EVALUATION OF EPOKE BULK SPREADER FOR WINTER MAINTENANCE

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16. Abstract

In the current economic climate, it is imperative to maximize efficiency while minimizing costs. As a result, ODOT is evaluating new methods to reduce expenditures in their winter maintenance budget. One such evaluation is of the Epoke Bulk Spreader, which is a salt and brine spreader capable of applying material over multiple lanes in a single pass. A thorough evaluation of the Epoke must be conducted in order to determine the feasibility for implementation, including: the impact on level of service (LOS), material usage, and versatility of the equipment. To successfully evaluate the Epoke, several areas of data must be collected, including: weather, traffic, plow truck, tanker anti-icing, and summer herbicide spraying data. The data collection for this project occurred in the Boston Heights garage in Summit County. A salt savings of 12% was realized through the use of the Epoke, with the payback period occurring in year eight with salt prices at $40 per ton and 20,000 tons of salt used annually by the garage. However, savings with the tanker truck were overall negligible. The Epoke is found to reduce salt usage and labor times, while maintaining the level of service.

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

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BTDCS – Bluetooth Data Collection Systems

DOT – Department of Transportation

FHWA – Federal Highway Administration

GIS – Geographic Information System

GPS – Global Positioning System

I – Interstate

LOS – Level of Service

M&R – Maintenance and Repair

MAC – Media Access Control

NB - Northbound

NOAA – National Oceanic and Atmospheric Administration

NPV – Net Present Value

ODA – Ohio Department of Agriculture

ODOT – Ohio Department of Transportation

SB – Southbound

SR – State Route

TSP – Traveling Salesman Problem

US – United States

USB – Universal Serial Bus

VRP – Vehicle Routing Problem

CHAPTER I

INTRODUCTION

The single largest cost item in the maintenance budget for the Ohio Department of Transportation (ODOT) is snow and ice control. ODOT has an annual expenditure including labor, equipment, and materials reaching approximately $50 million (ODOT, 2011), and the annual costs of snow and ice control nationally are now over $2.3 billion (FHWA, 2012). Given the current financial situation, it is imperative to maximize efficiency while minimizing costs, especially those for maintenance operations. As a result, ODOT is evaluating new methods to reduce expenditures in its winter maintenance budget. One such evaluation is of the Epoke Bulk Spreader (Epoke), which is a salt and brine spreader capable of applying materials over multiple lanes in a single pass. As with any new equipment, the Epoke needs to be thoroughly evaluated. The evaluation of the Epoke will include the following performance metrics:

- Baseline travel speeds,
- Travel speeds during winter weather events,
- Material usage of Epoke and standard ODOT spreader,
- Any additional uses of Epoke, and
- Cost–benefit analysis.

The travel speeds are recorded using Bluetooth data collection systems (BTDCS), while the material usages of the spreaders are recorded by data collection personnel riding along in the truck during winter events. With a thorough evaluation of the Epoke, a cost–benefit analysis is performed to determine the implementation potential of the spreader for ODOT’s use.

1.1 Purpose and Objectives

Four research objectives must be met in order to ensure that state job number 134651, "*Evaluation of Epoke Bulk Spreader for Winter Maintenance,*" will be considered a success. These four objectives, which are described in the ODOT request for proposal, are as follows:

- Objective One – Evaluate existing data reports with the Epoke, including those produced by the Pennsylvania DOT's Erie County garage and the City of Cuyahoga Falls, Ohio,
- Objective Two – Assess in-field performance of the Epoke,
- Objective Three – Perform a cost–benefit analysis of the Epoke, and
- Objective Four – Propose a deployment strategy for the Epoke consistent with current ODOT practices.

1.2 Benefits from this Research

The research described within this report will have both immediate as well as long-term benefits to ODOT for adopting the Epoke Sirius S4902 AST Combi Bulk Spreader, supplied by Epoke North America. The main immediate benefit of this project is the acquisition by ODOT of a piece of equipment that can be immediately placed into service for winter maintenance operations, as well as summer maintenance activities such as herbicide spraying.

