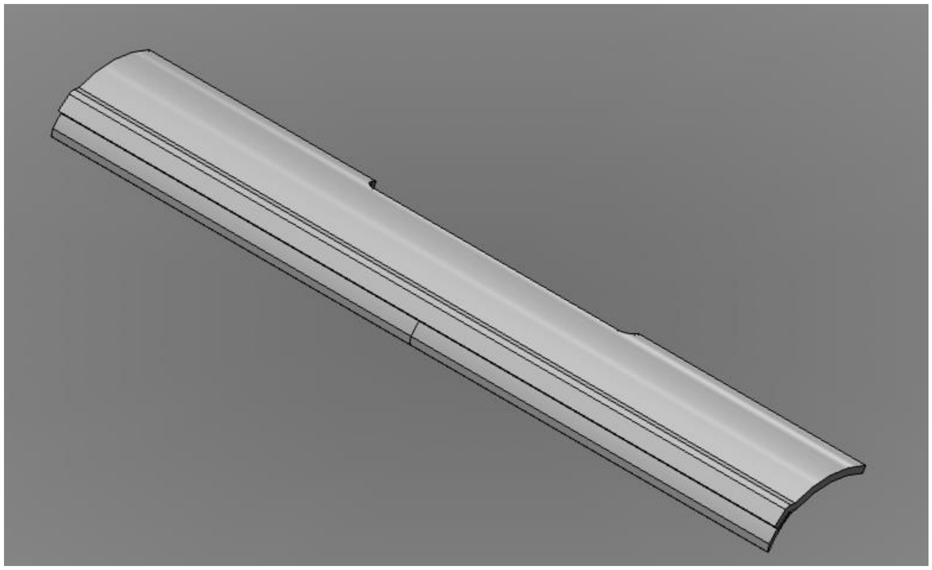


Figure 49. Simplified underbody scraper model used in Abaqus.

The moldboard was constructed first during the assembly of the model in Abaqus, using the simplified AutoCAD model. The blades were added to the assembly to create the underbody scraper. After the moldboard and blade were assembled, the model was meshed (Figures 50 and 51). The parts were partitioned into smaller sections to simplify the meshing process. The two meshing techniques used were a tetrahedron mesh and a structured mesh. Although the structured mesh was generally the preferred technique, the tetrahedron mesh was used for the parts that contain curved elements. The underbody scraper model was imported as a solid homogenous part and was seeded into a fine mesh size. A finer mesh density was chosen for the model, with further refinement taking place in the regions around the connections of the carrier structure. The complete FE model of the underbody scraper is composed of approximately 27,000 individual elements. Figure 52 shows the FEA model of the full-scale underbody scraper after it was meshed.

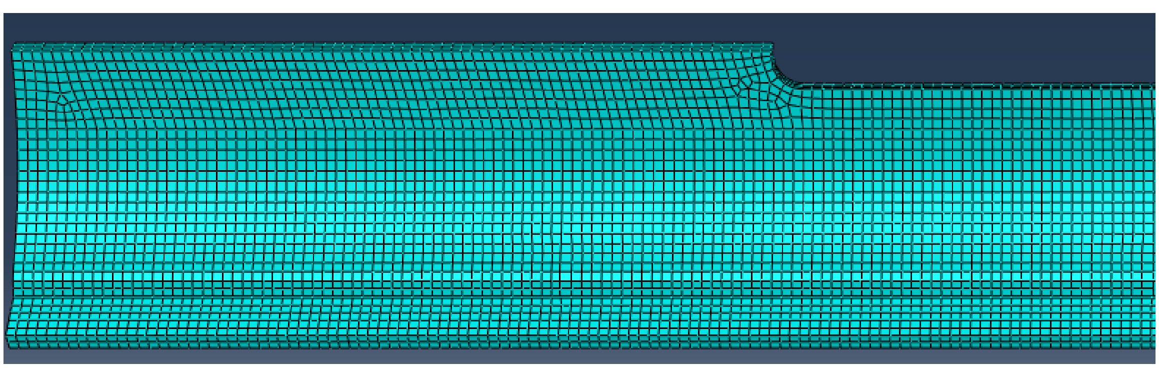


Figure 50. Meshed moldboard.

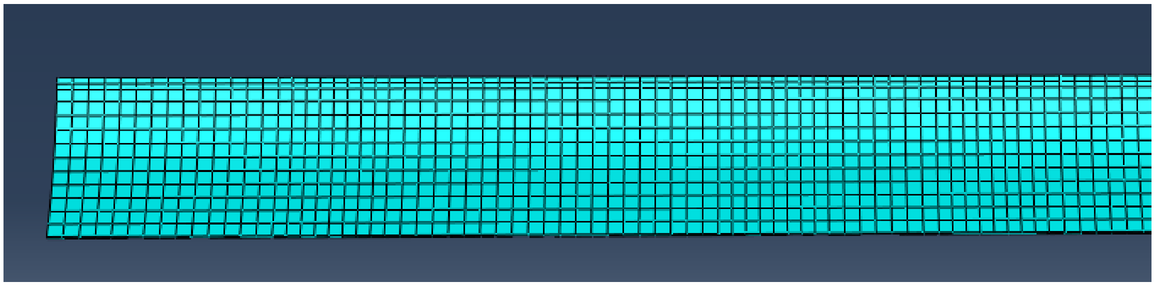


Figure 51. Meshed blade.

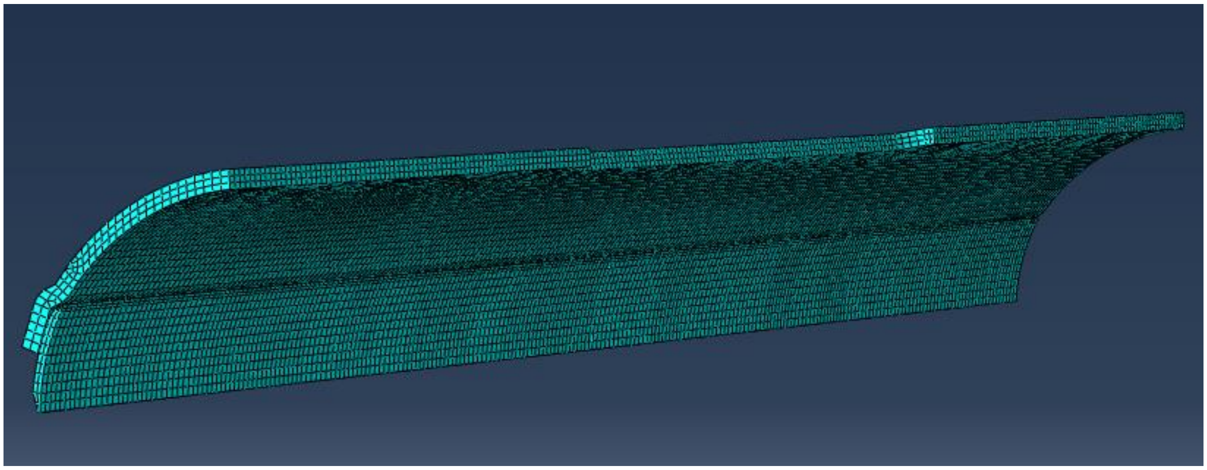


Figure 52. Meshed underbody scraper.

5.2.2.2 Boundary Condition

To properly simulate the base fixity of the model, the FEA model of the underbody scraper was restrained about each translational degree of freedom. The locations where the moldboard connects to the corresponding carrier structure were represented by fixing the moldboard in those specific locations. The underbody scraper was fixed across the surface of where the carrier structure brackets mount to the moldboard of the underbody scraper (Figure 53).

Loading of the model was achieved through the use of face pressures applied to the elements in different regions to represent an equivalent loading that acts on the scraper during the snow removal operation. This provided for the worst-case scenario, although the scraper has a set of tripping mechanism springs that are triggered once a certain load is reached. The largest stresses will occur around these boundary conditions.

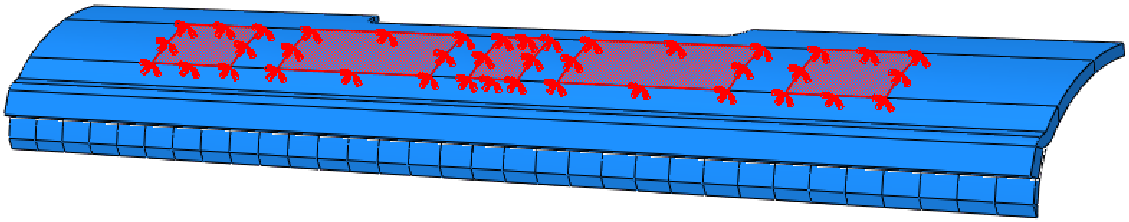


Figure 53. Underbody scraper boundary conditions.

5.2.2.3 Constraints

The parts on the plow were tied together using the tie constraint. A tie constraint in this case acts like a welded connection. The tie constraint is fixed in all directions. Because the bolts are so close together and of high-strength grade, it was assumed that the moldboard and blade were welded together. This assumption made the model easier to assemble and mesh.

