Winter Operations Decision Support Tools for the Iowa DOT Maintenance Bureau

Final Report
June 2020

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16. Abstract

This research serves as a beginning point to explore new ways to support timely and accurate decision making during winter operations given the massive stream of data coming from the Iowa Department of Transportation (DOT) snowplow fleet. The Iowa DOT Maintenance Bureau manages roughly 900 snowplows, which are equipped and continuously transmitting important operational data every few seconds during winter operations. These data provide truck locations using automated vehicle location (AVL) pings and report operational status such as whether the plow is up or down and which materials, if any, are being applied to the roadway.

This research project created visual and tabular summaries of one day of winter operations data to provide practical information based on the interest and needs of both administrative and district maintenance staff. Future efforts can consider integrating these summaries and similar tools into daily operations.

This report includes the results of an attempt to conduct an analysis of snowplow blade performance using periodic measurements from specific trucks at the beginning of, and regularly throughout, two winter seasons. Unfortunately, the analysis was not possible given that snowplow operators are faced with too many demands and providing these driver-reported blade measurements was problematic, even with the significant efforts made and refined to secure the data over a second winter season. These efforts are described along with a framework that can be used for future efforts to complete this analysis.

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WINTER OPERATIONS DECISION SUPPORT TOOLS FOR THE IOWA DOT MAINTENANCE BUREAU

Final Report
June 2020

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EXECUTIVE SUMMARY

Purpose and Background

This research serves as a beginning point to explore new ways to support timely and accurate decision making during winter operations given the massive stream of data coming from the Iowa Department of Transportation (DOT) snowplow fleet. The Iowa DOT Maintenance Bureau manages roughly 900 snowplows, which are equipped and continuously transmitting important operational data every few seconds during winter operations. These data provide truck locations using automated vehicle location (AVL) pings and report operational status such as whether the plow is up or down and which materials, if any, are being applied to the roadway.

This research project created visual and tabular summaries of one day of winter operations data to provide practical information based on the interest and needs of both administrative and district maintenance staff. Future efforts can consider integrating these summaries and similar tools into daily operations.

This report also includes an analysis of snowplow blade performance and provides a suggested framework for further study efforts. The Iowa DOT spends roughly $1.5 million per year on snowplow blades, so performance is critical given that changing out broken or worn blades takes the truck off the road and can increase the risk of injury for maintenance staff doing the work. This analysis is focused on determining blade performance on a cost per plowed mile comparison, which was challenging given that blade wear depends on multiple factors, from miles used to snow/ice type, pavement type, damage from hitting curbs and debris, and overall plow pressure applied.

Findings

Project findings in this report are organized by the following four key tasks:

1. **Data Preparation** – This task identified, acquired, and processed a variety of data to serve the functionality needs of all project activities. This report summarizes each data source used as well as the required efforts made to prepare the various data sources for analysis. For example, a unique process to conflate all of the AVL data to the Iowa DOT Linear Referencing System (LRS) was required for integration of these different data sources. This effort helped to identify issues with truck sensors (blade up/down) and truck configurations from the initial AVL vendor. During the study period, the Iowa DOT switched AVL vendors and this required some doubling of effort to reconnect to and establish the new AVL data.

2. **Data Visualization** – This task demonstrated the ability to produce a visual data summary including AVL pings, material usage, and the number of truck plow passes by road segment. Visualizing snowplow location and operations data was achieved through development of a Data Visualization tool. The tool provides both a map as well as graphical information specific to when and where winter operations and materials are applied. The content and

different tabs of information are based on an iterative process, which identified the most relevant information to Maintenance and District field staff. The tool is based on one day of data, yet contains roughly 3.5 million records, which reinforces the idea of how large these data sets are and the necessity to create visual and analytical tools to support timely staff actions.

3. **Maintenance Impact Visualization** – This task explored opportunities to visualize winter maintenance impacts by user-defined time periods, locations, crash, and mobility data sources. A Maintenance Impact visualization tool was developed to show the interaction of weather, traffic, and winter maintenance operations by both location and time. Crash data were included to show the proximity of snowplow passes with observed crashes. This information supports understanding trends and patterns across these data sets. A dynamic filter was added to select specific time ranges, time aggregate levels, and roadway networks.

4. **Snowplow Blade Wear Analysis** – This task set out to investigate the performance of different front-mounted snowplow blade types. The analysis required retrieving periodic measurements from specific trucks at the beginning of, and regularly throughout, two winter seasons. Unfortunately, the analysis was not possible given that snowplow operators are faced with too many demands and providing these driver-reported blade measurements was problematic, even with the significant efforts made and refined to secure the data over a second winter season. However, a framework is presented to obtain and control for blade measurement data over time should any future analysis be conducted.

Conclusions

Overall, the project demonstrates the analytic and visual display options available to Iowa DOT staff during winter operations based on the use of both AVL and other roadway data sources. Beyond demonstration, these types of "data to information" tools and visual aids will support timely decision making, can guide improvements to efficiency, help to monitor data accuracy by truck number, and provide the ability to report on snowplow operator compliance with material application rates.

This project included a number of learning opportunities shared between Iowa DOT staff and the research team with some overall conclusions as follows:

- This study found a way to integrate large data streams to a common reference. This included developing techniques to process all of the data within one minute so that supervisors can make timely decisions during a winter storm.

- This process was instrumental in identifying trucks that were not set up correctly, including AVL issues as well as issues with the plow up/down sensors.

- The visualizations demonstrate potential displays of information available for decision making from snowplow miles driven to number of passes made for a road segment or material applied along with compliance to application rates by truck.

- The blade-wear analysis was dependent on getting measurements from the field, and, even with these efforts, not enough data were available. Therefore, analysis was not possible, but a framework for a potential follow-on study was developed.

Further integration and refinement of these types of practical tools can support Iowa DOT staff during critical times as well as support overall program efficiency throughout the year.

INTRODUCTION

The Iowa Department of Transportation (DOT) Maintenance Bureau has a fleet of about 900 snowplow trucks, which are all equipped to continuously transmit important operational data every few seconds while making the roads safer during winter storms. These data provide truck locations using automated vehicle location (AVL) pings and report operational status such as whether the plow is up or down and which materials, if any, are being applied to the roadway. Figure 1 lists these data attributes.
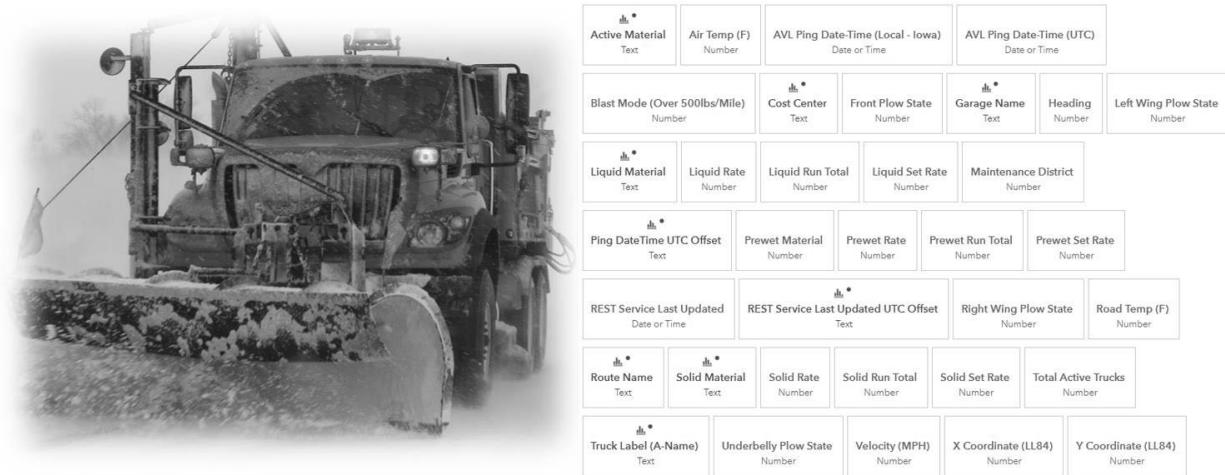
Figure 1. Iowa DOT plow truck data attributes

The Iowa DOT is a leader in the US in having accomplished the difficult task of getting the equipment and communications installed for its snowplows. Now, the remaining hurdle is to support human decision making through visualization tools for this massive continuous stream of data. To date, the degree of visualization support is limited for supervisors and key decision makers. The increased data capability can now support increased attention and consideration of opportunities to enhance both the quality and timeliness of winter operation decision making.

In addition, the Iowa DOT spends about $1.5 million annually on snowplow blades and purchases nine different types of snowplow blades. Changing out blades takes time away from keeping the roads safe. Determining which blade type provides the best cost per plowed mile is difficult, especially considering that blade wear depends on multiple factors, from miles used to snow/ice type, pavement type, damage from hitting curbs or debris, and overall plow pressure applied.

Objectives

This project included the following two key objectives:

- Demonstrate opportunities to visualize and aggregate winter operations data to support timely and effective decision making

- Investigate the performance of a variety of snowplow blades by manufacturer in terms of actual blade wear over time by miles of exposure to each roadway surface type

METHODOLOGY

This report is organized around the efforts and findings from four key tasks, which varied in scoped deliverables. The visualization efforts resulted in Tableau tool demonstrations in contrast to the snowplow blade-wear task, which resulted in an analysis. A summary of the methodology and deliverables follows.

Visualizing the Data using Tableau

Tasks 1 through 3 addressed visualizing winter operations data. The resulting Tableau tools in Task 2 and 3 were demonstrated to the project technical advisory committee (TAC). This report includes a brief description of effort by task along with links to the resulting Tableau tools where relevant. Tasks 1 through 3 are summarized as follows:

1. **Data Preparation** – Identify, acquire, and process a variety of data to serve the functionality needs of all project activities
2. **Data Visualization** – Demonstrate the ability to produce a visual data summary including AVL pings, material usage, and the number of truck plow passes by road segment
3. **Maintenance Impacts** – Demonstrate opportunities to visualize winter maintenance impacts by user-defined time periods, locations, crash, and mobility data sources

Analyzing Snowplow Blade Wear

Task 4 focused on conducting an analysis using the variety of data sources to investigate the performance of snowplow blades, in terms of wear, by miles of exposure to each roadway surface type, as follows:

4. **Snowplow Blade-Wear Analysis** – Investigate the performance, in terms of cost, of nine different snowplow blade types using the front-mounted blades only, as these blades are used on different road surface types.

FINDINGS

Task 1. Data Preparation

Accomplishing the project goals required both the acquisition and integration of data from a variety of sources—from AVL and snowplow operations data to crash, roadway surface type, and traffic sensor data. The data preparation efforts presented challenges in terms of the quantity and access to the source data, as well as equating everything back to the Iowa DOT's Linear Referencing System (LRS) to allow for seamless data integration. The data preparation effort began by working with the project TAC to identify each of the relevant data sources and then working through both acquiring and processing these data.