In addition to the immediate benefits, there are several long-term benefits that may arise from the outcome of this project. ODOT will gain information regarding the cost savings of the Epoke, and this knowledge will be used in the decision making processes for widespread incorporation of this technology into the winter maintenance fleet. ODOT will also be supplied with an implementation plan with recommendations on the best way to utilize the Epoke, which may result in additional cost savings.

1.3 Organization of this Report

This report is divided into eight chapters. Chapter 1 is the introduction of the topic and a statement of the research objectives. Chapter 2 presents a literature review of winter maintenance practices and similar research efforts. Chapter 3 presents the project setting including details about ODOT's routes and garages. Chapter 4 presents the research methodology used in collecting the appropriate data for use in the analysis. Chapter 5 summarizes the results from the data collection, including all data from the plow systems and trucks as well as the speed data collected from the roadways. Chapter 6 presents the cost calculations associated with the Epoke including the payback period on investment. Chapter 7 presents an implementation plan and training for the Epoke. Chapter 8 presents the conclusion and recommendations found in this evaluation.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

As a result of the increased costs associated with winter maintenance across the country, there is a need to develop and implement new technologies that will improve efficiency and reduce costs associated with winter maintenance operations. A number of winter maintenance evaluations for a variety of snow plow accessories and snow removal systems are available. These reports help the sponsoring agencies to determine if the equipment being evaluated is beneficial for the particular agencies and locations conducting the study. While these evaluations are not directly developed for ODOT, they will provide a baseline on how other agencies evaluate their equipment.

2.2 Data Collection Methodology

In accordance with this project, four data collections areas have been identified:

- Winter Maintenance Evaluations – Evaluations of Epoke and other equipment,
- Travel Time and Speed Evaluations – Methodologies for data collection in winter as well as for Bluetooth data collection,
- Weather Data – Snowfall data as well as any processing techniques required prior to the analysis of the data, and
- Route Modeling – Route optimizations for snow plowing and material allocation.

As a result, a literature search and review is conducted highlighting these topic areas. Additional details regarding each of these areas are provided in the subsections below:

- Subsection One – Winter Maintenance Evaluations,
- Subsection Two – Travel Time and Speed Evaluations,

- <u>Subsection Three</u> – Weather Data, and
- <u>Subsection Four</u> – Route Modeling.

2.2.1 Winter Maintenance Evaluations

A number of evaluations of winter maintenance equipment have been conducted over the past several years. A summary of these methods and techniques is presented in Table 2.1.

Table 2.1: Winter Maintenance Equipment and Material Evaluations.

Equipment/Material Evaluated	Evaluation Application	Findings	Reference
	Anti-/De-Icing Evaluations		
Chloride-based ice control products for anti-icing and de-icing.	Evaluated reports providing information on effectiveness of chloride-based ice control products.	Reports include reported savings, reduced crashes, and benefits to motorists.	Shi et al., 2013
Fixed anti-icing tracking systems for snow removal and ice control.	Monitoring and documentation of system placement and construction, data collection of system operations, both during and subsequent to actual inclement winter conditions.	When properly functioning, the system is an impressive winter management tool. Improved road/travel conditions in ice and snow.	Hurst and Williams, 2003
Chloride-based deicers, acetate-based deicers, and sanding materials.	Conducted literature review of various de-icing materials and their impacts on health, the environment, performance, and costs. Surveys to determine health impacts.	List the different advantages and disadvantages of each deicer tested.	Fischel, 2001
Physical pavement modifications to facilitate ice disbanding by traffic action or other external energy.	Investigated the possibility of developing a curved, optimized, cutting edge profile to remove a bonded ice layer from highway pavements.	Improved geometry of cutting edge (15º to 30º rake angle) with result in significant energy savings in cutting ice from pavement.	Wuori, 1993
	Plow Blade Evaluations		
Four different blade types.	Recorded number of hours spent plowing. Compared service life, effectiveness, efficiency,	JOMA and Polar Flex lasting on average 3 to 4 times longer than	Mastel, 2011