5.2.2.4 Loading and Analysis

To investigate and understand how the plow reacts during normal operation and unusual impact loading, the FE model involved a total of five loading stages, which are shown in Figures 54 through 58 and outlined as follows:

- blade vertical edge pressure
- friction loading
- uniform blade pressure
- uniform moldboard pressure
- concentrated forces

During the initial loading analysis on the plows, only unit loads were applied. The different loading conditions for the unit loads consisted of vertical blade edge pressure, friction loading, uniform blade pressure, uniform moldboard pressure, and concentrated forces.

Blade edge pressure represents a simulation of plowing ice and snow that is packed down on the roadway by vehicular traffic. Friction loading represents the interaction of the weight of the snow plow and the pavement surface. Triangular loading represents plowing snow with the plow directed toward the shoulder. During that operation, more snow will be on the plow edge that is directed toward the side of the road. Uniform blade pressure represents the snow build-up that happens in general across the blade. Uniform moldboard pressure represents the snow traveling up the plow to be launched out onto the shoulder. The concentrated force, which is applied near an end of the plow, is used to simulate the plow hitting pavement reflectors, potholes, manhole covers, or grates. Loads are applied to the models to gain an understanding of the stresses in the plows.

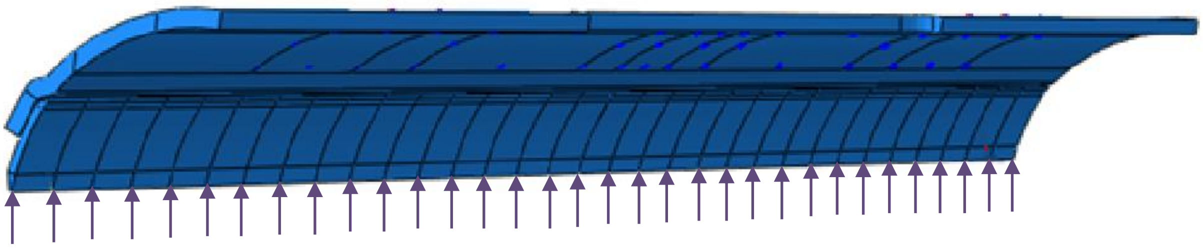


Figure 54. Vertical blade edge pressure.

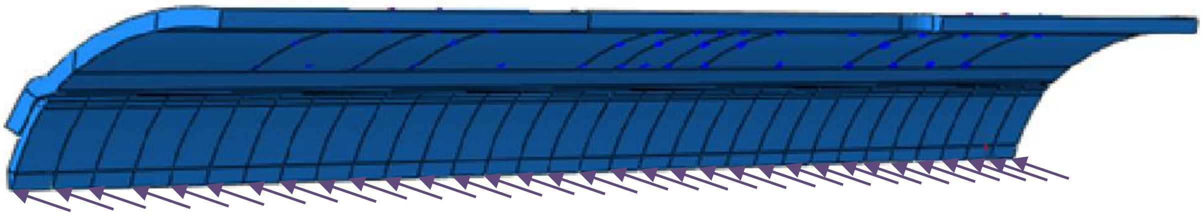


Figure 55. Friction loading.

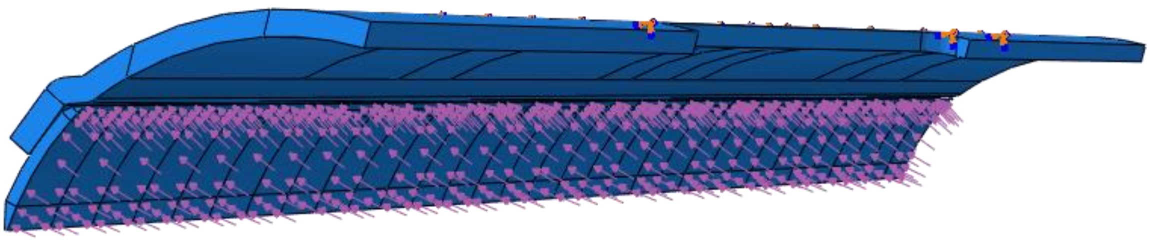


Figure 56. Uniform blade pressure.

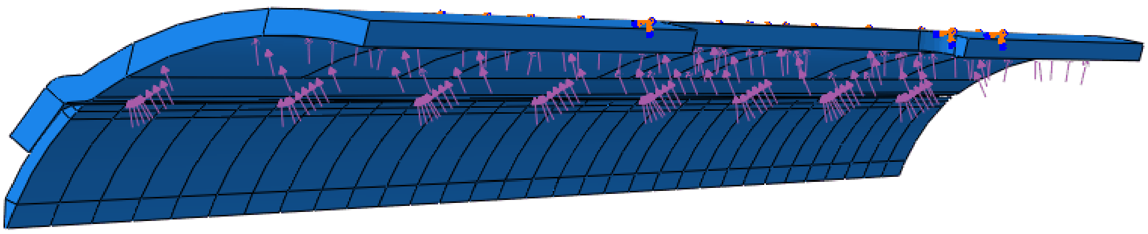


Figure 57. Uniform moldboard pressure.

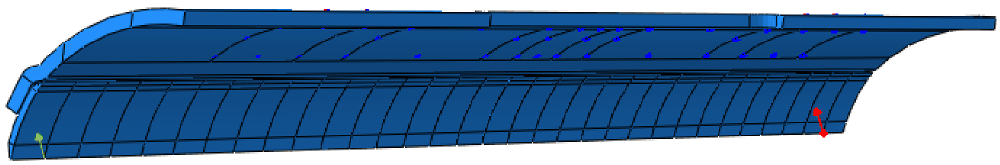


Figure 58. Concentrated forces.

5.2.2.5 Results of Analyses

The results of the analyses of the underbody scraper under the effect of the loads described above are presented Table 8 for specific sensor locations on the scraper. The stresses are given in psi. Here again, the stresses were obtained from the finite element model by averaging the stresses around the node closest to the sensor location.

Table 8. Computed Stresses (psi) at Various Locations of Underbody Scraper

Sensor location	Plow self-weight	10 psi vertical blade edge pressure	10 psi blade edge friction	10 psi blade pressure	10 psi moldboard pressure	1000 lb force applied at sensor 0 blade corner	1000 lb force applied at sensor 5 blade corner
0V	5904	–9.17	–29.97	–856.25	–138.63	–943.26	–0.03
1H	14768	–13.20	–22.85	–972.63	–887.75	–1768.79	–0.01
2H	2753	–5.03	–14.64	–444.00	–27.82	24.52	13.76
3V	7974	–14.58	–42.05	–1260.75	–70.50	29.54	40.20
4H	14652	–13.20	–21.99	–878.00	–944.00	–0.01	–1733.18
5V	5858	–8.95	–29.46	–839.88	–138.63	–0.04	–938.33

5.2.3 Material Properties

An elastic perfectly plastic material model was adopted for the steel plows, as illustrated in Figure 59. A modulus of elasticity of 2.0e6 kPa (29,000 ksi) and a Poisson's ratio of 0.3 were used. The density of the steel was 7850 kg/m^3 (490 lb/ft^3).

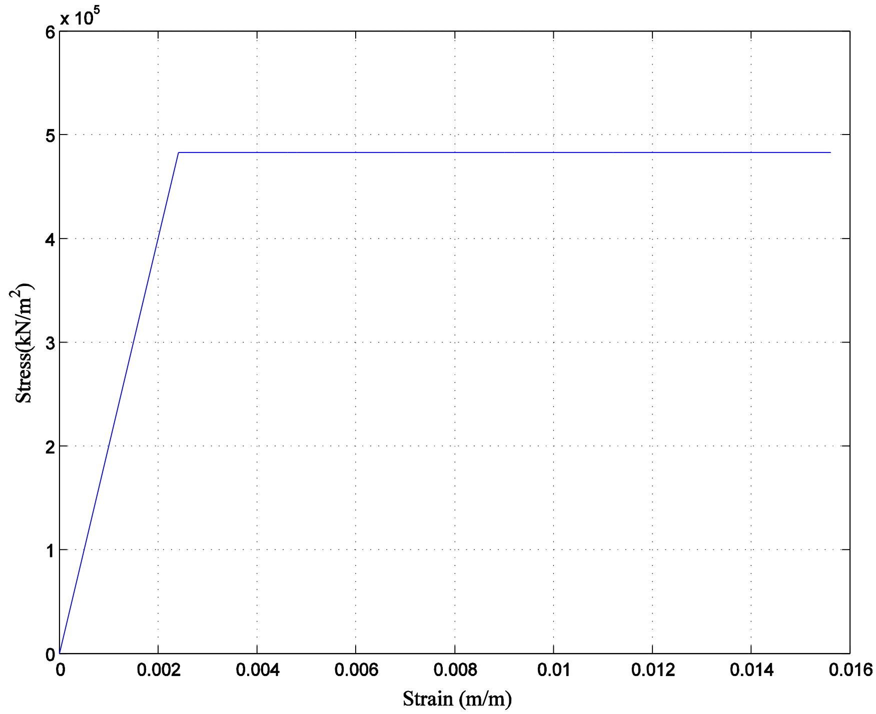


Figure 59. Stress–strain curve for steel plows.