This effort required developing a unique process to conflate all of the AVL data to the Iowa DOT LRS for integration with the other data sources. This process allowed for conflation of the AVL data to any roadway within the LRS, which includes the interstates, US highways, Iowa highways, secondary roads, and local roads across the state. Route dominance (how events are snapped to concurrent routes) as described in the LRS was also considered to ensure data were assigned to the correct route for seamless data integration.

Key Data Sources

A descriptive summary of the primary data sources follows.

Automatic Vehicle Location

The Iowa DOT has been collecting snowplow operational data since 2011. The snowplow AVL system records the date and time, longitude and latitude, traveling speed, plow position (up or down), and material spreading rates at approximately a 10-second refresh rate for each vehicle.

The Iowa DOT has about 900 snowplow trucks spreading material through its 101 garages. Three types of spreading rates are recorded, namely solid rate, pre-wet rate, and liquid rate. Four plow wing positions are recorded: front plow, left wing, right wing, and underbelly. Each truck capacity is 12,000 pounds for single-axle trucks and 24,000 pounds for tandem-axle trucks. The spreading rate is about 200 pounds per lane mile for solid material and 60 gallons per lane mile for liquids. The travel speed when plowing and spreading material is about 30 miles per hour and the deadheading speed can be as high as the speed limit.

Weather

Weather data were obtained from the Iowa Environmental Mesonet system based on the National Oceanic and Atmospheric Administration (NOAA) Multi-Radar/Multi-Sensor (MRMS) data, which combines information from many sources and radar systems to create precise weather information. The weather variables include air temperature, wind speed, hourly- and minute-

based precipitation, daily snowfall depth, precipitation type, and so forth. The precipitation and precipitation type were recorded at 5-minute intervals.

Roadway

Roadway information is obtained from the Iowa DOT Roadway Asset Management System (RAMS). In RAMS, each roadway segment is associated with a unique RouteID and mile marker (MM), or "from measures" information. The LRS in combination with RAMS is used to merge data from various sources. RAMS also provides information such as the number of lanes and the route type, speed limits, and roadway surface types by roadway segment.

Traffic

The Iowa DOT has deployed more than 900 Wavetronix sensors throughout the state. These sensors collect traffic speed, occupancy, and volume data that are archived at 5-minute aggregation intervals. The majority of sensors are located along urban interstates. Travel speeds during winter conditions were compared to the speed limits (obtained from RAMS) to create the Relative Speed variable, or the difference between the observed speed and the speed limit. Negative relative speeds signify slower speeds than the posted speed limit.

Crash

Crash data, obtained from the Iowa DOT crash database, provide crash details such as severity, time and location, direction of travel, lighting conditions, and contributing weather conditions. Crashes during winter weather conditions (i.e., snowfall, freezing rain, or blowing snow) were used in the analysis.

Four data fields in the crash reports were used to define winter weather related crashes. (1) Environmental Contributing Circumstances—if the environment/weather played role in the crash; (2) Weather 1—the primary weather conditions at the time of the crash; (3) Weather2—any other contributing weather conditions; and (4) Surface Conditions—the roadway surface condition at the time of the crash.

If one of the four fields contained a winter weather-related variable, the crash was considered a winter weather-related crash. A total of 5,089 winter weather-related crashes occurred along the Iowa DOT maintained roadways during the 2016/2017 and 2017/2018 winter seasons. To examine the impact of snowplow operations, only those crashes identified to have occurred within two hours of a snowplow pass were included. In total, 1,372 crashes were linked to snowplow passes via the LRS system.

Conflation involves the merging of one or more data sets, which in this study includes data from multiple sources, each of which had to be aligned with the LRS. To accomplish this using the snowplow information, the team established a procedure for snowplow AVL data using a three step method:

- Part 1 Conflation – Relating snowplow AVL to the LRS
- Part 2 Correction – Correcting the AVL data and converting it to lines
- Part 3 Dynamic Segmentation – Performing dynamic segmentation

The team began testing the initial conflation of the AVL data to the LRS in Part 1 using the RAMS geometry to measure the geolocations for the LRS application programming interface (API). The "geometry to measure" service provided by the ArcGIS server takes the geolocations as the input and provides all the RouteIDs and also the measures that fall within the given input radius. Figure 2 provides an example where raw AVL coordinates are input to the API and the corresponding RouteIDs and measure values along the route are returned from the LRS.
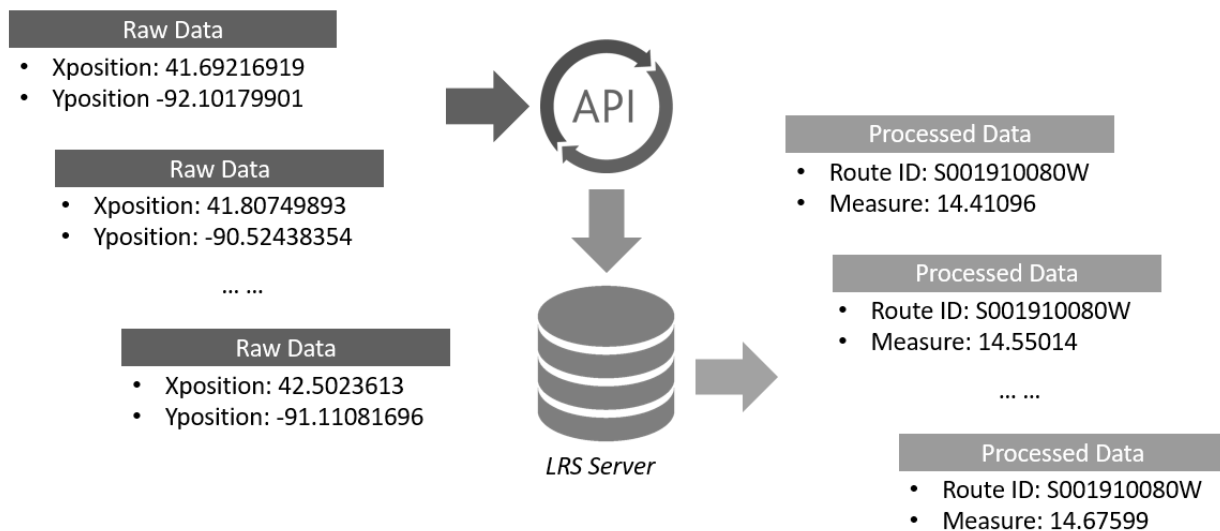
Figure 2. Sample API results from geolocation inputs

With these results, the data can be seamlessly integrated with other data for the locations using the LRS based on their route and measure values through database functions rather than using spatial functions.

This API limits the number of geolocation points in a single network call to 1,500, and the process takes about 60 seconds to return the results for 500 points. After initial testing, it was determined that this method would not be sustainable with the potential of 900 snowplow trucks all active during a statewide winter event. The team needed a process capable of conflating all of

this AVL data within one minute. Local implementations to replicate the API behavior and increase the performance were tested using ArcGIS Python modules and PostgreSQL with PostGIS extensions.

ArcGIS provides Python (ArcPy) site packages to perform the geographic data analysis, conversion, management, and automation with Python. To implement the "Locate Features Along Routes" method provided by ArcPy, the Linear Referencing Toolbox can be directly used. This method takes a list of input points as one feature layer and the routes as the other feature layer and then generates a table that gives the RouteIDs and the measures. Although the implementation is straightforward and accurate, this method has very limited options for customizing and takes a longer time to process the request.

PostGIS is a geographic information system (GIS) extension to PostgreSQL, which is an open source database system. The extension provides significant inbuilt functions to perform the spatial queries in an object-relational database. Two approaches within PostgreSQL were tested to determine the accuracy and speed of the procedures.

The first approach converted the geometric data from the LRS into geographical data. With the geographical data, the spheroid distance between two points could be calculated instead of using the less accurate Cartesian distance. Once the data were converted, functions were used that calculate the measure and RouteID for a specific point. Even though geographic data provides accurate results, it is more expensive to calculate the distance, which is why a second approach was evaluated. The second approach attempted to optimize the processing by transforming the original data into a new spatial reference (SRID: 26986).

Table 1 shows the summary results of the three local implementations on a sample of 13,000 pings using a 50-foot tolerance.

Table 1. Comparison of local implementation methods

Local Implementation Method	Time to Process (seconds)	Approximate Throughput (pings/second)
ArcPy	933	14
PostGIS with Geography (approach 1)	1,200	11
PostGIS with Geometry (approach 2)	36	361

The PostGIS results were compared to the ArcPy results, and measure values calculated by PostGIS only differed by the first or second decimal value. Due to the significant increase in processing time, the PostGIS with Geometry was used for implementation.

The process implemented using PostGIS would return the RouteID and measure values for the most dominant route within 50 meters. The route dominance is defined within RAMS and takes into account the type of roadway, the number of the roadway, and the direction of roadway. But, because of the accuracy of the GPS pings, the most dominant route may not be the correct route to which the data should be conflated. To correct this, the RouteID of the ping was compared to the previous three pings to verify all pings were on the same route. If the RouteIDs were not the same, the ping was re-conflated as shown in Figure 3 with the corrected RouteID from the previous three pings.
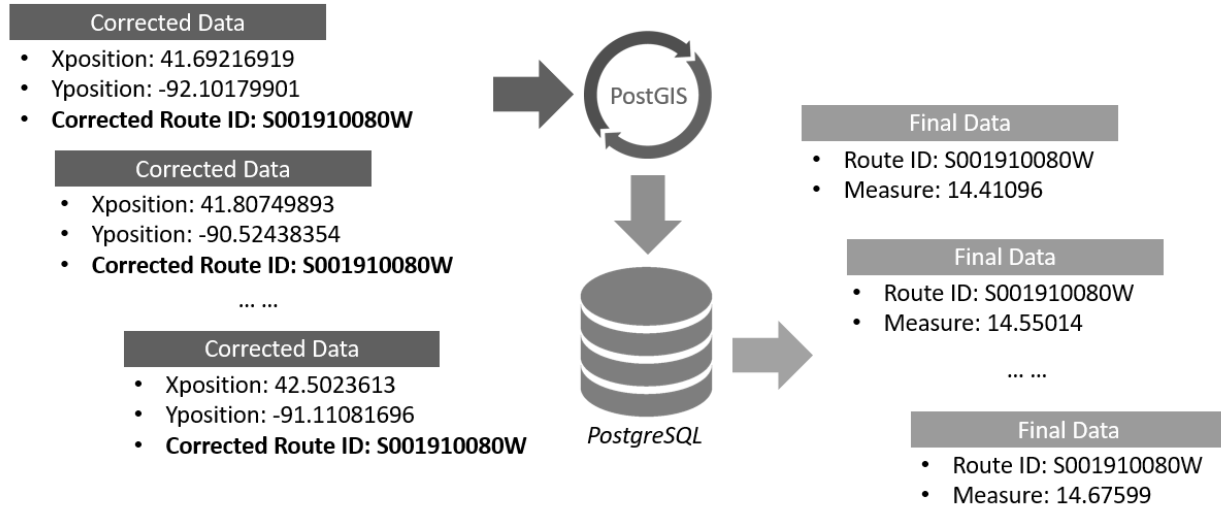