	and costs. Surveyed operators on various aspects of effectiveness of the blades.	carbide steel blades.	
Three sets of plow blades with carbide inserts.	Developed a standardized test to aid buyers in determining any deficiencies in the carbide inserts before purchasing.	Poorly performing inserts appear to have excessive voids and internal cracks.	Braun Intertec Corp., 2010
Multiple plow blades on a single plow for clearing various snow conditions.	Manufacturers developed various blades, which were evaluated during two winter seasons.	All states involved expressed continued interest in the concept of the multiple-blade plow. Vendors received feedback to help produce other prototype multiple-blade plows.	CTC and Associates LLC, 2010
Kuper – Tuca SX36 plow blades.	Plow blades were installed on three MaineDOT plow trucks. Miles of plowing were recorded and compared to the standard carbide insert.	Only two blades gave good data, which showed the Kuper blades lasted 2.25 times longer than the carbide. However because of small sample size, more research is needed to verify.	Colson, 2010
Various plow blades.	The total miles of plowing are tracked and costs reported per mile. The amount of noise created when plowing is also recorded.	More data need because of small sample size.	Colson, 2009
Equipment Evaluations			
Viking-Cives TowPlow.	Used TowPlow on SR-11, I-90, and US-20 in Ohio. Collected driver feedback.	TowPlow was a valuable addition to ODOT’s fleet for snow and ice removal. Reduced usage of fuel, labor, and material while still providing adequate LOS.	Griesdorn, 2011

Various equipment and techniques used for winter maintenance.	Conducted survey with maintenance professionals.	Developed a cost–benefit toolkit of most widely used techniques and equipment.	Veneziano et al., 2010
Automatic vehicle location (AVL) equipment.	Evaluated the cost–benefit ratio of a statewide deployment. Using the cost of the system and the annual maintenance cost while quantifying the expected benefits such as timely responses, reduced legal costs, improved efficiency, reduced crashes, etc.	Determined expected benefits of using AVL equipment.	Meyer and Ahmed, 2003
Zero velocity deicer spreader and salt spreader protocol.	Used a visual evaluation of the spreaders to determine if the zero velocity spreader kept salt on roads better than the standard spreaders.	Too many other variables, i.e. truck speed, were present to determine if the zero velocity spreader is more beneficial. Visual evaluation is not enough to draw a conclusion.	Nantung, 2001
Winter maintenance activities in Utah, which includes labor, material, and equipment.	Developed winter maintenance metric to compare the price of winter maintenance to the storm severity and amount of lane kilometers maintained.	An effective performance measurement and management system links individual and teamwork behaviors to business goals.	Decker et al., 2001
Epoke models 3500 and 4400.	Purchased several Epokes and evaluated salt savings compared to standard spreader with dry material. Conducted cost–benefit analysis after each winter season.	Data shows that Epoke is a cost-effective system that pays off in two seasons. The agency equipped their entire fleet with Epoke.	Cuyahoga Falls, 2013 (Personal Conversation)

Many evaluations of various equipment and materials used for winter maintenance operations have been conducted. Several of the studies conduct a cost–benefit analysis similar to what will be performed in this report. These studies provide a background on winter maintenance evaluation methodology and typical cost–benefit analysis associated with equipment.

2.2.2 Travel Time and Speed Evaluations

An integral aspect of the evaluation process for winter maintenance equipment is the impact on travel times, speeds, and the resulting level of service (LOS) for motorists. Using roadside devices to identify and record the timestamp of a vehicle is a common way to determine vehicle speeds; similar nodes are utilized in this study to determine vehicle speeds, which are used as surrogate measures of roadway conditions. Accordingly, several studies evaluating the characteristics of Bluetooth data collection systems are presented in Table 2.2.