5.3 RESULTS OF ANALYSIS

The purpose of the FE modeling of the plows was to determine a way to numerically simulate plow behavior and perform parametric analyses. Modeling the plows presented two major challenges: (1) complexity of the geometry of the plows and (2) lack of information about the loads the plow might be subjected to during an ice and snow clearing operation. The first challenge was resolved by obtaining 3D models of the front plow and the underbody scraper from a plow manufacturer to ensure dimensional accuracy.

The lack of information about loads, however, was a more difficult problem to resolve. However, if one were to assume that the strain data collected in the field were adequate, it might be possible to work backward to calculate the loads that produced them using the FE models. If one set of field data were used to determine the loads, other field datasets may be used to verify that the obtained loads were indeed correct. This, of course, assumes that the load cases that were described above represent all the types of loads that are actually applied to the plow. The details of the approach to determine possible front plow and underbody scraper loads is presented in the following subsections.

5.3.1 Plow Analysis

The front plow will be used as an example to explain how the collected data and the stresses computed using the FE models can be used to better understand actual plow behavior.

If the loads described in Section 5.2.1.4 of this report are taken as an accurate representation of the loads the plow may be subjected to during operation, it is possible to obtain an idea about what these loads might be at any given time by matching plow stresses obtained from field measurements to the ones obtained from the FE models. However, some assumptions must be made to ensure a realistic representation of plow behavior. These assumptions are as follows:

1. Plow material is linear elastic and remains so during service.
2. When the truck is stationary and the plow is in the up position, the plow is subjected to the effect of only its own weight.
3. When the plow is in the up position while the truck is in motion, it is subjected to the effect of its own weight, some dynamic effects, and any lateral wind pressure that would be produced by the moving truck.
4. When the truck is stationary and the plow is in the down position, the plow is subjected to the effect of its own weight and blade vertical edge pressure.
5. When the plow is in the down position during a dry run, it is subjected to its own weight, lateral wind pressure, blade vertical edge pressure, and friction force.
6. When the plow is in the down position during an actual ice and snow removal operation, it is subjected to its own weight, possible wind pressure, and any combination of all the loads listed in Section 5.2.1.4.

On the basis of those assumptions, the collected field data, and the results obtained from the FEAs can be used together to obtain an idea about the loads acting on the plow at any given time during a snow and ice clearing operation. The approach is explained in the following paragraphs for each situation.

Case 1: Truck at Rest—Plow in Up Position

This situation can be used to verify model accuracy in terms of geometry and boundary conditions because measured and computed stresses due to the plow’s own weight should match adequately well if the model truly represents the actual plow. If that is not the case, then one of two conditions could arise:

1. The measured stresses at different plow locations compare with the ones computed at the same locations by a constant ratio, which indicates that the plow model boundary conditions are accurate, while the geometry, which contributes to the weight, is not. In such a case, computed stresses that are caused by the weight of the plow can be adjusted by the obtained ratio.
2. The computed stresses do not compare with the measured ones, and no correlation can be found between the two types of stresses. In such a case, a thorough model evaluation and calibration must be performed to make sure the boundary conditions are modeled correctly. The challenge in this task is to accurately identify the situations when the truck is not moving with its plow up during a plowing event.

To identify front plow situations that fall under this case, truck motion and plow positions were obtained by observing video recorded during a plowing event. The video was obtained using a video camera mounted on the inside of the truck’s windshield and positioned to provide a good view of the front plow’s movement. The GPS-enabled camera also recorded truck speed and location, and the playback application can show the location on a map of the area. By matching the time stamps on the data acquisition system and the video, it becomes possible to match measured stresses with plow position and the motion of the truck. This was a very time-consuming task to carry out for all the storms, but it was necessary to undertake to be able to compare measured-to-computed plow stresses. This was done for four of the storms for all the strain gauges and the entire duration of each storm. As an example, Figure 60 shows the variation of the stress in the front plow at gauge location 0V over a five-minute period of time with the position of the plow indicated at each time.

It must be noted that the data analyses for a couple of the storms had to be repeated because enough discrepancies were found to shed some doubt about the validity of the information indicating plow position.

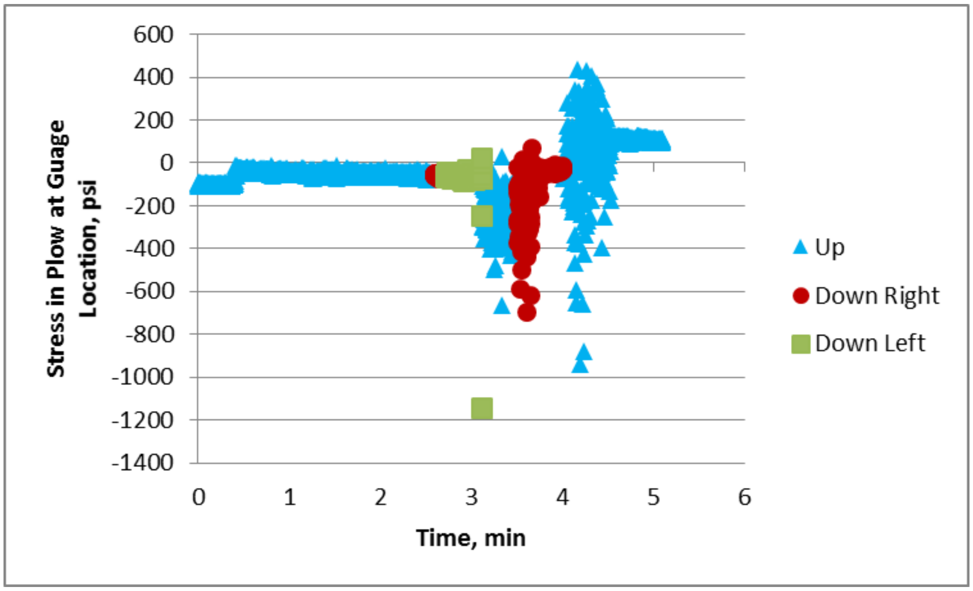


Figure 60. Front plow position and time variation of stress at location 0V for the 12/31/2012 snow storm.

Situations in which the truck was at a stop with the plow in the up position were identified, and the measured stresses in the plow were compared to the computed ones. The stresses did not match directly, and no consistency was observed in the ratios between measured stresses and those computed for the plow weight loading case, as can be inferred from Table 9.

Table 9. Comparison of Computed and Measured Stresses in the Front Plow Caused by Plow's Own Weight While Truck Is Not in Motion

	Time, min:	138.118		138.172		138.240	
Sensor Location	**Computed stress due to weight, σ_w, psi**	**σ_m, psi**	**$a_w = \sigma_m/\sigma_w$**	**σ_m, psi**	**$a_w = \sigma_m/\sigma_w$**	**σ_m, psi**	**$a_w = \sigma_m/\sigma_w$**
0V	-927	-306	**0.330**	-306	**0.330**	-305	**0.329**
1H	4338	20	**0.005**	16	**0.004**	15	**0.003**
12V	719	1815	**2.525**	1834	**2.551**	1567	**2.179**
13H	683	1566	**2.293**	1567	**2.294**	1557	**2.280**
14H	4655	1688	**0.363**	1718	**0.369**	1641	**0.352**
15V	998	1562	**1.566**	1562	**1.565**	1560	**1.563**
10H	7876	1304	**0.166**	1334	**0.169**	1565	**0.199**
11V	-1765	1526	**-0.865**	1532	**-0.868**	1540	**-0.873**

In Table 9, σ_m indicates the measured stress in the plow at the indicated sensor location, and σ_w is the stress obtained from the finite element model at the same location under the effect of the plow's own weight. The parameter a_w is the correlation factor between computed and measured stresses in the plow. It is important to note here that the range and direction of measured stresses were consistent between the different storms.

The lack of correlation indicates that the model must be reevaluated. One of the issues observed was that the variation of computed stress differed by a relatively high margin around the sensor's area. This can be seen clearly in Figure 61. It must be noted that the size of the mesh that was used was about 2 in., and using a finer mesh created numerical errors

				-2086				
				-1920				
				-1753				
				-1587				
-1841	-1736	-1631	-1525	-1420	-1358	-1297	-1235	-1173
				-1266				
				-1113				
				-959				
				-806				

Figure 61. Variation of computed stress (in psi) caused by the front plow's own weight around the Sensor 0 area.