Figure 3. Sample data input with corrected RouteID

An example of this is shown in Figure 4, where eight pings are shown with the corresponding RouteID as the label for each ping.
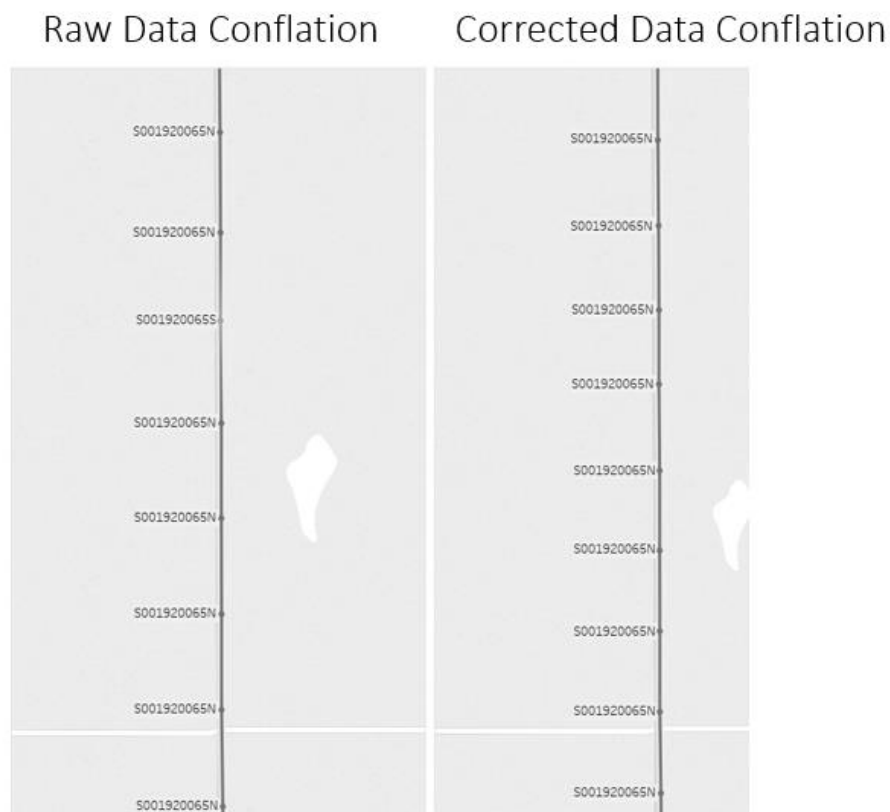
Figure 4. Comparison of RouteIDs before and after corrections

One of the pings in the raw data conflation is labeled S001920065S, while all of the other pings have the RouteID of S001920065N. Based on all of the other pings, this ping was incorrectly associated with the southbound direction (as indicated by the last letter in the RouteID), while all other pings were conflated to the northbound direction. Once the data were re-conflated, the results on the right show the same RouteID for all pings.

Once the corrected RouteID and measure value were found for each ping, the point was converted to a line by taking the route and measure value for the previous ping. This resulted in a line segment with a beginning and ending measure value. This allows the data to represent the section of road covered since the last ping rather than individual points along the roadway. The limitation with this is that the first ping on any new route will be disregarded resulting in a gap along the route. Since the previous ping is not located on the same route, a line segment cannot be created. This process could be resolved with future processing and improved during implementation. The most common situations where a RouteID changes are at ramps, intersections, where a roadway changes from divided to undivided, and where a signed route ends.

The final part of the data processing requires dynamic segmentation to associate the AVL data together. Pings do not start/end at the same location, so there are slight differences between all of the plow passes, as shown in a sample scenario in Figure 5.

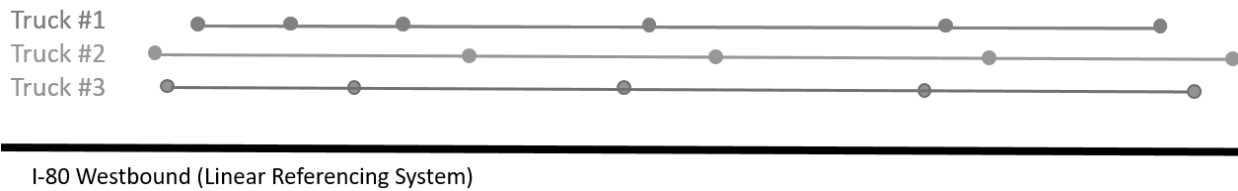I-80 Westbound (Linear Referencing System)

Figure 5. Example of dynamic segmentation

The approach taken to integrate the data does not use a static segmentation and is based, instead, on the exact locations of the pings. This provides more accurate results given specific locations where material is being applied can be located rather than aggregated across a defined segmentation. The dynamic segmentation looks across the roadway and will break the data at all of the individual data points. The unique identifier for each part of the roadway will be summarized to include the number of passes, the amount of material spread, and the material type. In Figure 5, the process would be able to identify there were three AVL passes based on the segments having overlapping route and measure values.

In addition to the improvement in the processing of the data, some additional issues were found with the data that were addressed. The primary issue identified was that data for all relevant fields were not being consistently reported for every ping. The logic developed assumes that data for each ping is complete and is representative of the snowplow status until the next ping. The status of the snowplow is what is used to determine the amount of material placed on the roadway or whether the snowplow was down at that location. The incompleteness of the data is due to the frequency of the reporting by the given sensor. Given the location is reported more frequently than the plow position or material amount, the data would show as null. Using this information, a process was developed to forward-fill the data until the next reported reading. For example, if the plow reported the blade position as down, the pings that followed with null blade positions would be updated during the down position until a new blade position was reported.

After reviewing the data, the velocity, heading, coordinates, and timestamp appear to be complete and were not modified in the forward-filling process. In addition to these, the engine hours, odometer, air temperature, and road temperature were reported intermittently, but were not forward-filled given these do not affect the current plowing operations. Sixteen additional fields, including the plow status, the material rates and set rates, and material types were all forward-filled according to the logic described above. This process ensured that each ping had all of the necessary data available.

During the forward-filling process, it was noted that a single snowplow could have multiple pings at the same timestamp. In these situations, it appears that part of the data was reported in one ping and the second (or third) part of the data was reported in the other pings. In these situations, the data were aggregated to include only a single ping with all relevant information.

A summary of the additional issues faced in developing this capability follows.

- Refined conflation process to account for multi-line segments that are in the LRS. This was realized when comparing data to field-collected information. Once resolved, the results were validated using the same data set.

- Issue with snowplow blade data position (up/down): Determined there were a number of trucks not correctly configured by the AVL vendor. This list was provided to the Iowa DOT, which then worked with their vendor to reconfigure these trucks. As a note, all Iowa DOT fleet trucks are configured by a unique "A" truck number, such as A32861.

- A script was written to filter the data by truck "A" number for use in the snowplow blade-wear analysis. This process would also allow for the roadway surface type to be reported based on the available surface type in RAMS.

Task 2. Data Visualization

This task resulted in a Tableau tool that provides map, tabular, and graphical information specific to when and where winter operations materials were applied. The tool demonstrates one day of data and required integration of snowplow AVL data with material (salt, liquids, etc.) application information by time and location. The tool used the data as output after the dynamic segmentation process from Task 1.

The data were retained at the individual truck level to support filtering based on material type, material rate, and plow status (up or down). To allow these functions, the data size remained large, which is why Tableau was utilized to quickly process and view the data. The example in the previous Figure 2 only shows a single day of data but includes more than 3.5 million records.

Figure 6 shows a screenshot for the first tabs of the resulting Tableau tool display for a single day.
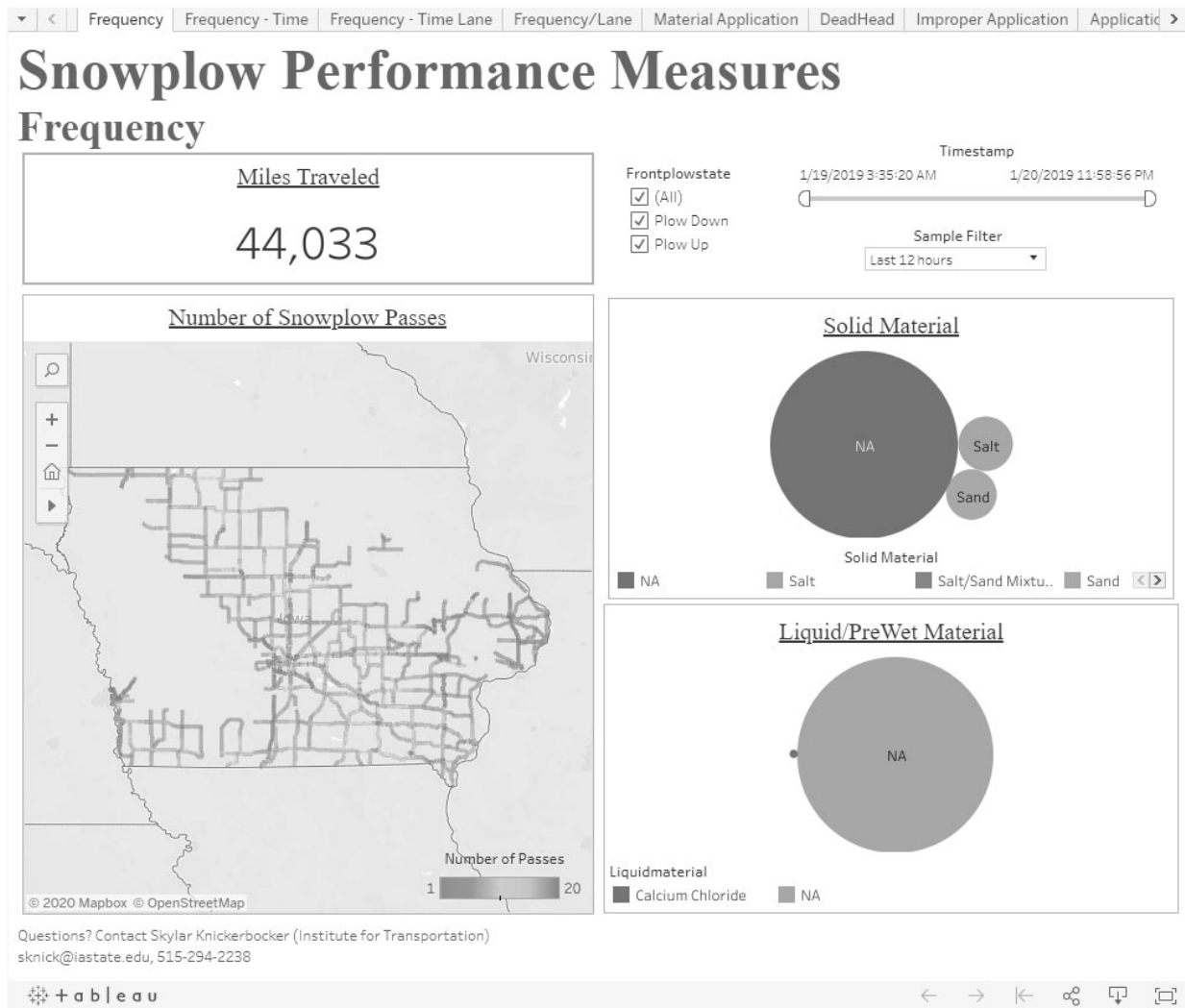
Figure 6. Data Visualization Tool: Frequency

Click here to access the Data Visualization Tool. The information presented was arrived at through multiple discussions with the project TAC specific to the types of data and information they would like to have available and the data that are collected from the snowplows. A brief summary and key theme for each Snowplow Performance Measure tab is noted below.