Table 2.2: Speed and Travel Time Evaluations.

Collection of Speed Data	Evaluation Approach	Findings	Reference
Bluetooth nodes are developed to collect speed and travel time data from interstate highways in Ohio.	Nodes determined the travel times and speeds in various deployments to determine optimal uses and strategies for ODOT.	Portable nodes are ideal for construction zones and short-term studies, while solar-powered nodes may be used for permanent deployments.	Schneider et al., 2012
Bluetooth nodes are used to collect media access control (MAC) addresses of enabled devices.	Nodes record the time stamps, which determine travel times along interstates in Indianapolis, Indiana. Variability of travel times are discussed, including travel during snow events.	The improvement in estimation accuracy depends on the technique, the number of probe vehicles, and traffic levels.	Martchouk et al., 2011
Bluetooth detectors are used to capture MAC addresses of passing devices, which are matched in a database.	Antennae are placed at heights from 0 to 10 feet to determine the difference in amount of hits recorded based on antennae placement.	The near side bias was much more significant for short antennas.	Brennan et al., 2010
Bluetooth detectors are utilized to capture the MAC addresses of passing Bluetooth enabled devices in vehicles.	The nature of matching algorithms and the accuracy of the speeds are described.	The performance of the filtering system proves to be an effective method for processing the travel times collected by Bluetooth sensors.	Haghani et al., 2010
Vehicles equipped with automatic vehicle identification (AVI) were recorded by roadside antenna; times and distances were used to	Speed and weather data from New York State is used to determine the effectiveness of winter maintenance operations. Speed reductions and time	Average loss of speed is about 5.6% to 5.7% higher on I-290 segments than I-90 segments during snow events.	Thill and Sun, 2009

calculate space mean speed.	for speeds to return post event were evaluated.		
Bluetooth detectors are used along interstate and arterial corridors to determine travel times.	Nodes collect travel times in Indianapolis, Indiana. Differences between data collected for interstates and corridors are acknowledged.	Arterial data have a significantly larger variance due to the impact of signals and the noise that is created when motorists divert from the roadway network.	Wasson et al., 2008
Bluetooth detectors are used to record the MAC addresses of Bluetooth devices passing the roadside nodes.	Nodes are used to determine travel times on I-95 between Baltimore, Maryland, and Washington, D.C. Privacy concerns and placement of nodes are discussed.	Accurate travel time can be measured using Bluetooth technology.	Young, 2008

The use of BTDCS to measure travel speeds is a widely used practice, and many studies have been conducted demonstrating the capabilities of such systems, as well as highlighting some methods for optimizing the amount of responses recorded.

It is the belief of the research team and other researchers that vehicles will reduce their speeds based on the conditions of the highway, as shown in Table 2.3.

Table 2.3: Evaluations of Speed Reduction due to Weather Conditions.

Weather and Speed Evaluation	**Evaluation Approach**	**Findings**	**Reference**
Automatic number plate recognition (ANPR) data are used to determine travel times.	Collected data in the Greater London, U.K., area from October 2009 to December 2009.	Light snow increases travel times 5.5 – 7.6%, heavy snow increases travel times 7.4 – 11.4%. Rain increases travel times 0.1 – 2.1%, 1.5 – 3.8%, and 4.0 – 6.0% for light, moderate, and heavy rain, respectively.	Tsapakis et al., 2012
Data from automated surface observing systems (ASOS) and automated weather observing system (AWOS) are used to determine new weather adjustment factors.	Collected data in Baltimore, Minneapolis, St. Paul, and Seattle. Performed regression analysis to determine weather adjustment factors.	Reductions in speed and speed at capacity are found for rain and snow conditions. Rain reduces speeds 2 to 10%; snow reduces speeds 5 to 16%.	Hranac et al., 2006