Case 2: Truck Moving—Plow in Up Position

This situation can be used to determine dynamic effects on the plow once the model is calibrated using the procedure described in case 1. The dynamic effects can be established using the following approach: assuming that stresses from three different sensors (S1, S2, and S3) are to be considered, the following parameters are defined:

σ_{m1}, σ_{m2} and σ_{m3}: stresses measured at the locations of sensors S1, S2, and S3, respectively

σ_{w1}, σ_{w2} and σ_{w3}: stresses from the weight of the plow, computed at the locations of sensors S1, S2, and S3, respectively

σ_{b1}, σ_{b2} and σ_{b3}: stresses from uniform blade pressure loading, computed at the locations of sensors S1, S2, and S3, respectively

σ_{mb1}, σ_{mb2} and σ_{mb3}: stresses from uniform moldboard pressure loading, computed at the locations of sensors S1, S2, and S3, respectively

If the three aforementioned loads are the only ones applied to the plow, then a relationship can be established between the measured and computed stresses as follows:

$$\begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{b1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{b2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{b3} & \sigma_{mb3} \end{bmatrix} \begin{Bmatrix} a_w \\ a_b \\ a_m \end{Bmatrix}$$

In the above equation, s_{1w}, s_{1b}, and s_{1m} are the stresses computed at sensor location S1 under the effects of assumed loads for the weight of the plow, blade pressure, and moldboard pressure. The coefficients a_w, a_b, and a_m are load multipliers that can be obtained from the following equation:

$$\begin{Bmatrix} a_w \\ a_b \\ a_m \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{b1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{b2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{b3} & \sigma_{mb3} \end{bmatrix}^{-1} \begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \end{Bmatrix}$$

Assuming the loads that were used to compute the stresses σ in the FE model are self-weight, a blade pressure p_b = 10 psi, and a moldboard pressure p_m = 10 psi, then the actual loads acting on the plow during a plowing event while the truck is moving and the plow is in the up position are a_w × self-weight, a_b × 10 psi, and a_m × 10 psi. When this is done for each set of three sensors at a time, a range of values for each of the assumed loads is obtained. An analysis of the ranges thus obtained will lead to either identification of the loads or revision of the calibration performed based on the results of case 1, and it may lead to introducing modifications to the instrumentation plan and collecting additional field data.

This case was investigated for the situation where the truck was at a stop and the plow was in the up position. If the model and the measured stresses are accurate, then the resulting load multipliers should be around 1.0 for a_w and around 0.0 for a_b and a_m. This again was not the case as indicated in Figure 62, which shows values of a_w, a_b, and a_m obtained for the 12/14/2013 snow storm.

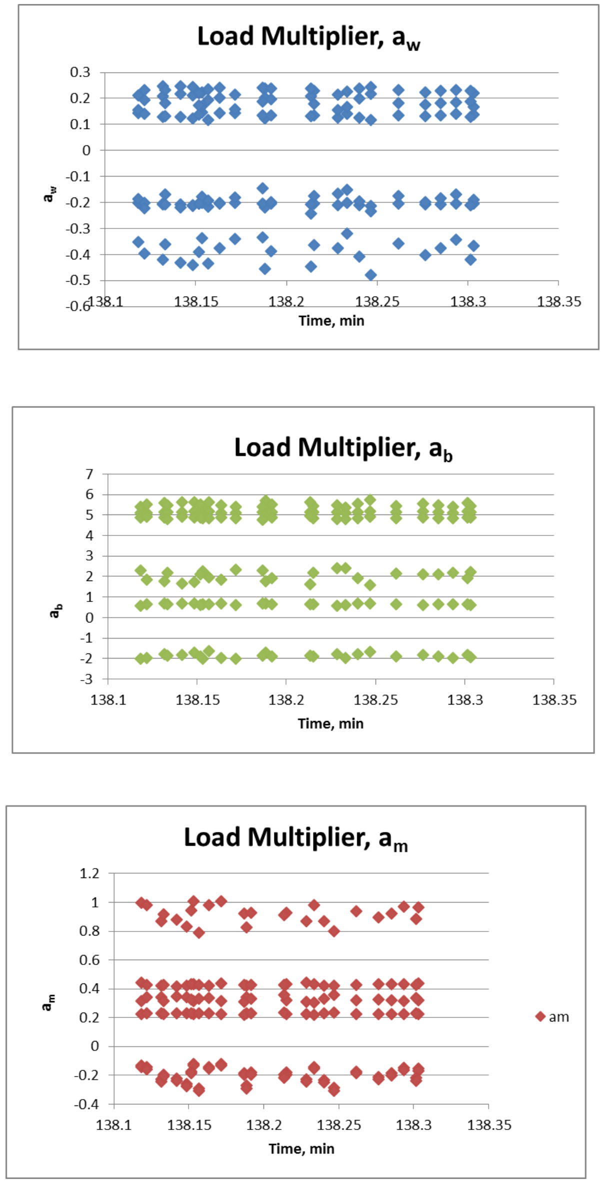


Figure 62. Computed load multipliers for plow weight, blade pressure, and moldboard pressure for a stopped truck with the plow in the up position, 12/14/2013 snow storm.

Case 3: Truck Moving—Plow in Down Position with No Snow or Ice
This situation can be used to better understand the interaction of the plow with the pavement. In this case, the plow is assumed to be subjected to the effect of its own weight, a vertical force applied to the bottom of the blade representing the reaction from the pavement, and a friction force from the interaction of the moving truck with the pavement, in addition to dynamic effects and wind resistance of the plow. Assuming that stresses from four sensors (S1, S2, S3, and S4) are to be considered, the following parameters are defined:

σ_{m1}, σ_{m2}, σ_{m3}, and σ_{m4}: stresses measured at the locations of sensors S1, S2, S3, and S4, respectively

σ_{w1}, σ_{w2}, σ_{w3}, and σ_{w4}: stresses from the weight of the plow, computed at the locations of sensors S1, S2, S3, and S4, respectively

σ_{v1}, σ_{v2}, σ_{v3}, and σ_{v4}: stresses from vertical blade pressure loading, computed at the locations the sensors S1, S2, S3, and S4, respectively

σ_{f1}, σ_{f2}, σ_{f3}, and σ_{f4}: stresses from blade friction loading, computed at the locations of sensors S1, S2, S3, and S4, respectively

σ_{mb1}, σ_{mb2}, σ_{mb3}, and σ_{mb4}: stresses from uniform moldboard pressure loading, computed at the locations of sensors S1, S2, S3, and S4

If the four aforementioned loads are the only ones applied to the plow, then a relationship can be established between the measured and computed stresses as follows:

$$\begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \\ \sigma_{m4} \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{v1} & \sigma_{f1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{v2} & \sigma_{f2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{v3} & \sigma_{f3} & \sigma_{mb3} \\ \sigma_{w4} & \sigma_{v4} & \sigma_{f4} & \sigma_{mb4} \end{bmatrix} \begin{Bmatrix} a_w \\ a_v \\ a_f \\ a_m \end{Bmatrix}$$

In the above equation, s_{1w}, s_{1b}, and s_{1m} are the stresses computed at sensor location S1 under the effects of assumed loads for the weight of the plow, blade pressure, and moldboard pressure. The coefficients a_w, a_b, and a_m are load multipliers that can be obtained from the following equation:

$$\begin{Bmatrix} a_w \\ a_v \\ a_f \\ a_m \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{v1} & \sigma_{f1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{v2} & \sigma_{f2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{v3} & \sigma_{f3} & \sigma_{mb3} \\ \sigma_{w4} & \sigma_{v4} & \sigma_{f4} & \sigma_{mb4} \end{bmatrix}^{-1} \begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \\ \sigma_{m4} \end{Bmatrix}$$

Assuming the loads that were used to compute the stresses σ in the FE model are the self-weight, a vertical pressure p_v = 10 psi, a friction force applied as a pressure p_f = 10 psi, and a moldboard pressure p_m = 10 psi, then the actual loads acting on the plow during a plowing event while the truck is moving and the plow is in the down position are a_w × self-weight, a_v × 10 psi, a_f × 10 psi, and a_m × 10 psi. When this is done for each set of four sensors at a time, a range of values for each of the assumed loads is obtained. An analysis of the ranges thus obtained will lead to identification of the loads that were actually applied to the plow during the snow control operation. Furthermore, the results will lead to identification of the effective friction coefficient between the pavement and blade at the time of plowing.

Case 4: Truck Moving—Plow in Down Position with Snow or Ice
This situation can be used to better understand the interaction of the plow with the pavement and the snow or ice. In this case, the plow is assumed to be subjected to the effect of its own weight, a vertical force applied to the bottom of the blade representing the reaction from the pavement, a friction force from the interaction of the moving truck with the pavement, and the weight of the snow acting on the blade and plow, in addition to dynamic effects and wind resistance of the plow. Assuming that stresses from five different sensors (S1, S2, S3, S4, and S5) are to be considered, plow loading information can be inferred. The following parameters are defined:

σ_{m1}, σ_{m2}, σ_{m3}, σ_{m4}, and σ_{m5}: stresses measured at the locations of sensors (S1, S2, S3, S4, and S5), respectively

σ_{w1}, σ_{w2}, σ_{w3}, σ_{w4}, and σ_{w5}: stresses from the weight of the plow, computed at the locations of sensors (S1, S2, S3, S4, and S5), respectively

σ_{v1}, σ_{v2}, σ_{v3}, σ_{v4}, and σ_{v5}: stresses from vertical blade pressure loading, computed at the locations of sensors (S1, S2, S3, S4, and S5), respectively

σ_{f1}, σ_{f2}, σ_{f3}, σ_{f4}, and σ_{f5}: stresses from blade friction loading, computed at the locations of sensors (S1, S2, S3, S4, and S5), respectively