Tabs Within the Data Visualization Tool

- **Frequency**: Displays the number of snowplow passes by roadway segment, colored thematically, along with several selection and filter options and solid/liquid material quantities. This tab is intended to provide a high-level overview of the how many miles the snowplows traveled, how much material was used, and the locations of the snowplows.
- **Frequency – Time**: Displays the calculated minutes between snowplow passes and includes several filters. This provides an alternative way of monitoring the roadway rather than total snowplow passes and can help verify if passes are not frequent enough for the roadway.

- **Frequency – Time Lane**: Displays the normalized minutes between snowplow passes by lane (calculation takes into account the number of lanes per roadway segment).
- **Frequency/Lane**: Displays the number of snowplow passes per lane (calculation takes into account the number of lanes per roadway segment).
- **Material Application**: Displays the total amount of solid and liquid material applied in both a tabular and map format.
- **Deadhead**: Displays snowplow deadhead by distance, time, and idle time using both tree maps and an overall statewide map. Deadhead was defined as when speeds were greater than 35 mph and no material was being applied and plows were up. These charts allow users to identify which roadways the deadhead is occurring on (either by time or distance).
- **Improper Application**: Displays improper application by route, map, district, and truck (calculation based on travel speed greater than 35 mph and applicator on). This allows the user to identify which routes the improper applications are occurring on, if specific districts or garages have more improper application, or if it is a specific truck that is doing improper application.
- **Application and Plowing**: Displays snowplow speed distributions (mph) by distance for both plowing and material application.
- **Improper Plowing**: Displays improper plowing actions by route, map and distance, district, and truck. This calculation is similar to the improper application in that the blade is down and speeds are greater than 35 mph.
- **Time**: Displays the amount of time spent on a specific route, within the district and within the count and can provide a metric to determine the level of effort based on the given area. The time per mile of the route also provides a metric to determine how much time is spent per mile of plowing on a route.
- **Pass Frequency**: Displays the number of passes per hour thematically on the map including the average time between passes. The bottom display provides a timeline of passes and the reported direction to determine exactly when plows passed.
- **Plow + Material Application**: Displays truck status by distance and time by plow and material state, as well as individual truck status by distance and time. This is intended to provide a quick overview of the actions taken by the truck during a storm. This can also be used to identify data quality issues if the truck never has the plow up/down or no material is ever applied.
- **Plow Change**: Displays plow status changes by fleet truck number, by time, and spatially on a map. This chart is again intended to provide a way to determine any data quality issues with the plow status. During the data processing, it was identified that, in some cases, the plow status quickly jumped between plow up and plow down, which indicated possible sensitivity issues with the sensor.

Task 3. Maintenance Impacts

To visualize the interactions amongst weather, traffic, and winter maintenance operations, a data dashboard was developed in Tableau to show the spatial and temporal relationships among these multiple factors during winter conditions. In addition, focusing on the proximity of snowplow passes and crashes, the safety benefits of winter road maintenance was explored via visual display. This visual demonstration tool was assembled to consider the complex data sets and to

shed light on ways to mitigate the adverse effects of winter weather on traffic operations and safety.

The traffic, weather, and snowplow AVL data were linked based on temporal and spatial attributes. In particular, the LRS assigned a route and measure to each AVL record, crash location, and intelligent transportation system (ITS) sensor location. The LRS references were used to integrate relevant data together.

Using the database, a data dashboard was developed to display the traffic conditions (e.g., speed), weather conditions (e.g., snowfall, intensity, and visibility), and snowplow operations (e.g., solid and liquid rates of material). In order to create an intuitive display, a heat map template was employed.

For example, to display the speeds measured by ITS sensors, the heat map was constructed to show speed difference (relative to the speed limits) at different locations in 5-minute intervals. Each bin is populated thematically (by a color) to describe the relative intensity of that variable. When put together, users can observe differences across sensor locations for a single time period by viewing a single column. Also, by observing a single row across the columns, users can observe any temporal trends for the same location. This provides an effective way to conduct a location- and time-based analysis.

In the data dashboard, three dynamic and identically styled heat maps are stacked and aligned on top of each other. Each heat map has the ability to specify its own variable from the combined data set. This provides users the ability to observe three different variables at the same location and across the same time window. Additionally, to mitigate visual overload, the maps have a dynamic highlight function. When a time interval is selected, a highlight bar appears across each heat map and the relevant data on the map. The heat map provides an easy way to identify trends and patterns across various data sets.

To aid in the functionality, a dynamic filter process was created. This filter allows for the selection of specific time ranges, time aggregate levels, and roadway networks. A map provides a geographical reference for the analysis area that incorporates the crash data. Each crash is color-coded based on its severity.

The crash icons in this dashboard are also interactive. By selecting a crash icon, another dashboard window appears displaying the proximity of snowplow passes to the crash time. In order to help identify storm conditions more easily, a calendar heat map is also available. This uses a similar style color scheme to represent the variables. This heat calendar also provides a dynamic variable selection that allows users to select the type of events they desire.

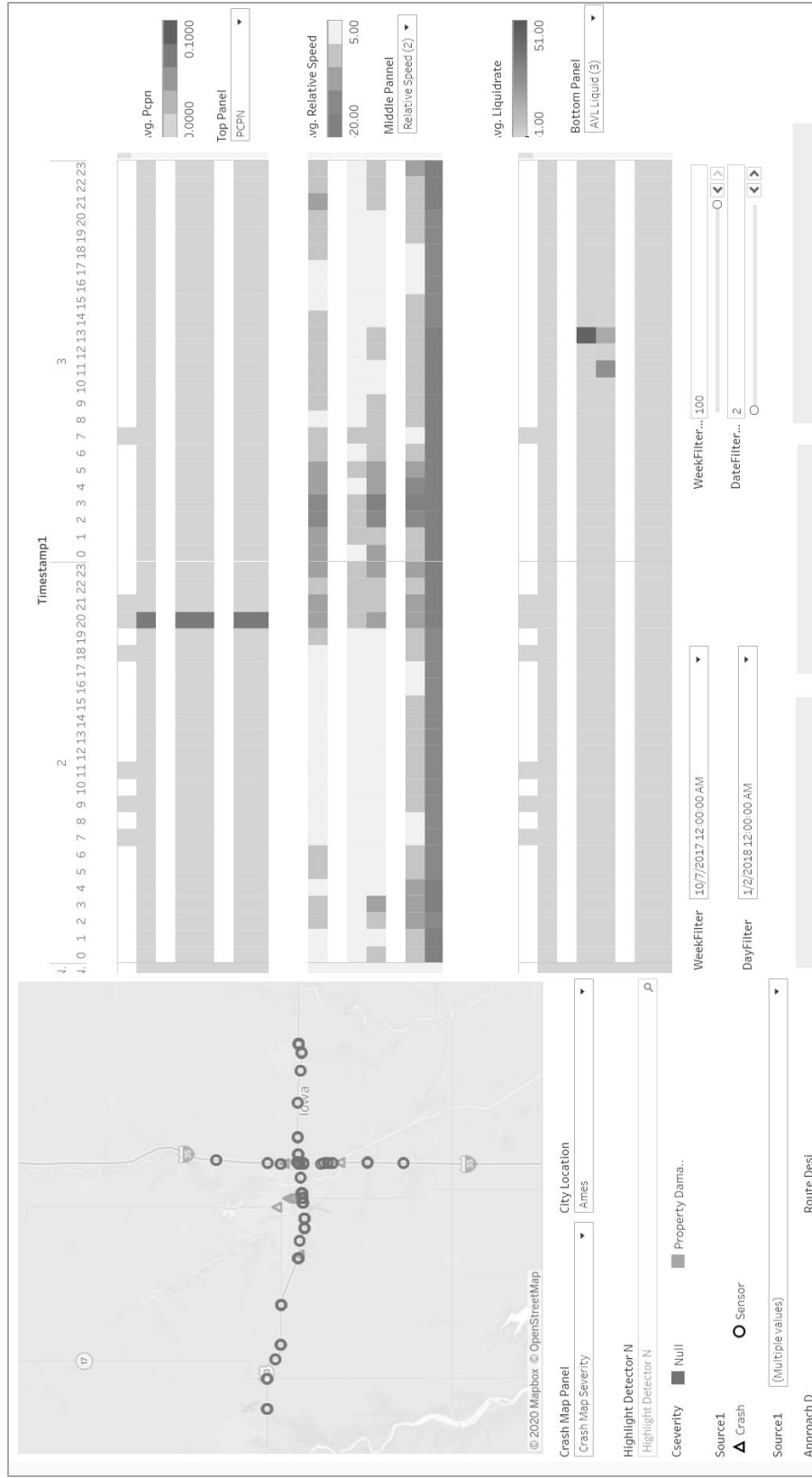A screenshot of the data dashboard is shown in Figure 7.

Figure 7. Data dashboard showing trends and interactions between different variables

15

Click here to access the Maintenance Impacts Visualization Tool. The right side contains three stacked heat maps. Each heat map is broken down into 5-minute aggregate bins. In this screenshot, the time filter is set to 2 days, so a 48-hour window is displayed. The right side includes the heat map legend as well as a tile window that drops down to allow users to select the variable to display.