Determine change of speeds due to different rain intensities.	Calculated mean speeds in Hampton Roads, Virginia, then tested the percent changes in operating speeds due to rain for statistical significance.	Rain, regardless of intensity, decreases speeds by 5.0 to 6.5% of normal operations.	Smith et al., 2004
Determine if a special time plan is needed during adverse weather conditions.	Over a three-month time period, data was collected using videotape from a signalized intersection in Burlington, Vermont.	Saturation headways are impacted by developing special time plans for adverse weather conditions but start-up times are not affected.	Abolosu-Amison, Sadek, and Elessouki, 2004
Analyze driver behavior under various weather conditions.	Examined traffic behavior in three weather categories: fine, rain, and misty conditions.	Drivers acknowledge the need to modify behavior because of weather but in practice only alter their behavior marginally.	Edwards, 1999
Evaluate how roadway users, vehicles, and weather affect traffic relations.	Created a statistical model to show the relationship between roadway users, vehicles, weather and the flow-density curve.	Models that compare the various variables promise to refine the debate on the form of the flow-density relation and improve the modeling of traffic flows.	Kockelman, 1998
Weather and speed data collected.	Multiple regression analysis was conducted on data collected on I-84 in Idaho.	Mean speeds reduce by 19.2 km/h during snow events.	Liang et al., 1998
The effect of adverse weather conditions on the flow-occupancy and speed-flow relationships.	Estimated the speed reductions from data collected from inductive loops near Toronto, Canada.	Speeds are reduced 2 km/h due to light rain, 3 km/h in light snow, 5 to 10 km/h in heavy rain, and 38 to 50 km/h in heavy snow.	Ibrahim and Hall, 1994

Many studies support that motorists will reduce their travel speeds based on the roadway conditions. Of importance to this study are the reductions due to snowfall and other winter road conditions. Through the speed data collected, the effectiveness of the Epoke's ability to treat the roadway may be analyzed by using the vehicle speeds as surrogate measures for roadway conditions.

2.2.3 Weather Data

In order to evaluate winter maintenance equipment, it is necessary to obtain accurate weather data. Several sources are available and are used for the collection of weather information. Some of these sources are presented in Table 2.4.

Table 2.4: Weather Data Sources.

Weather Data Source	Purpose of Study	Findings	Reference
Next-Generation Radar data on precipitation and wind conditions.	Evaluate speed and weather data to determine the impacts of winter maintenance operations on user mobility.	Speed reductions occur during winter events.	Thill and Sun, 2009
Evaluated agencies using various sources of data including Meridian, Meteorlogix/DTN, and the National Weather Service (NWS), amongst others.	Compared the frequency of reviewing weather data to anti-icing practices. Evaluated the frequency and accuracy of weather data on winter maintenance costs.	Presented a general approach for the modeling of winter maintenance costs.	Ye et al., 2009
Road Weather Information System, NWS weather stations in California, Montana, and Oregon.	Develop a roadway winter weather index to correlate winter weather to safety.	Index scale was developed.	Strong and Shvetsov, 2006
Interactive software package called BUFKIT, developed at NWSFO Buffalo. BUFKIT is a forecast profile visualization and analysis tool kit. It is used as a training and forecast tool for the decision makers at the NWS.	Evaluation of BUFKIT to help predict the lake effect snow events around the Great Lakes region.	BUFKIT may provide valuable guidance about the evolution, location, and movement of snow bands downwind of the Great Lakes.	Niziol, Snyder and Waldstreicher, 1995
NOAA weather data were used to determine weather patterns.	To determine optimum maintenance manpower during the winter in Pennsylvania.	Dual-shift operation can be more economical than single-shift operation.	Rissel and Scott, 1985

Table 2.4 presents several sources of data utilized in various winter maintenance evaluations. The National Oceanic and Atmospheric Administration (NOAA) is found to provide the most readily available data and is utilized in this study.