σ_{b1}, σ_{b2}, σ_{b3}, σ_{b4}, and σ_{b5}: stresses from blade pressure loading, computed at the locations of sensors (S1, S2, S3, S4, and S5), respectively

σ_{mb1}, σ_{mb2}, σ_{mb3}, σ_{mb4}, and σ_{mb5}: stresses from uniform moldboard pressure loading computed at the locations of sensors (S1, S2, S3, S4, and S5), respectively

If the five aforementioned loads are the only ones applied to the plow, then a relationship can be established between the measured and computed stresses as follows:

$$\begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \\ \sigma_{m4} \\ \sigma_{m5} \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{v1} & \sigma_{f1} & \sigma_{b1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{v2} & \sigma_{f2} & \sigma_{b2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{v3} & \sigma_{f3} & \sigma_{b3} & \sigma_{mb3} \\ \sigma_{w4} & \sigma_{v4} & \sigma_{f4} & \sigma_{b4} & \sigma_{mb4} \\ \sigma_{w5} & \sigma_{v5} & \sigma_{f5} & \sigma_{b5} & \sigma_{mb5} \end{bmatrix} \begin{Bmatrix} a_w \\ a_v \\ a_f \\ a_b \\ a_{mb} \end{Bmatrix}$$

In the above equation, s_{1w}, s_{1b}, and s_{1m} are the stresses computed at sensor location S1 under the effects of assumed loads for the weight of the plow, blade pressure, and moldboard pressure. The coefficients a_w, a_b, and a_m are load multipliers that can be obtained from the following equation:

$$\begin{Bmatrix} a_w \\ a_v \\ a_f \\ a_b \\ a_{mb} \end{Bmatrix} = \begin{bmatrix} \sigma_{w1} & \sigma_{v1} & \sigma_{f1} & \sigma_{b1} & \sigma_{mb1} \\ \sigma_{w2} & \sigma_{v2} & \sigma_{f2} & \sigma_{b2} & \sigma_{mb2} \\ \sigma_{w3} & \sigma_{v3} & \sigma_{f3} & \sigma_{b3} & \sigma_{mb3} \\ \sigma_{w4} & \sigma_{v4} & \sigma_{f4} & \sigma_{b4} & \sigma_{mb4} \\ \sigma_{w5} & \sigma_{v5} & \sigma_{f5} & \sigma_{b5} & \sigma_{mb5} \end{bmatrix}^{-1} \begin{Bmatrix} \sigma_{m1} \\ \sigma_{m2} \\ \sigma_{m3} \\ \sigma_{m4} \\ \sigma_{m5} \end{Bmatrix}$$

Assuming the loads that were used to compute the stresses σ in the FE model are the self-weight, a vertical pressure p_v = 10 psi, a friction force applied as a pressure p_f = 10 psi, a blade pressure p_b = 10 psi, and a moldboard pressure p_m = 10 psi, then the actual loads acting on the plow during a plowing event while the truck is moving and the plow is in the down position are a_w × self-weight, a_v × 10 psi, a_f × 10 psi, a_b × 10 psi, and a_m × 10 psi. When this is done for each set of five sensors at a time, a range of values for each of the assumed loads is obtained. An analysis of the ranges thus obtained will lead to identification of the loads that were actually applied to the plow during the snow control operation. Knowing the characteristic of the storm that caused the snow and the amounts of snow that fell will provide a correlation between the size of the storm and expected plow behavior.

This approach can also be applied to the underbody scraper and to situations where a single concentrated force is suspected of having acted on the plow. A situation like this might occur when the plow hits a reflector or a manhole and the event can be detected from the spike in the collected data and plow shaking observed in the video. Using the data from the different sensors and the stresses calculated for the two concentrated loads applied at either edge of the blade, it is possible to calculate the magnitude and location of the force that caused the measured stresses in the plow.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

Snow plowing is a generally messy and dangerous operation. This report presented a thorough review of literature about best practices in snow and ice control in addition to a synthesis of best practices that were produced based on a survey of professionals in the field. The research team was also able to develop and implement an instrumentation plan that allowed them to collect useful information pertaining to the behavior of snow and ice plows under actual plowing conditions.

In general, stresses in the front body plow and the underbody scraper do not exceed 10,000 psi. Higher stresses were observed when plowing concrete pavements compared with asphalt pavements. It was found that using the underbody scraper simultaneously with the front body plow during a heavy snow event is an effective way of providing a cleaner driving lane faster.

In addition, using the underbody scraper simultaneously with the front body plow on a ramp is an effective way to ensure that more ice is removed. The ramp can then be made even less slippery by the addition of salt. Finally, snow plow operators should be alert during the operation and need to have a thorough understanding of the equipment they are working with to reduce potential or unexpected hazards to themselves and the public.

The blade-saver option was found to reduce stresses in the snow plow and the carrier structure; this was true for three different cases: (1) dry runs on asphalt pavement, (2) dry runs on concrete pavement, and (3) dry runs on soil on concrete pavement.

The instrumentation and data collection system developed for this study was effective in assessing several field factors. Collecting strain data on the plow as well as video of the plowing operation turned out to be very useful in understanding plow and blade behavior and gaining a better understanding of the snow and ice control operation as a whole. However, the colossal amount of field data that were collected required more time to be fully analyzed than was allocated to this project. Snow and ice control operations are complicated and involve many parameters that can affect plow and blade performance. Accordingly, the researchers recommend that a new data-mining project be launched to identify trends in the collected data that may be used to better understand plow behavior and optimize plowing operations.

The researchers developed finite element models for the underbody scraper and an Alaskan plow using the finite element analysis program Abaqus. The models were used to simulate plow behavior under a variety of loads, including the weight of the plow and forces resulting from the interaction of the plow with the road and environmental factors such as snow, ice, and wind. The research team made a number of attempts to sort through the massive amount of collected data to find information that could be used to calibrate the models and use it to simulate the behavior of snow and ice plows. Up to the time of the publication of this report, the research team was not able to adequately correlate the collected data to the results of the finite element analyses. The research team therefore recommends that a separate project be undertaken to perform this time-consuming task.

REFERENCES

Bell, G.T., W.A. Nixon, and R.D. Stowe (2006). A Synthesis to Improve the Design and Construction of Colorado's Bridge Anti-Icing System. Colorado Department of Transportation Research Branch.

Blackburn R.R., K.M. Bauer, D.E. Amsler, S.E. Boselly, and A.D. McElroy (2004). Snow and Ice Control: Guidelines for Materials and Methods. NCHRP Report 526. Midwest Research Institute.

Breen, B.D. (2001). "Success of the Anti-Icing Program in Idaho." http://ops.fhwa.dot.gov/weather /publications/antiicingidaho.pdf.

Boselly, S.E. (2001). Benefit/Cost Study of RWIS and Anti-Icing Technologies. Final report prepared for NCHRP.

Carney, Jim (2008). Snow Plowing Best Practices. Missouri Department of Transportation, http://library.modot.mo.gov/RDT/reports/ad09077/orb09003.pdf.

Conger, S.M. (2005). A Synthesis of Highway Practice. National Cooperative Highway Research Program Synthesis 344.

Cuelho, E., J. Hardwood, M. Akin, E. Adams. (2010). Establishing Best Practices for Removing Snow and Ice from California Roadways. Western Transportation Institute. Sponsored by the California Department of Transportation. December.

Engen, H. (2006). "Førsøk med å utvide bruken av fastsandmetoden for å bedre friksjonen på vinterveger." MS thesis, Department of Civil and Transportation Engineering, NTNU, Trondheim, Norway.

Hansen, A.C. (1990). An Analysis of Energy Dissipation Caused by Snow Compaction During Displacement Flowing. SHRP Contract H-206, University of Wyoming, Laramie. November.

Ketcham, S.A., and L.D. Minsk (1996). "Anti-Icing Field Evaluation." 4th International Symposium on Snow Removal and Ice Control Technology, August 1996. Volume 1.

Minsk, D., R.R. Blackburn, and E.J. Fleege (1996). Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel. Publication No. FHWA-RD-9-202. Army Cold Regions Research and Engineering Laboratory.

Luker, C., B. Rokash, and T. Leggett (2004). "Laboratory Melting Performance Comparison: Rock Salt With and Without Prewetting." SNOW04-032. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-063: Snow and Ice Control Technology. June, pp. 585–601.

Nixon, W.A. (1993). Improved Cutting Edge for Ice Removal. SHRP-H-346 Report.

Nixon, W.A., T.J. Gawronski, and A.E. Whelan (1996). Development of a Model for the Ice Scraping Process. Iowa Department of Transportation Project HR 361. IIHR Technical Report No. 383.

Nixon, W.A., Y. Wei, and A.E. Whelan (1997). Field Measurements of Ice Scraping Loads on Front Mounted Plow Blades. Iowa Department of Transportation and Iowa Highway Research Board Project HR 374.

Nixon, W.A. and J.D. Potter (1997). Measurement of Ice Scraping Force on Snow-Plow Underbody Blades. Iowa Department of Transportation Project 372.

Nixon, W.A. (2002). "Anti-Icers: Driving Towards Clearer Roads." Snow and Ice Manager, February 15, 2001.