Below the heat maps are the time filter controls. These allow the user to select the day(s) and week(s) of the analysis. The Wavetronix sensor locations and crash locations are shown on the map on the top left, with the highway route filters below. The blue circles indicate the Wavetronix sensor locations, while other shapes and colors depict crash events. For example, the orange triangle indicates a location where a property-damage-only crash occurred.

This tool provides agencies with the ability to pinout the conditions that lead to a breakdown in traffic operations and to observe, record, and evaluate mitigation strategies. One observation is the link between visibility and crash counts. In particular, several storms across Iowa showed a rapid decrease in visibility that led to crashes occurring before the snowplows were in operation. Accordingly, proactive actions and timely warnings can be designed to mitigate the adverse impact when visibility drops quickly. Another observation was the high degree of variability in speeds during winter-weather events. Advanced traffic control strategies, such as dynamic speed limits and warning messages, might help improve traffic flow and safety during winter-weather events, particularly on higher daily traffic roadway segments.

Furthermore, the data dashboard also provides a way to examine the interactions between snowplow operations and crashes. By clicking on a crash event on the map in the dashboard tool, as shown previously in Figure 7, a dashboard of the relevant AVL and crash data appears, as shown in Figure 8.
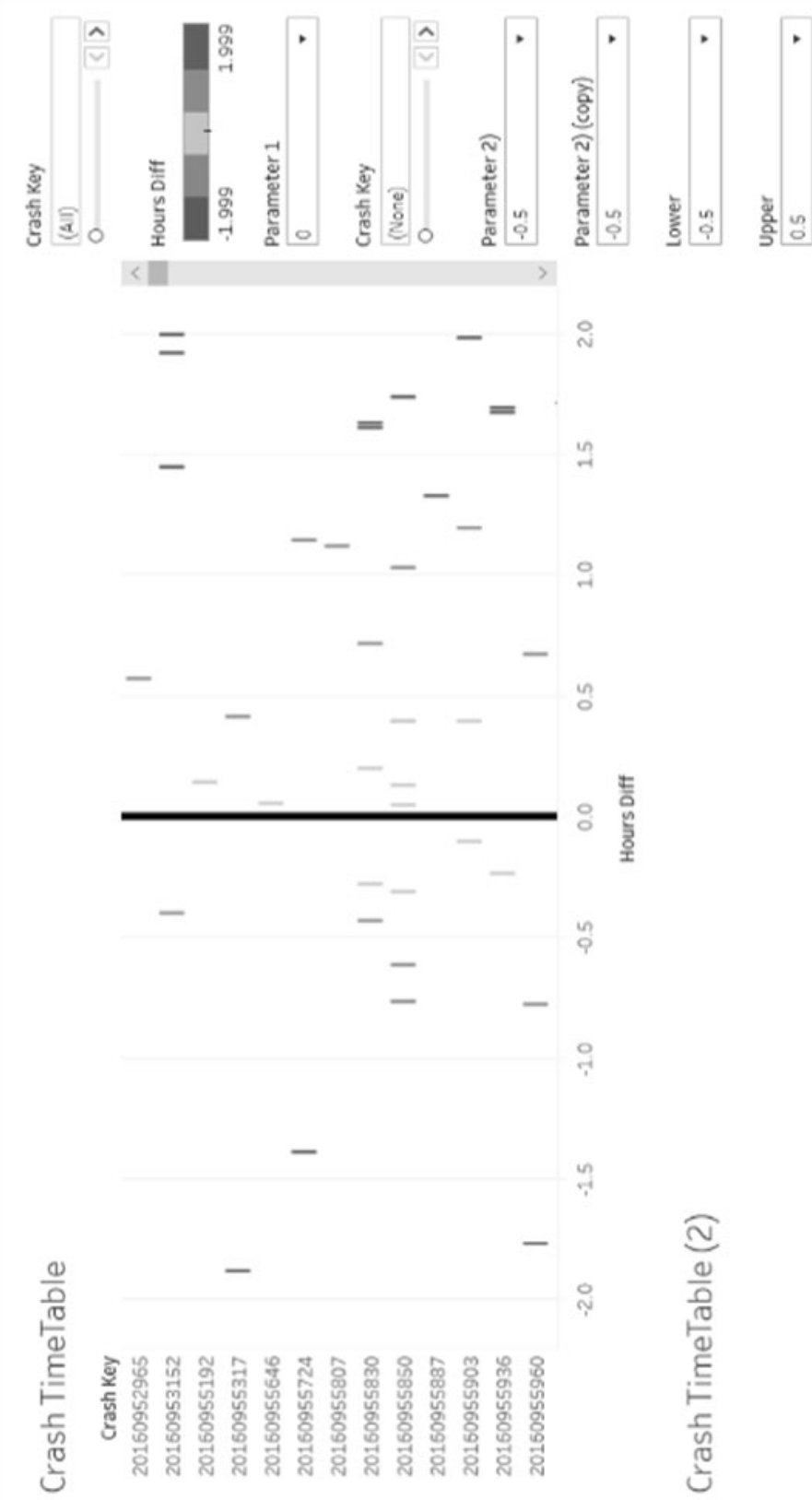
Figure 8. Snowplow pass proximity visualization tool

Each crash event is associated with any AVL data point that overlapped its LRS mile reference point. In the dashboard, each row represents a crash and each column is a time bin ranging from two hours before to two hours after the crash event. A colored bar indicates the presence of a snowplow pass at that time and location, and the black bar represents the time of the crash.

Task 4. Snowplow Blade Performance

The objective of this task was to investigate which blade types (front-mounted only) appear to perform best on different road surface types in terms of cost. The project was initiated during the winter of 2017/2018 and concluded during the winter of 2018/2019. The study methodology during both winters was generally consistent, with a few exceptions, as noted below.

The project relied on three primary data sets:

1. Snowplow operator-reported blade measurements
2. Snowplow AVL data
3. Iowa DOT LRS and RAMS roadway centerline and roadway surface type

These data sets were integrated in an attempt to assess snowplow blade wear by several measures of mileage—total, by road surface type, and by plow state (up or down).

Several other data sets and data elements were also collected to supplement the analysis. The following sections provide an overview of each data set, including collection/reporting mechanisms and frequencies, and role in the project.

Snowplow Operator-Reported Data

Snowplow operators (drivers) were provided with data collection forms during both winters. Of primary interest on these forms were snowplow (fleet truck) number, blade type, date, blade measurements, and corresponding odometer readings. The forms were slightly modified the second winter with respect to reporting frequency. During the first winter (2017/2018), blade measurements were requested after each weather event; during the second winter (2018/2019), measurements were requested every two weeks (on specific dates), coinciding with operator timesheet submittal. This was done in an attempt to both establish a regular (and specific) submission interval and minimize the required effort.

Each form contained both critical and supplemental information for the analysis as described below. Figure 9 presents a sample winter 2017/2018 form, while Figure 10 presents a sample winter 2018/2019 form. For this report, the maintenance garage and snowplow numbers are obscured on the forms in the figures.

Iowa DOT Office of Maintenance Snowplow Blade Analysis

Garage	Wing Side	Curb/Blade Saver/Guard Position
	Passenger / Driver	Passenger / (Center) / Driver / None
	(Please circle one.)	(Please circle all that apply.)

Snowplow A#	Blade Type	Blade Age --Begin Winter 2017/18--
	Front Polar Flex	(New) / Used — (Please circle one.)

Weather Event Date	Odometer (Miles)		Blade Measure (1/16") --End of Event--		Comments (e.g. Blade damaged, replaced, etc.)
	Begin Event	End Event	Passenger Side	Driver Side	
2-10-18	128,052	128,174	5 5/8	5 5/8	Plow roads
2-20-18	128,174	128,336	5 5/8	5 5/8	Ice Storm, treat roads, scrape some
2-21-18	128,337	128,410	5 5/8	5 5/8	Brine roads
2-23-18	128,476	128,615	5 5/8	5 5/8	
2-24-18	128,615	128,760	5 5/8	5 5/8	
2-25-18	128,760	128,909	5 5/8	5 5/8	
3-5-18	128,910	129,188	5 5/8	5 1/2	
3-6-18	129,188	129,375	5 5/8	5 1/2	
3-7-18	129,376	129,498	5 5/8	5 1/2	
3-11-18	129,499	129,567	5 5/8	5 1/2	Plow light snow
3-25-18	129,567	129,799	5 5/8	5 1/2	
3-27-18	129,799	129,937	5 5/8	5 1/2	
4-3-18	129,937	130,090	5 5/8	5 1/2	
4-4-18	130,090	130,271	5 5/8	5 1/2	
4-8-18	130,271	130,359	5 5/8	5 1/2	
4-9-18	130,359	130,486	5 5/8	5 1/2	
4-14-18	130,486	130,551	5 5/8	5 1/2	
4-15-18	130,551	130,825	5 5/8	5 1/2	
4-16-18	130,825	131,005	5 5/8	5 1/2	
4-18-18	131,006	131,219	5 5/8	5 1/2	

Page [ ]

Figure 9. Sample winter 2017/2018 snowplow operator form

2018/19 Plow Blade Measurement

Iowa DOT Office of Maintenance Snowplow Blade Analysis

Garage: _____

Wing Side (Please circle one.): Passenger / **Driver**

Curb/Blade Saver/Guard Position (Please circle all that apply.): Passenger / Center / Driver / **None**

Snowplow A#: _____

Blade Type: Nordik Move

Blade Age --Begin Winter 2018/19-- (Please circle one.): New / **Used**

Measurement Date (End of Pay Period)	Odomoter	Blade Measure (1/16") --End of Event-- Passenger Side	Driver Side	Comments (e.g. Blade damaged, replaced, etc.)
10/19/2018 Turn in by: 10/23/2018	N A			
11/02/2018 Turn in by: 11/06/2018	N A			
11/16/2018 Turn in by: 11/20/2018	N A			
11/30/2018 Turn in by: 12/04/2018	74194	5 3/4"	5 11/16"	
12/14/2018 Turn in by: 12/18/2018	74530	5 3/4"	5 11/16"	Miles were read on 12-17-18
12/28/2018 Turn in by: 01/01/2019	74530	5 3/4"	5 9/16"	
01/11/2019 Turn in by: 01/15/2019	75199	5 3/4"	5 4/16"	
01/25/2019 Turn in by: 01/29/2019				
02/08/2019 Turn in by: 02/12/2019				
02/22/2019 Turn in by: 02/26/2019				
03/08/2019 Turn in by: 03/12/2019				
03/22/2019 Turn in by: 03/26/2019				
04/05/2019 Turn in by: 04/09/2019				
04/19/2019 Turn in by: 04/23/2019				
05/03/2019 Turn in by: 05/07/2019				

Figure 10. Sample winter 2017/2018 snowplow operator form

Critical Snowplow Operator Form Elements

Snowplow number was reported to uniquely identify each truck and was only required at the beginning of the winter unless a change occurred.