2.2.4 Route Modeling

To facilitate the implementation of the Epoke within ODOT's current winter maintenance fleet, the snow and ice routes are reviewed and optimized. The route optimization model is created in order to determine where the Epoke would be best utilized. Research in this area has evolved with recent advances in technology, and several of the accomplishments are found in Table 2.5.

Table 2.5: Route Modeling Sources.

Route Modeling Source	Purpose of Study	Findings	Reference
Model developed to synchronize arc routing for snow plowing operations. A set of routes are determined where multiple lanes are plowed with fleets of synchronized vehicles to minimize the duration of plowing for the longest route.	Introduces a synchronized arc routing problem for the snow plowing operations.	An improvement phase was added to the algorithm that yielded significant improvement to the efficiency of plowing model.	Salazar-Aguilar et al., 2012
Missouri DOT developed integrated algorithms for the most efficient route plans and fleet allocations.	To optimize the routes and fleet allocations for Missouri DOT in order to provide adequate level of service and to determine potential cost savings.	Provided a list of various conditions and the type of response needed by Missouri DOT.	Jang, 2011
Optimal workforce planning and shift scheduling for snow and ice removal.	Develop a methodology for efficient deployment of available crews and equipment to achieve the most efficient use of resources.	Use of contract employees resulted in the lowest total cost to Missouri DOT.	Gupta, 2010
Model takes into account a wide range of road and weather condition factors to aid in winter maintenance planning.	Methods for producing optimal deployment schedules for winter road maintenance planning.	Provides a method to produce optimal deployment schedules and a consistent framework to follow and compare in future research.	Fu et al., 2009
Level of service policy and the sector design problem for spreading and plowing operations.	Part I of a survey of models and algorithms for winter road maintenance. Part I focuses on system design for spreading and plowing.	Table 2 of report summarizes the characteristics of service level and sector design models for spreading and plowing. New mathematical formulations and solutions strategies are developed.	Perrier et al., 2006a
Modeling snow disposal for winter maintenance.	Part II of a survey of models and algorithms for winter road maintenance. Part II focuses on system design for snow disposal.	New mathematical formulations and solutions strategies are developed for snow disposal.	Perrier et al., 2006b

Adding the variables of vehicle routing and depot location for spreading to optimize winter maintenance planning.	Part III of a survey of models and algorithms for winter road maintenance. Part III focuses on vehicle routing and depot location for spreading.	New mathematical formulations and solutions strategies are developed for vehicle routing.	Perrier et al., 2007a
Adding the variables of vehicle routing and fleet sizing for plowing and snow disposal winter maintenance planning.	Part IV of a survey of models and algorithms for winter road maintenance. Part IV focuses on vehicle routing and fleet sizing for plowing and snow disposal.	New mathematical formulations and solutions strategies are developed for vehicle routing and fleet sizing.	Perrier et al., 2007b
Artificial-intelligence–based optimization of management of snow removal assets and resources.	Research on the development of an intelligent system to integrate a generation of snow plowing routes and asset/resource allocation.	Describes the development of analytical tools in a transportation asset management context through the use of the developed model.	Salim et al., 2002
Arc routing methods and applications	Teaching how to use arc routing methods and applications to determine routing. Snow plowing is an example of when to use arcs rather than nodes.	How-to steps to use for arc routing methods.	Assad et al., 1995
Developed a model to predict the costs and benefits of winter maintenance in Idaho.	Historical data was used to develop models for each district in order to predict costs and benefits.	The model helps to estimate the benefits to safety, travel time, and fuel cost.	Haber and Limaye, 1990
A detailed description of a computer system for the routing and scheduling of street sweepers.	Using computer programs to optimize street sweeping trucks; the same concept may be applied for snow plowing.	How-to steps to create routing models	Bodin and Kursh, 1979

These are a sample of the common route modeling technologies and processes used for winter maintenance activities. Also, these studies provide a background from which the research team’s model is developed.