Norem, H. (2009). “A Selection of Strategies for Winter Maintenance of Roads Based on Climatic Parameters.” ASCE. December.

O'Keefe, K., and X. Shi (2005). Synthesis of Information on Anti-Icing and Pre-Wetting for Winter Highway Maintenance Practices in North America. Western Transportation Institute and Montana State University–Bozeman.

Roosevelt, D.S. (1997). A Survey of Anti-Icing Practice in Virginia. Virginia Council ResearchProject VTCR 98-R19.

Shi, X., K. O’Keefe, S. Wang, and C. Strong (2007). Evaluation of Utah Department of Transportation’s Weather Operations/RWIS Program: Phase I. Final Report, Western Transportation Institute, Montana State University–Bozeman.

Vaa, T. (2004). “Forsøk med befuktning med magnesiumkloridløsning i Oslo. Sesongen 2003/2004. Statens vegvesen, Teknologiavdelingen, Trondheim.” Internal Rep. No. 2373, Trondheim, Norway, http://www.vegvesen.no/fou_vinterdriften/Intern_2373.

Walderman, J. (2004). “State-of-the-Art Fixed Automated Spray Technology.” SNOW04-001. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June, pp. 379–390.

APPENDIX A ANTI-ICING TREATMENT TABLES

Table A-1. Precipitation Dilution Potential in the Presence of Precipitation (Blackburn et al. 2004)

		Precipitation rate			
	Precipitation type	**Light**	**Moderate**	**Heavy**	**Unknown**
1	Snow 1 (powder)	Low	Low	Medium	Low
2	Snow 2 (ordinary)	Low	Medium	High	Medium
3	Snow 3 (wet/heavy)	Medium	High	High	High
4	Snow U (unknown)	—	Medium	—-	—
5	Rain	Low	Medium	High	Medium
6	Freezing rain	Low	Medium	High	Medium
7	Sleet	Low	Medium	High	Medium
8	Blowing Snow	—	Medium	—	—
9	Snow with blowing snow	(Same as type of snow)			
10	Freezing rain with sleet	Low	Medium	High	Medium

Table A-2. Precipitation Dilution Potential in the Absence of Precipitation for Various Wheel Path Area Conditions (Blackburn et al. 2004)

Precipitation	Wheel path area condition	Precipitation dilution potential
None	Dry or damp	Not applicable (NA)
	Wet	Low
	Frost or black ice (thin ice)	Low
	Slush or loose snow	Medium
	Packed snow or thick ice	High

Table A-3. Adjustment Table to Precipitation Potential for the Presence of Various Wheel Path Area Conditions (Blackburn et al. 2004)

Precipitation	Wheel path area condition	Increase precipitation dilution potential by number of levels
Yes	Bare	0
	Frost	0
	Slush, loose snow, packed snow, or thick ice	1

Table A-4. Cycle Time and Traffic Volume Adjustments to Precipitation Dilution Potential (Final Level Not to Exceed High) (Blackburn et al. 2004)

Cycle time, hours	Increase precipitation dilution potential by number of levels
0–1.5	0
1.6–3.0	1
More than 3.0	2
For traffic speeds > 35 mph Traffic volume (vehicles per hour)	
Less than 125	0
More than 125	1

Table A-5. Application Rates for Solid, Pre-Wetted Solid, and Liquid Sodium Chloride (Blackburn et al. 2004)

Pavement temperature (°F)	Adjusted dilution potential	Ice pavement bond	Application rate	
			Solid (1) lb/LM	Liquid (2) gal/LM
Over 32°F	Low	No	90 (3)	40 (3)
		Yes	200	NR (4)
	Medium	No	100 (3)	44 (3)
		Yes	225	NR (4)
	high	No	110 (3)	48 (3)
		Yes	250	NR (4)
Over 32°F	Low	No	130	57
		Yes	275	NR (4)
	Medium	No	150	66
		Yes	300	NR (4)
	high	No	160	70
		Yes	325	NR (4)
Over 32°F	Low	No	170	74
		Yes	350	NR (4)
	Medium	No	180	79
		Yes	375	NR (4)
	high	No	190	83
		Yes	400	NR (4)
Over 32°F	Low	No	200	92
		Yes	425	NR (4)
	Medium	No	210	96
		Yes	450	NR (4)
	high	No	220	NR
		Yes	475	NR
Over 32° F	Low	No	230	NR
		Yes	500	NR
	Medium	No	240	NR
		Yes	525	NR
	high	No	250	NR
		Yes	550	NR
Over 32° F	Low	No	260	NR
		Yes	575	NR
	Medium	No	270	NR
		Yes	600	NR
	high	No	280	NR
		Yes	625	NR
Below 10°F	A. If unbonded, try mechanical removal without chemical. B. If bonded, apply chemical at 700 lb/LM. Plow when slushy. Repeat as necessary. C. Apply abrasives as necessary.			

NR = Not Recommended

(see next page for additional table notes)

Specific Notes:

Values for "solid" also apply to pre-wet solid and include the equivalent dry chemical weight in pre-wetting solutions.

Liquid values are shown for the 23% concentration solution.

In unbonded, try mechanical removal without applying chemicals. If pretreating, use this application rate.

If very thin ice, liquids may be applied at the unbonded rates.

General Notes:

These application rates are starting points. Local experience should refine these recommendations.

Pre-wetting chemicals should allow application rates to be reduced by up to about 205, depending on such primary factors as spread pattern and spreading speed.

Application rates for chemicals other than sodium chloride will need to be adjusted using the equivalent application rates shown in Table A-6.

Before applying any ice control chemical, the surface should be cleared of as much snow and ice possible.

Table A-6. Equivalent Application Rates for Five Ice Control Chemicals (Blackburn et al. 2004).

Temperature (°F)	NaCl		$CaCl_2$		$MgCl_2$		KAc		CMA	
	100%* Solid	23%* Liquid	90–92%* Solid	32%* Liquid	50%* Solid	27%* Liquid	100%* Solid	50%* Liquid	100%* Solid	25%* Liquid
	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM
31.5	100	45	109	32	90	31	159	30	159	69
31	100	46	111	32	91	32	161	31	161	72
30.5	100	48	111	33	91	32	155	30	155	71
30	100	48	107	33	94	33	158	31	158	74
29	100	49	109	34	91	33	155	31	155	79
28	100	52	109	34	91	33	152	31	152	81
27	100	54	109	35	90	34	153	31	153	86
26	100	56	104	34	96	36	161	33	161	95
25	100	57	102	34	99	35	167	35	167	108
24	100	61	108	38	402	41	167	35	167	114
23	100	62	112	41	102	41	164	35	164	117
22	100	65	110	41	102	42	160	35	160	121
21	100	68	107	40	101	42	155	35	155	125
20	100	70	108	42	98	42	150	34	150	129
15	100	90	103	44	96	44	142	34	142	170
10	100	120	101	49	95	47	138	35	138	265
5	100	165	104	57	96	51	139	37	139	630

NaCl: Sodium chloride
$CaCl_2$: Calcium chloride
$MgCl_2$: Magnesium chloride
KAc: Potassium acetate
CMA: Calcium magnesium acetate
* Typical percent concentrations of the solid and liquid forms with the balance being water.

APPENDIX B   RESULTS FROM ANDREW C. HANSEN'S STUDY

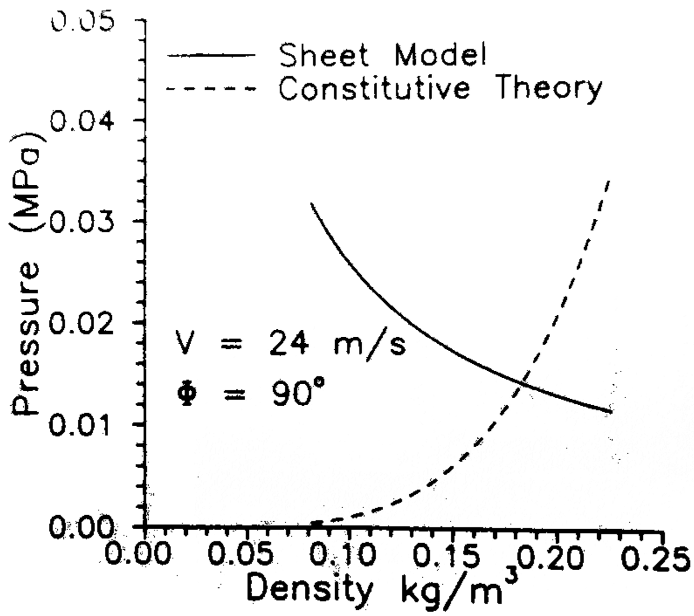


Figure B-1. Pressure versus density as predicted by the sheet model and the constitutive law (Hansen 1990).