Front blade type was reported to track performance of specific blade types and was only required at the beginning of the winter unless a change occurred.

Winter event dates (2017/2018) or **measurement dates** (2018/2019) were collected to temporally relate blade-wear measurements to AVL-based mileage, surface type(s), and blade state(s). Dates were reported throughout the winter.

Physical front blade measurements (passenger and driver side) were reported throughout the winter. These measurements were used to determine blade wear over time, mileage, surface type, and blade state. Nine different blade types were included during each winter season. Given that configurations and mounting of each blade may be different, guidance documents were prepared and distributed to snowplow operators describing the desired blade measurement technique. Measurements were requested to the nearest 1/16 inch. Figure 11 presents a sample guidance document for measuring wear on the Polar Flex blade.
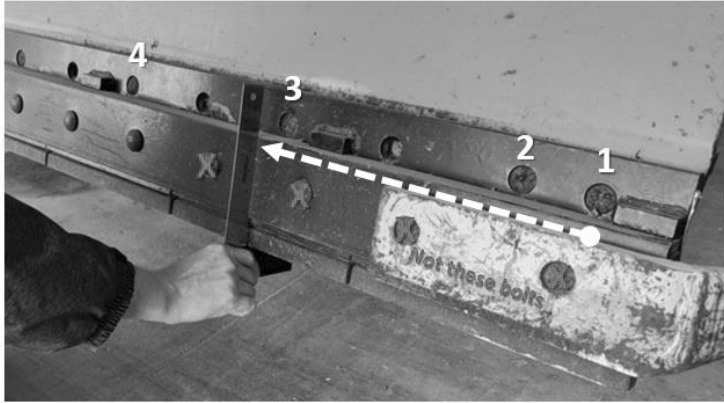

Figure 11. Sample blade wear measurement guidance document

Comments could be considered either critical or supplementary elements. A critical comment would be front blade change date(s). Change date(s) were only reported when/if applicable

throughout the winter season. This information was necessary to accurately attribute wear to a specific blade.

Other Critical Snowplow Operator Data

During the 2017/2018 winter season, some potentially incomplete or inaccurate AVL-based blade status data were observed. For example, nearly one-third of the snowplows had no reported plow-down status. In addition, one snowplow only reported down status for the front blade for 135 miles of 4,640 miles driven. In an effort to try to confirm plow blade status prior to the next winter season (2018/2019), snowplow operators were provided with instructions to report the time corresponding to various plow states and whether or not the blade-saver hydraulic feature was disengaged or engaged. Figure 12 shows an example of the front plow status confirmation form, which includes both instructions and reported times by the operator.

Front Plow Status Confirmation Process

The following process will be used for trucks participating in the plow blade wear project conducted by Iowa State University. This process is to ensure that the front plow status reported through the AVL system is correct. The process can be completed while the truck is stationary but should be done outside of the garage to ensure accurate GPS data is reported. The procedure will take approximately 15 minutes and will be as follows:

Follow steps 1 to 6 with blade saver disengaged. Enter the truck number and times in the table below.

1) Place the **blade down** and record the time (time from a cell phone/tablet/computer is sufficient). Leave the blade in the down position for **one minute**.
2) Place the **blade up** and record the time. Leave the blade in the down position for **one minute**.
3) Place the **blade down** and record the time. Leave the blade in the down position for **one minute**.
4) Place the **blade up** and record the time. Leave the blade in the down position for **one minute**.
5) For the final reading, place the **blade down but lift the blade up slightly** so the full weight of the blade is slightly off the ground. Leave the blade in this position for **one minute**.
6) Record the final time when the process is completed.

Done 12-3-2018

Repeat steps 1 to 6 with blade saver engaged. Enter the time in the second table below

	Truck Number	A 32861
	Recording	**Time**
Blade Save Disengaged	1) Blade Down Time (1 minute)	11:13 Am 12/3/18
	2) Blade Up Time (1 minute)	11:14 Am
	3) Blade Down Time (1 minute)	11:15 Am
	4) Blade Up Time (1 minute)	11:16 Am
	5) Blade Down Slightly Time (1 minute)	11:17 Am
	6) Completed Time	11:18 Am

	Recording	**Time**
Blade Saver Engaged	1) Blade Down w/Blade Saver On - Time (1 minute)	
	2) Blade Saver Off (1 minute)	
	3) Blade Up Time (1 minute)	
	4) Blade Down w/Blade Saver Off – Time (1 minute)	
	5) Blade Down w/Blade Saver On – Time (1 Minute)	
	6) Completed Time	

Figure 12. Front plow status confirmation form and instructions

The corresponding AVL data for the snowplow and time period of the confirmation test were extracted from the database, and plow state and time were compared to that reported by the operator. Confirmation suggested that the AVL plow status data may be more reliable for analysis. If unconfirmed, an effort was made to perform the confirmation process again. However, confirmation was not always possible, and not all operators participated in the confirmation process. Plow status confirmation was only required at the beginning of the winter, unless a change occurred.

Supplemental Snowplow Operator Form Elements

Front wing side – passenger, driver – was only required at the beginning of the winter, unless a change occurred. The wing side was collected because it could potentially impact blade wear characteristics.

Front curb/blade sever/guard position – passenger, center, driver, none – was, like wing side, collected because this feature (presence/position or absence) could potentially impact wear characteristics. This element was only required at the beginning of the winter, unless a change occurred.

Front blade age at the beginning of the season – new, used – was collected at the beginning of the winter season because new and used blades may wear at different rates. Updates were only necessary if a blade was changed or moved.

Snowplow odometer readings associated with the previous physical blade measurements were collected throughout the winter seasons. Odometer readings were primarily collected to serve as a comparison to (and validation of) AVL-derived mileage. In absence of AVL-derived mileage, blade wear per mile could potentially be calculated. In the absence of AVL data, odometer readings were a more critical data element. During both winter seasons, some operators reported hours instead of odometer readings.

Comments could be considered either critical or supplementary elements. Supplementary comments were those more related to blade condition (damage), maintenance activity type, precipitation type, or surface conditions, etc. This information was reported at the frequency and discretion of the operator and could be useful in identifying anomalies in blade wear.

Other Supplemental Snowplow Operator Data

Front blade photographs were requested at the beginning of each winter season. Images simply provided a visual record of the blade configuration and condition. If any changes occurred during the winter, such as blade damage and certain wear patterns, operators could submit additional images at their discretion.

AVL Data

Snowplow AVL data streams were another critical data set for analysis. These data were obtained throughout each winter season and were necessary to derive total mileage, mileage by road surface type, and mileage by plow state (up or down). As mentioned previously, prior to the second winter season (2018/2019), these data were also used to try to confirm plow status.

During the first winter season (2017/2018), Task 1developed protocols to access and integrate (conflate) AVL data with RAMS data. This process was not fully developed and implemented

until near the end of the winter. Several iterations were necessary, with the snowplow operator-reported odometer readings serving as a partial source of validation. Since the process was not available until late winter, the ability to conduct quality assurance throughout the winter was somewhat limited, e.g., identification of the potentially incomplete or inaccurate blade status data. During the second winter season (2018/2019), an attempt was made to more frequently access and integrate the AVL data.

LRS and RAMS

The Iowa DOT LRS and RAMS centerline and corresponding road surface type were obtained once per winter and assumed representative for the entire winter. This data set was critical for integration of the snowplow AVL data to derive the total mileage and mileage by road surface type for winter maintenance activities.

Wear Analysis Results: Participation

During the first winter season (2017/2018), 35 snowplows from 23 maintenance garages participated in the project, accounting for 42 blades. Wear on nine different blade types was measured. During the second winter season (2018/2019), 25 snowplows from 16 maintenance garages participated in the project, accounting for 30 blades. Wear on seven different blade types was measured.

Table 2 presents the distribution of blade types by winter season.

Table 2. Blade type by winter

Blade Type	2017/2018	2018/2019
JOMA	9	2
KUEPER	10	3
POLAR FLEX	7	11
BLOCKBUSTER	3	3
RAZOR XL	1	0
NORDIK MOVE	5	8
IRON HAWK	5	2
STRAIGHT CARBIDE	1	0
STRAIGHT CARBIDE (CYRO)	1	1

Only blades with reported data are included, given that not all trucks provided data. Additionally, if multiple blades were associated with a single snowplow, due to a blade being changed mid-winter, each blade is represented in Table 2.

Error! Not a valid bookmark self-reference. presents several statistical measures of the frequency of blade measurements.

Table 3. Blade measurement frequency by winter

Statistical Measure	2017/2018	2018/2019
Minimum	1	1
Maximum	49	12
Average	10.38	3.97
Standard Deviation	8.37	3.05

Challenges

Unfortunately, several challenges were encountered during both winter seasons prohibiting accurate assessment of blade wear. Therefore, this project yielded inconclusive results. This section includes a discussion of these challenges.

Physical front blade measurements were assumed accurate but, often, no differences in measurements were reported for long periods of time. This may be due to several factors, including limitations in the measurement technique (wear not being easily detectable at 1/16 inch) and inaccuracies in measurement reporting. Occasionally, reverse wear was reported.

A limited number of reported blade measurements, particularly in the second winter season (2018/2019), made it difficult to track wear. For example, in 2018/2019, eight blades (of 25 total), only had one measurement reported.

Lastly, some snowplows were driven hundreds of miles prior to measurements being taken, and measurements were not necessarily taken after each winter-weather event in the winter of 2017/2018.

AVL data inaccuracies/inconsistencies, particularly during the first winter season (2017/2018), limited confidence in plow status given 11 of 35 plows had no down status. Many of the plows with a down state had limited percentages of miles reported for that status, e.g., only three percent of the total miles driven. Furthermore, AVL data were missing for some plows upon a database update.

Both reliable plow status data and frequent (or consistent) reporting of blade measurements are necessary to assess blade wear. During the winter 2017/2018 season, blade measurements were relatively frequent, but the plow status did not appear reliable. A combination of reliable plow status readings and the higher frequency of blade measurements during the first winter season (2017/2018) would have been necessary to yield preliminary blade-wear rates for further assessment.

While improvements were made to the AVL data in the second winter season (2018/2019), issues appeared to still exist with respect to plow status. During the second winter season, only

14 of the 25 snowplows submitted plow status confirmation information. Five of the 14 (more than one-third) confirmations resulted in an error that could not be, or was not, resolved.

AVL data conflation to LRS and RAMS data also resulted in some mileage inconsistencies among the raw AVL data, the conflated output, and the driver-reported odometer readings. At one point, the mileage represented by the raw AVL data was approximately 10 percent greater than the conflated data. Improvements were made in the conflation process to minimize these differences, but differences may still be expected given conflation assumptions. This holds true for mileage based on snowplow odometer readings as well.