CHAPTER III

PROJECT SETTING

This project setting chapter is divided into three sections:

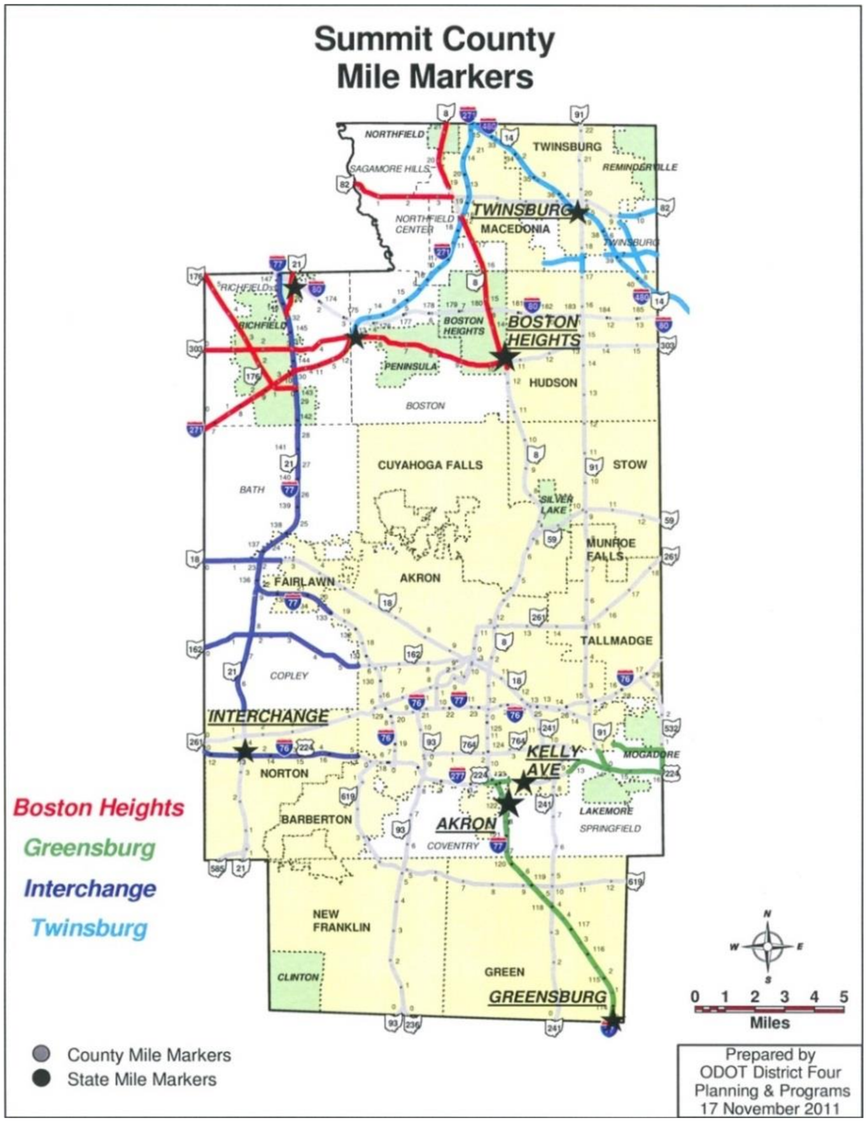
- Section One – Introduction,
- Section Two – Project Setting, and
- Section Three – Spreader Systems.

3.1 Introduction

The evaluation of the capabilities of the Epoke in this study is focused on two areas: winter maintenance and summer maintenance. The Epoke is capable of spreading salt and liquid brine for winter maintenance and, after minor modifications, may be used for herbicide spraying during the summer. This flexibility may allow the Epoke to be utilized on a year-round basis. For the entirety of the study, the Epoke is located in the ODOT's Boston Heights Garage in northern Summit County.