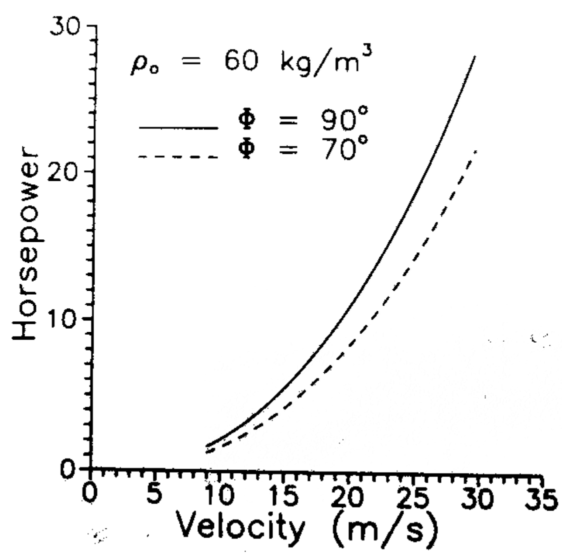


Figure B-2. Horsepower versus the velocity for cutting angles of 70 and 90 degrees and an initial density of 60 kg/m³ (Hansen 1990).

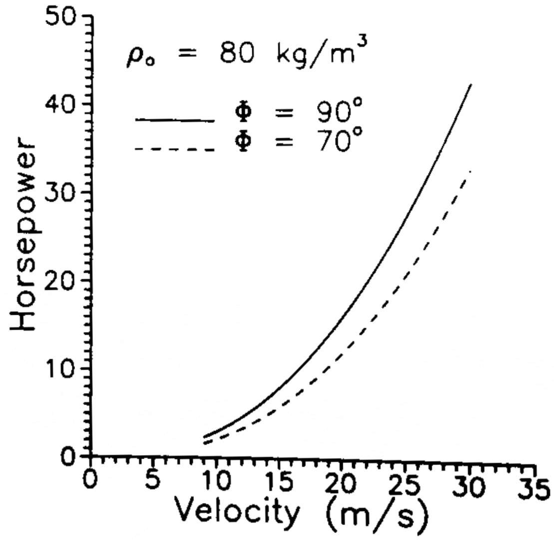


Figure B-3. Horsepower versus velocity for cutting angles of 70 and 90 degrees and an initial density of 80 kg/m^3 (Hansen 1990).

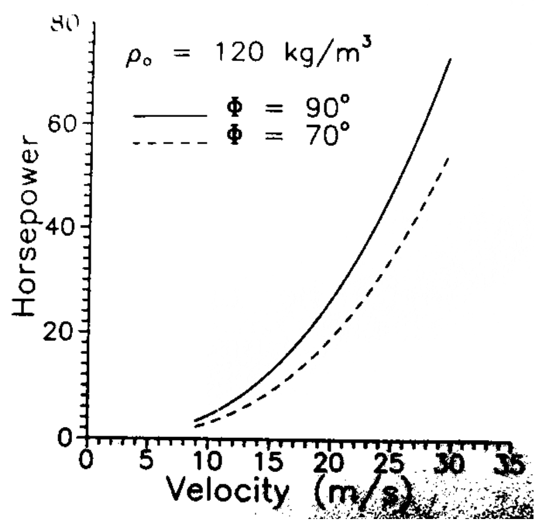


Figure B-4. Horsepower versus velocity for cutting angles of 70 and 90 degrees and an initial density of 120 kg/m^3 (Hansen 1990).

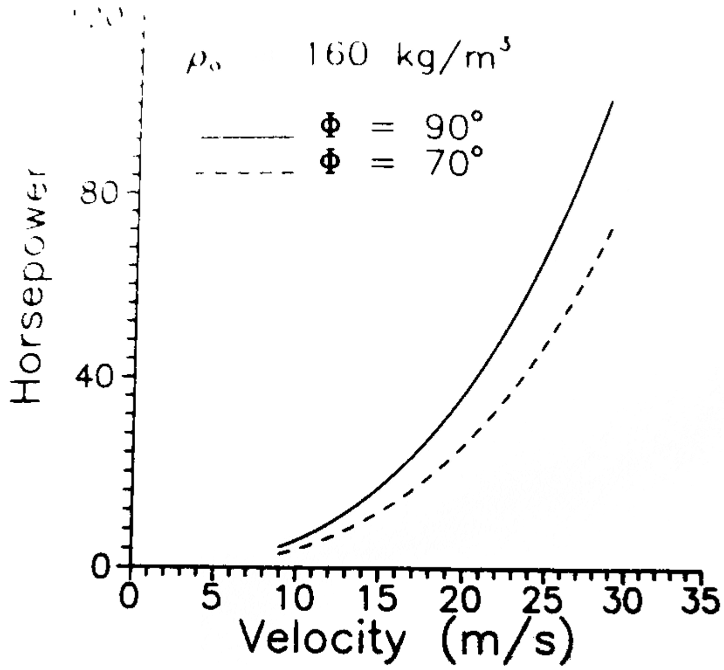


Figure B-5. Horsepower versus velocity for cutting angles of 70 and 90 degrees and an initial density of 160 kg/m^3 (Hansen 1990).

BRADLEY UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTIO

Best Practices in Snow and Ice Control

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The Illinois Department of Transportation
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TRP Chair – Tim Peters

Illinois Department of Transportation

ILLINOIS CENTER FOR TRANSPORTATION

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BU CEC

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Introduction

- Removal of ice and snow from road surfaces is a critical task in the northern tier states of the United States
- Highways with high levels of traffic are expected to be cleared of snow and ice quickly after each snowstorm

Objective:

Increase efficiency and effectiveness of snow removal operations

- Conduct a comprehensive study to evaluate performance of snow and ice plows
- Develop an instrumentation and data collection system for IDOT snow plow trucks. Both front and belly mounted plows should be considered
- **Develop a Synthesis of Best Practices in Snow and Ice Removal**

Project Tasks

- Literature review and synthesis of best practices
- Develop a performance evaluation procedure including researching instrumentation alternatives and calibration and installation of selected instruments
- Perform field tests
- Develop finite element models to synthesize a comprehensive performance database
- Documentation of project activities and findings

Synthesis of Best Practices

- Conducted interviews with agency personnel, DOT engineers, and consultants actively involved in snow and ice plowing
  - Wisconsin DOT, Iowa DOT, Monroe Truck & Equipment, District 4, District 1
    - Equipment
    - Material
    - Procedures
    - Policies
- Focus on collecting information related to safety, best practices, and standards for: plow selection, blade selection, installation & maintenance practices.

Synthesis of Best Practices

- Visited with a national plow manufacturer
- Visited with a blade manufacturer
- Summarizing the best practices in a well organized report based on a classification system and criteria that were developed by the research team

Synthesis of Best Practices Interview

- General information about best practices
- Standards and guidelines
- Equipment
- Technology
- Personnel and training

Characteristics of a successful snow/ice plowing operation

- **No accidents/fatalities**
- **Cleanest road**
- **Quickest time**
- **Least amount of salt**
- **Most effective cost**

Best Practices Categories

- Management
- Training
- Planning
- Preparedness
- Equipment
- Technology
- Environment
- Information
- Operation

Best Practices - Management

- Management and field operators need to be flexible in terms of adopting the changing technology and procedures of operations.
- Management and field operators need to make sure equipment is ready and drivers are prepared to respond in a timely manner when the weather condition warrants it.
- The efficiency of ice and snow control operations diminishes when managers focus on reducing hours of operation and use of materials. Operators should be instructed to focus on ensuring the safety of the traveling public first.

Best Practices - Management

- Management and field operators must watch for changing weather conditions. Sometimes a storm may start with 100% snow but a sudden change in temperature and dew point creates favorable conditions for the sudden formation of black ice, necessitating a change in the treatment approach.
- Plow drivers are first on the road; therefore, they are the best positioned to evaluate the situation and adjust the snow-clearing operation as necessary to ensure successful results.

Best Practices - Training

- Initial and continual training must be required of all truck operators. Hands-on training is necessary, and job shadowing or riding along during an actual snow- and ice-clearing operation is highly recommended. The Clear Roads Project and AASHTO offer a number of training manuals and videos that can be incorporated in a comprehensive training program.
- Training programs must be updated on a regular basis to incorporate new information and the use of new technology.

Best Practices - Training

- Over-applying or under-applying salt and other chemicals may create unsafe conditions. Plow operators need to be provided with instructions on when and how much anti-icing or deicing material to apply and also be properly trained to make sure they follow the guidelines.

Best Practices - Training

- Make procedure manuals and guidelines for application of chemicals and plowing available to operators to ensure they are familiar with the procedures and guidelines and are able to follow the instructions as required and applicable. These guidelines usually include what chemicals to apply under what conditions, how much to use, and how to plow.
- Blowing snow and freezing rain represent challenges that operators need to be well trained and prepared for. For example, anti-icing with liquid chemicals is not recommended during freezing rain or sleet events (NCHRP Report 526).

Best Practices - Training

- Drivers must perform a walk-around inspection of their trucks every time before they head out. They must be trained on how to look for problems such as loose bolts and cracked blades.

Best Practices - Planning

- Snow and ice control operations may be severely hampered by shortages in material, equipment, and personnel. Failure to plan ahead will put the safety of the public at risk.
- Larger counties may need to have different operations running in different parts (such as one for snow and one for sleet). Such counties need to have the proper equipment and materials ready to be deployed where they are needed in a timely manner.