Blade sample size was somewhat limited and would need to be increased to yield statistically significant results. Specifically, at least 25 blades of each type of interest would be required for a statistically valid analysis. However, several practical challenges, including the number of blade types used by the Iowa DOT, somewhat hindered the ability to establish a statistically appropriate sample size. That said, if the blade wear, blade status, and mileage variables had been sufficiently accurate for the original sample size, the resulting descriptive statistics may have indicated some general trends or characteristics for further consideration or evaluation in a more rigorous analysis.

Demonstration

Figure 13 provides an example of several of the winter 2017/2018 challenges previously covered.

Mileage by Plow State & Surface Type

Plow	Date	Begin Passenger Measure	Begin Driver Measure	End Passenger Measure	End Driver Measure	Difference Passenger Measure	Difference Driver Measure	Begin Mileage	End Mileage	Difference Mileage	Front Plow State Up ACC	Up PCC	Up Other	Up Total	Down ACC	Down PCC	Down Other	Down Total	Total Mileage
A00000	1/14/2018			5.75	5.75			126,563	126,650	87									
A00000	1/15/2018			5.75	5.75			126,650	126,747	97									
A00000	1/15/2018										83.38	82.87	0.79	167.03					167.03
A00000	1/16/2018			5.75	5.75			126,747	126,801	54									
A00000	1/16/2018										43.75	36.24	0.76	80.75					80.75
A00000	1/22/2018			5.75	5.75			126,801	126,884	83									
A00000	1/22/2018										15.88	29.65	0.38	45.91					45.91
A00000	1/23/2018			5.625	5.625	-0.125	-0.125	126,884	127,006	122									
A00000	1/23/2018										53.07	56.16	0.77	110.00					110.00
A00000	1/26/2018			5.625	5.625			127,006	127,069	63									
A00000	1/26/2018										49.59	10.71	0.38	60.67					60.67
A00000	1/28/2018			5.625	5.625			127,069	127,103	34									
A00000	1/28/2018										199.09	67.38	0.36	266.84					266.84
A00000	1/29/2018			5.625	5.625			127,103	127,177	74									
A00000	1/29/2018										54.86	17.47	0.37	72.70					72.70
A00000	1/30/2018										52.34	7.80	0.37	60.51					60.51
A00000	2/3/2018			5.625	5.625			127,177	127,341	164									
A00000	2/3/2018										0.97	6.66	0.38	8.01	21.26	21.91		43.16	51.18
A00000	2/4/2018			5.625	5.625			127,341	127,442	101									
A00000	2/4/2018										2.63	21.35	0.47	24.44	51.99	64.98	0.30	117.28	141.72
A00000	2/5/2018			5.625	5.625			127,442	127,448	6									
A00000	2/5/2018										2.15	7.60	0.23	9.98	56.53	47.92		104.45	114.43
A00000	2/6/2018			5.625	5.625			127,448	127,597	149									
A00000	2/6/2018										10.31	41.05	0.73	52.08	48.37	40.97	0.20	89.55	141.63
A00000	2/7/2018			5.625	5.625			127,597	127,741	144									
A00000	2/7/2018										18.81	29.32	0.40	48.53	44.48	40.22		84.70	133.23
A00000	2/8/2018			5.625	5.625			127,742	127,827	85									
A00000	2/9/2018			5.625	5.625			127,827	128,052	225									
A00000	2/9/2018										11.39	22.05	0.75	34.20	129.33	119.36	0.44	249.13	283.32
A00000	2/10/2018			5.625	5.625			128,052	128,174	122									
A00000	2/14/2018										17.53	6.47	0.38	24.38					24.38
A00000	2/17/2018										2.15	7.43	0.70	10.28	38.37	35.67		74.04	84.32
A00000	2/19/2018										3.20	3.37	0.33	6.90					6.90
A00000	2/20/2018			5.625	5.625			128,174	128,336	162									
A00000	2/20/2018										23.89	63.52	1.16	88.57	39.23	19.60	0.00	58.83	147.40
A00000	2/21/2018			5.625	5.625			128,337	128,410	73									
A00000	2/21/2018										0.46	0.11		0.58	51.18	18.38	0.38	69.94	70.52

Field Data | AVL - Plow State - Surface Type Data

Figure 13. Sample operator vs. AVL data – winter 2017/2018

The left side represents snowplow operator-reported data. Regarding blade wear, a change occurred one week into the five-week period shown. No additional wear occurred after hundreds of miles driven during the next four weeks.

The right side of Figure 13 presents a summary of the conflated AVL data by front plow state and surface type. Nearly three weeks exist with no down plow state reported. This, in turn, leads to a lack of confidence in the data once a down state was eventually reported.

Comparing the dates of the operator-reported and AVL-based data indicates that blade measurements were not taken after each winter-weather event; however, measurements were fairly comprehensive.

Lastly, some minor inconsistencies are apparent between the operator-reported and AVL-derived mileages. These mileages are also somewhat difficult to correlate due to differences in reporting intervals and the denoted dates. That said, given no blade wear resulted, these differences would have no impact on wear-per-mile calculations.

Figure 14 through Figure 16 present mileage, plow status, and blade wear (over time) for a plow in the second winter season (2018/2019). This plow was selected because multiple blade measurements were reported during that winter season.

Figure 14 presents a comparison of operator-reported odometer readings to AVL-derived mileage.
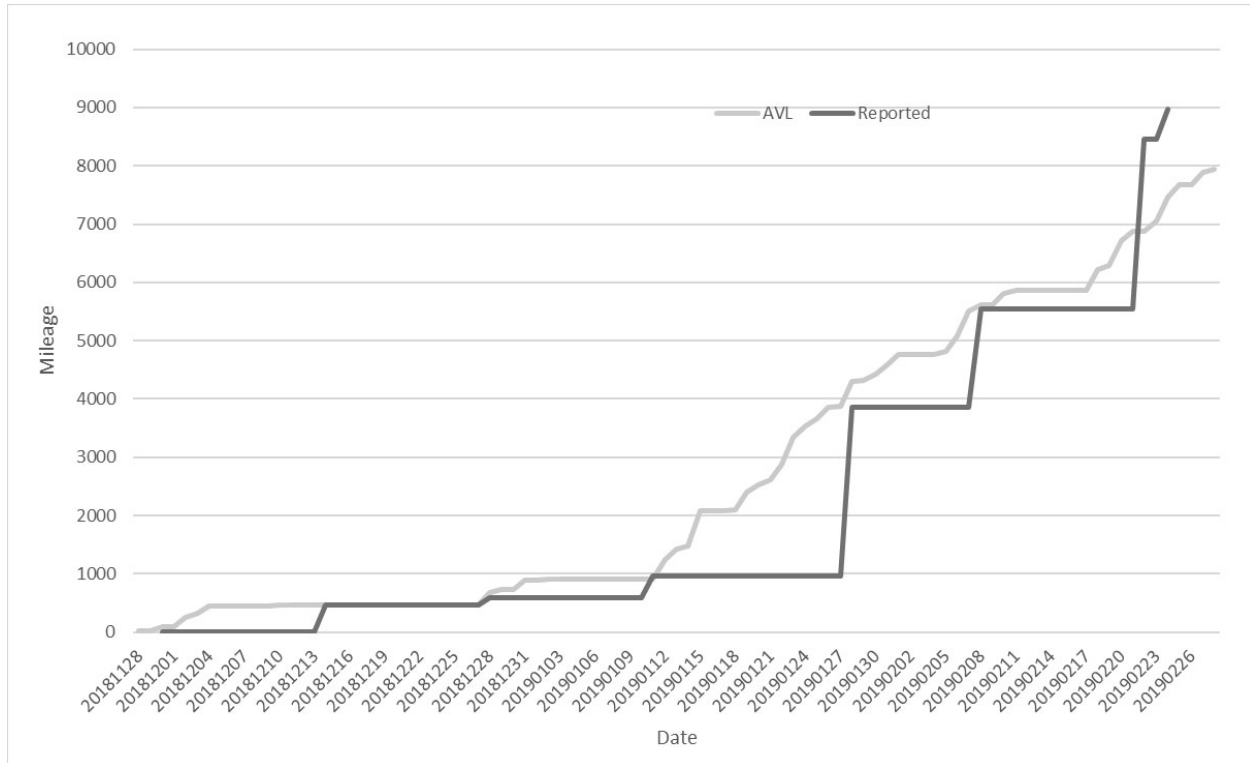

Figure 14. Sample operator vs. AVL mileage – winter 2018/2019

Horizontal portions of the AVL-derived mileage simply indicate no snowplow activity over time. Horizontal portions of the odometer-based mileage indicate that no data were reported, while vertical portions indicate that data were reported. AVL-derived mileage estimates are generally consistent with the reported odometer readings, with the exception of near the end of the analysis period. If the operator had not recorded the odometer readings, comparison and validation of the AVL-based results would have not necessarily been possible. Given the consistency of the prior data, the AVL conflation process appears to accurately represent snowplow activity. Yet, the differnces near the end of the analysis period would need to be explored prior to performing wear analysis. These differences could potentially be related to data entry or missing AVL data.