Best Practices - Planning

- Night operations present additional challenges because visibility is greatly reduced, temperatures are typically lower, and traffic is not as heavy—allowing more snow to accumulate on the pavement. Shifts should be planned in such a way to ensure that drivers remain alert during the operation.

Best Practices - Preparedness

- Some of the challenges that may interfere with a successful snow and ice control operation include equipment reliability, physical road condition, and drivers' lack of experience.

Best Practices - Preparedness

- It is extremely important for drivers to be familiar with the routes they are assigned to clear snow and ice from. Drivers need to be aware of obstacles on the roadway surface, such as manhole covers, curbs, and joints at railroad crossings and bridges. Driver training programs should include route scouting missions before the snow season, and drivers should be assigned to clear the same route throughout the season.

Best Practices - Preparedness

- Pre-plowing guidelines: Perform a quick inspection of the equipment (truck and plow) and ensure adequate quantities of anti-icing and deicing materials.
- Make sure there is enough of the blade left to avoid having to change it during the storm.
- It may also be worthwhile to mention here that a more thorough inspection of the equipment is necessary after the current operation is completed to make sure the equipment is ready for the next storm.

Best Practices - Preparedness

- A safety inspection should be conducted on trucks every 6 months.
- Keep adequate truck maintenance and inspection records.
- Keep adequate blade replacement records.

Best Practices - Equipment

- Plow trucks should have the adequate capacity to carry the required amount of material, both solid and liquid, for treating their assigned route.
- In connection with knowing when and how much anti-icing or deicing material to apply, trucks should be equipped with sensors to measure road temperature.
- High-output plows, such as the Alaskan plow, should be used in rural areas only. In urban areas, 12-ft-long flush plows are best.

Best Practices - Equipment

- One-way plows can handle more snow and may be more efficient in clearing large areas such as parking lots and interstate highways. Reversible blades are more efficient for clearing roadways because they can be used to push the snow away to the left or right of the road.
- Use a hydraulic system that limits the down force on the blade when available. It does make a difference.

Best Practices - Equipment

- High performance blade systems that use multiple materials, such as Joma or PolarFlex, provide improved performance. Some materials may wear out quicker but they are also less expensive.
- Steel blades cut ice better than carbide blades, but also they wear out faster. The best setup is to use a steel blade in front of a carbide-reinforced plate. The steel blade ensures cutting adequacy, while the carbide ensures durability.

Best Practices - Equipment

- Change blades when less than the width of two fingers is left on them.
- Some plows, such as the Alaskan plow, cause uneven wear on the blades. It is common practice to replace the whole blade set—not just sections of it.

Best Practices - Equipment

Best practices for installing plow blades:

- Make safety your number one concern. Immediately replace cracked or otherwise broken blade.
- Blades should be replaced by at least two people—and preferably three. Always use jack stands or a hoist.
- It is usually safer and more efficient to torch off old bolts.
- Always use new bolts with each blade replacement.

Best Practices - Equipment

Best practices for installing plow blades:

- Use an impact wrench to tighten bolts and secure blade in place. The impact wrench should be such that it does not over torque the bolts. An inexpensive ½ inch drive unit is better in this application than a ¾-inch air impact wrench. Torque sticks or torque wrenches are ideal.
- Replace the carbide bits and the blade at the same time. Set the carbide and then install the steel blade.

Best Practices - Equipment

Best practices for installing plow blades:

- Shops should develop carriers to hold the blades in place and allow for a safer installation operation. Two or three piece blades reduce the weight that staff has to deal with. The smaller size of two or three piece blade segments may also be necessary if blades are heat treated. This is because the segments can grow; the longer they are the greater the variability and the harder it is to maintain tolerance for holes.

Best Practices - Equipment

- Supervisors should be provided with pickup trucks that are safe to use in snow. Supervisors sometimes have to go out to check road conditions and assist operators or check on snow-clearing progress. Rear-wheel-drive pick-up trucks are not adequate for performing these tasks, and supervisors often end up having to be driven around in a snow-plow truck to be able to do their work.

Best Practices - Equipment

- Guidelines for truck replacement must be developed. These guidelines must take into consideration any value added by new technology in addition to comparing maintenance to replacement costs. Plows do not need to be replaced as long as they are still structurally adequate and safe to use.

Best Practices - Technology

- Technology is improving and can be integrated to make snow and ice control operations more efficient. This includes GPS, weather-monitoring systems, road temperature sensors, computerized salt control and slurry technology, automatic vehicle location (AVL), a maintenance decision support system (MDSS), and mobile apps to keep the public informed about road conditions.

Best Practices - Environment

- Type of pavement: The dark color of asphalt makes it absorb solar radiation and radiate heat better than concrete, which means that concrete is quicker than asphalt to freeze. Moreover, the permeability of asphalt allows the liquids to dissipate faster and not freeze.
- Bridge vs. roadway: Bridges are more likely than roadways to have ice on them as bridges cool much faster because of the air passing under them. The soil underneath provides thermal mass to roads.

Best Practices - Environment

- Time of day: Night operations are more challenging and require increased alertness. Also, temperature is typically lower during the night, which increases the probability of ice formation.
- ADT: Affects the priority and timing of snow-clearing operations.
- Topography and trees: They affect snow distribution and the amount of snow accumulated.
- When there is blowing snow, do not get pavement wet because it will build snow packs.

Best Practices - Environment

- Look out for reflectors ("cat eyes") because hitting them will tear up the carbide, will cause vibrations in the plow, and may cause bolts that are holding the blade to come loose. Raised pavement markers can also be knocked loose and become a dangerous projectile. They tear up the carbide by acting as a ramp and causing the blade to bounce. This problem is worse for blades with trapezoidal carbide. The material used to hold the carbide in the blade fractures and the carbide is lost in chunks.

Best Practices - Information

- Pavement temperature: Critical in determining the type of anti-icing or deicing material to use, if any.
- Temperature: The warmer it is, the faster and easier it is to get snow off the pavement.
- Dew point: The higher the dew point, the quicker and more likely ice is to form on the pavement.
- Wind speed and direction: Wind can completely change the operation because it can cause snow drifts and possibly blow the dry chemicals away from the pavement.

Best Practices - Operation

- Keep communications open with the foreman and report any incidents immediately.
- Monitor temperature and general weather conditions on a regular basis.
- If conditions are favorable, pretreat the roadway before the snow starts to fall. It could take up to four times the amount of salt to remove ice and snow than it it does to prevent it from bonding in the first place.
- Pre-wetting rock salt before spreading it on a dry roadway will prevent it from bouncing. A sodium chloride brine solution will help salt stick to roadway.

Best Practices - Operation

- When plowing on an interstate highway using the front plow, speed may be as high as 30 to 40 mph. A lower speed should be used on secondary roads. The operator must consider weather and traffic conditions and use an appropriate and safe speed.
- The underbody scraper is harder on the pavement, so a lower speed of 20 to 30 mph should be used.
- When wind is blowing above 10 mph, do not use solid pretreatment on a dry pavement.

Best Practices - Operation

- Completely clean and adequately inspect trucks and plows after the plowing event.
- Inspect tires, bolts, lights, springs, spreaders, curb guards, liquid tanks, truck fluids, etc.
- All maintenance must be performed if due.

Pitfalls to watch out for in snow/ice plowing operations

- Changing weather conditions
- Equipment reliability
- Railroad crossing and bridge joints
- Road obstacles: manhole covers, curbs, reflectors
- Inexperienced drivers
- Not knowing proper amounts of salt and chemicals to apply
- Sudden changes in temperature
- Blowing and drifting snow

Most important parameters in snow/ice plowing operations

- Pavement and air temperature
- Dew point - High dew point means ice on pavement is quicker to form
- Wind can completely change the operation
- Type of pavement - Asphalt holds heat longer so concrete freezes quicker
- Topography
- Time of day
- ADT

Pre-plowing guidelines

- Maintenance check of truck and plows
- Test salt and liquid applicators
- Check blade and bolts
- Check for loose fittings
- Apply anti-icing agents before storm

Plowing guidelines

- Be familiar with and Follow your agency's policies and procedures
- Get major roads open first
- Get two lanes open first then plow shoulders

Post-plowing guidelines

- Verify roads are clean
- Clean equipment and check truck, plow, and blades
- Make sure equipment is ready to go out again if need be

Safety Guidelines

- Be familiar with and follow safety guidelines
- Be familiar with route
- Speed:
  - Interstate and state highways: 30-40 mph
  - Two-lane highways: 30-35 mph
  - Secondary roads: 20 mph
- Make sure equipment is safe to use and conforms to standards
- Use common sense

Rules of Thumb

- Pre-treatment is effective: it takes four times the amount of salt to remove ice than it takes to prevent it from bonding to the pavement
- Lookout for reflectors
- Do not get pavement wet in blowing snow situations
- Replace blade when blade is less than two fingers (about 1.5 in) away from the bottom of the plow

New Technology

- Road sensors have improved quite a bit
- A variety of types of blades are available
- GPS
- Speed controlled salt distribution
- Communications with the public through mobile apps
- Snow plow route optimization

Thank You

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