Figure 15 presents a comparison of the AVL-derived blade up and blade down status, essentially segregating the AVL-based data from Figure 14.
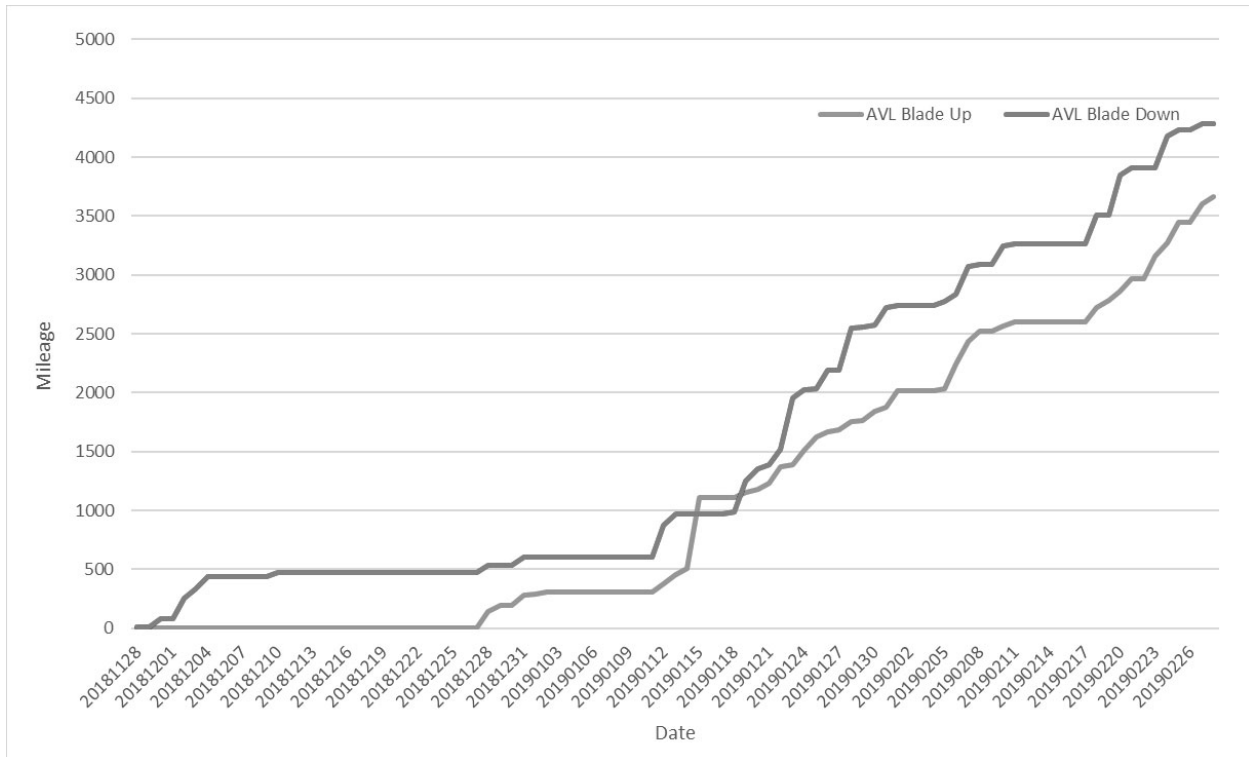
Figure 15. Sample AVL plow status – winter 2018/2019

Because of some of the previously discussed potential issues regarding plow status, input regarding accuracy may be needed from the snowplow operator, or an experienced mainenance supervisor may need to critically assess the data given winter-weather conditions during that period. This would be impractical for the those snowplows participating in the study or the entire fleet. Lack of confidence in the data can hinder efficient and effective application.

Figure 16 presents the blade wear over time based on operator measurements and demonstrates, in part, the importance of accurate measurements and the possible impacts of inaccurate data.
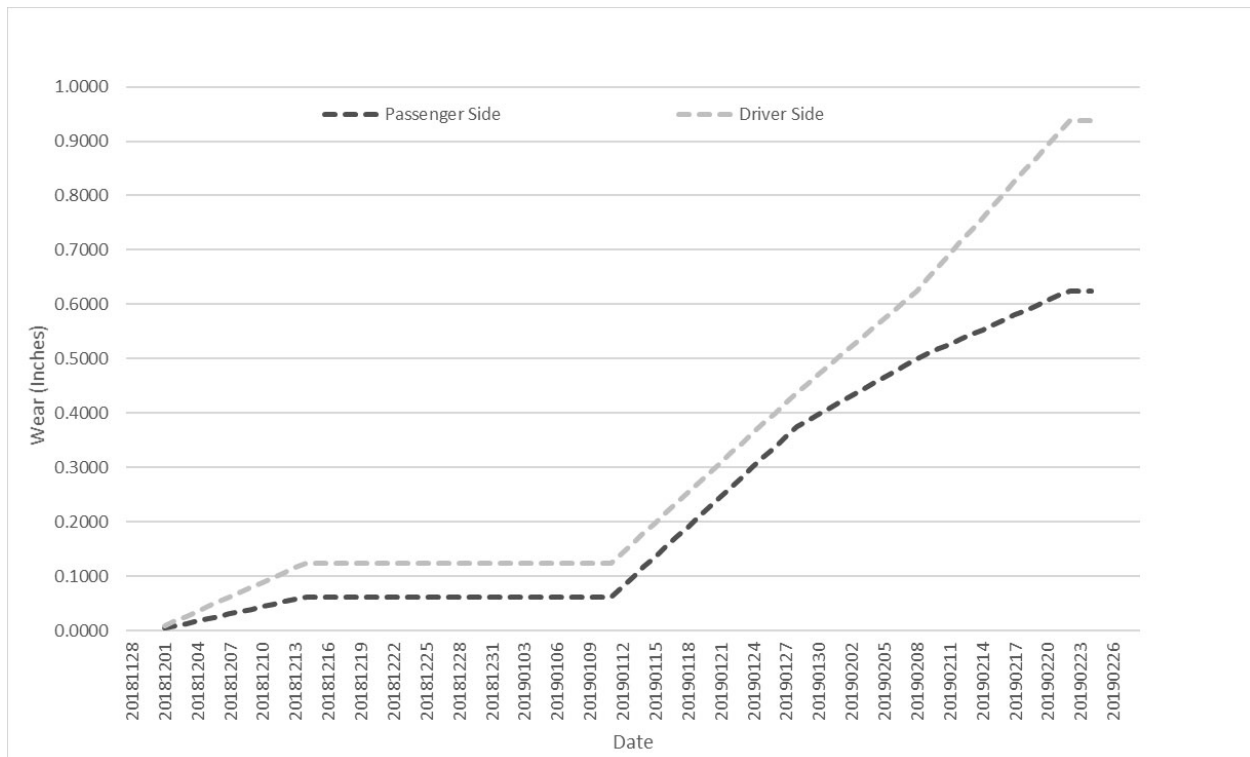
Figure 16. Sample blade wear – winter 2018/2019

In this example, the driver side generally wore more, and at a greater rate, than the passenger side. However, there was a period of time when both sides appear to have worn at the same rate. When assessing and reporting blade performance, blade side based wear as well as several of the supplemental data elements mentioned previously (e.g., wing side, curb saver presence/position) would need to be considered. Futhermore, mileage based on surface type and plow status would also need to be integrated.

Recommendations and Potential Framework

This section includes recommendations for future research into blade wear and some timeframes for those. Future research is predicated on accurate AVL data and more limited involvement of snowplow operators with respect to measurement and reporting. The study framework requires that the research team become primarily responsible for measurements, ideally yielding more consistent and accurate results at the desired time intervals. Table 4 presents past project challenges and the proposed corresponding remedies.

Table 4. Blade-wear assessment challenges and proposed remedies

Challenge	Proposed Remedy
Blade Measurement Accuracy, Frequency	The research team will be responsible for measuring participating blades at a predetermined time interval.
AVL-Based Plow Status	The research team will confirm AVL-based blade status readings prior to the winter maintenance season and reconfirm the status during the winter season. Snowplows with an unconfirmed status will not participate in the project.
AVL Completeness	Prior to the winter season, the research team will collect odometer readings for selected snowplows and compare odometer-based mileage to AVL-derived mileage. During the winter, the research team will collect snowplow odometer readings while taking blade measurements and compare odometer-based mileage to AVL-derived mileage. The research team will also compare the dates of winter-weather events to AVL-based snowplow activity for consistency.
Statistical Validity	At least 25 blades of each type (of interest) will be selected for inclusion in the project. If fewer blades are utilized, the results may be considered informative but not statistically valid.

Late Summer Activities

The Iowa DOT should first identify primary blade type(s) of interest. If possible, the DOT should identify at least 25 for each of the aforementioned blade types used within limited proximity (to be determined) of the Iowa DOT central office in Ames, Iowa. This would help facilitate the field visits by the research team.

If identification of 25 blades of the same type is not feasible, it may be necessary to reconsider the blades being evaluated, e.g., fewer of the selected types. However, the research project may not yield statistically valid results. Alternatively, the proximity to the central office may be expanded to allow for the desired sample size.

Because the Iowa DOT AVL vendor changed after the second winter (2018/2019), the research team should begin working with the new vendor's AVL data, including obtaining possible in-field access for future plow calibration testing. An effort should also be made to validate mileage. This may be accomplished by obtaining odometer readings from active trucks in a maintenance garage near the central office and comparing mileage to the AVL-derived mileage estimates. If necessary, adjustments may be necessary to the AVL post-processing methodology. Lastly, possible new blade measurement techniques should be investigated to ensure the most appropriate and accurate indication and reporting of wear.

Early Fall Activities

The Iowa DOT should provide a study overview to appropriate staff during their fall maintenance meeting. Appropriate maintenance garages should also be contacted regarding participation, and a list of the participating garages and trucks should be provided to the research team.

If necessary, the research team should continue mileage validation with the local maintenance garage. The team should also coordinate with the appropriate garages regarding when plows have been mounted on trucks of interest. Lastly, a site visit should be scheduled with each garage for the following:

- Record initial odometer readings
- Record initial blade measurements
- Record pertinent plow details, e.g., blade age (new, used), wing position, curb saver
- Conduct blade state/position calibration using field and corresponding AVL data
- Conduct material quantity calibration using field and corresponding AVL data (if of interest to the DOT)

Winter Activities

The research team should schedule monthly site visits with each garage to perform the following:

- Record odometer readings
- Record blade measurements
- Conduct blade state/position calibration using field and corresponding AVL data (optional)

While site visits can be scheduled, they may be impacted by operations activities and need to be rescheduled.

The research team should also coordinate with garages regarding blade replacement and other service details, e.g., truck in shop, blade damage. The AVL data should be processed monthly and compared to field measurements. Mileage and blade-wear data for each participating plow should be presented via a web interface, such as a Tableau dashboard, to allow monitoring and identification of possible issues.

Spring and Summer Activities

The research team should conduct and complete analyses on the comprehensive data set. A technical memorandum should be prepared presenting findings, issues encountered, and recommendations regarding future work.

CONCLUSIONS

Overall, this project demonstrates the analytical and visual display options available to Iowa DOT staff during winter operations based on the use of both AVL and other roadway data sources. Beyond demonstration, these types of "data to information" tools and visual aids will support timely decision making, can guide improvements to efficiency, help to monitor data accuracy by fleet truck number, and provide the ability to report on snowplow operator compliance on material application rates.

This project included a number of learning opportunities shared between Iowa DOT staff and the research team with some overall conclusions as follows:

- This study found a way to integrate large data streams to a common reference. This included developing techniques to process all of the data within one minute so that supervisors can make timely decisions during a winter storm.

- This process was instrumental in identifying trucks that were not set up correctly, including AVL issues as well as issues with the plow up/down sensors.

- The visualizations demonstrate potential displays of information available for decision making from snowplow miles driven to number of passes made for a road segment or material applied, along with compliance to application rates by truck.

- The blade-wear analysis was dependent on getting measurements from the field, and, even with these efforts, not enough data were available. Therefore, analysis was not possible, but a framework for a potential follow-on study was developed.

Further integration and refinement of these types of practical tools can support Iowa DOT staff during critical times as well as support overall program efficiency throughout the year.

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