3.2 Project Setting

The research for this project is performed in Summit County, at the ODOT maintenance garage in Boston Heights, Ohio. For winter maintenance purposes, this garage is responsible for maintaining Ohio State Routes (SR) 8, 21, 82, 176, and 303, as well as Interstate (I) 271. The routes maintained by the Boston Heights Garage, as well as the other ODOT garages in Summit County, are shown in Figure 3.1



Note: The Boston Heights Garage routes are shown in red. During the 2012 – 2013 winter season, the Boston Heights Garage also maintained the portion of I-271 previously maintained by Twinsburg, as shown in this figure. [Source: ODOT, 2011].
Figure 3.1: ODOT Summit County Winter Maintenance Routes.

A summary of information regarding the routes maintained by the four garages is presented in Table 3.1.

Table 3.1: Characteristics of the Garages and Routes Maintained.

Garage	Routes Maintained	Lane Miles Maintained	Number of Snow Plow Trucks
Boston Heights	I-271, SR-8, SR-21, SR-82 SR-303	136	6
Greensburg	I-77, I-277, US-224, SR-91, SR-532, Albrecht County Rd.	85	4
Twinsburg	I-480, SR-82, SR-91, Ravenna County Rd., Twinsburg County Rd., Old Mill County Rd.	61	4
Interchange	I-76, I-77, SR-18, SR-21	153	6

The routes ODOT is mainly responsible for are Interstate, U.S. routes, and state routes; however, some garages also maintain county roads. Table 3.1 shows that the Boston Heights Garage and the Interchange Garage are responsible for maintaining the largest number of lane miles, and therefore have more snow plow trucks available than the Greensburg and Twinsburg garages. Given the variable amounts of traffic traveling on these routes, the possibility for evaluating the Epoke on different roadway classes is presented. After considering the various routes, it was decided that the Epoke would be evaluated on SR-8 during the first winter season of the study and on I-271 for the second winter season.

SR-8 is a highway divided by a barrier wall, and it varies between four and six lanes, with two and three lanes in each direction, in the area maintained by ODOT, while I-271 is a four-lane highway divided by a grassy median, with two lanes in each direction of travel. In addition to these roads, ODOT is also responsible for maintaining the newly constructed interchange between SR-8 and I-271, which includes two-lane ramps for traffic traveling in each direction. Portions of these ramps are elevated on bridges, further complicating the snow and ice removal in the interchange. Photographs taken during and after construction of the interchange ramps are presented in Figure 3.2.

During **After**

Note: SR-8 is the road going from the top to the bottom of the "During" picture, while SR-8 is the road going from corner to corner in the "After" picture. These images are aerial photographs provided by ODOT.

Figure 3.2: During and After Construction Photos of SR-8 and I-271 Interchange.

With the addition of the interchange, ODOT is responsible for maintaining additional lane miles, stressing the need to evaluate alternative methods to increase efficiency.

3.3 Spreader Systems

For the first winter season, Epoke supplied ODOT with their Sirius AST Combi S4902 spreader for evaluation. This section of the report is divided into the following four subsections in order to properly describe the Epoke and the standard ODOT truck system. The four subsections include the following:

- Subsection One - Standard ODOT Spreader: Typical ODOT spreader with pre-wet capabilities,

- Subsection Two - Epoke Theory: The concept behind the Epoke spreaders and their ability to reduce salt usage,
- Subsection Three - Sirius AST Combi S4902: Epoke Spreader placed on a truck and used for typical winter maintenance operations, and
- Subsection Four – Epoke Virtus Spreader: Epoke Spreader mounted to the rear of a 5000-gallon tanker truck and used in anti-icing operations.

The following sections will describe the concepts of each system and its potential for implementation into ODOT's winter maintenance fleet.

3.3.1 Standard ODOT Spreader

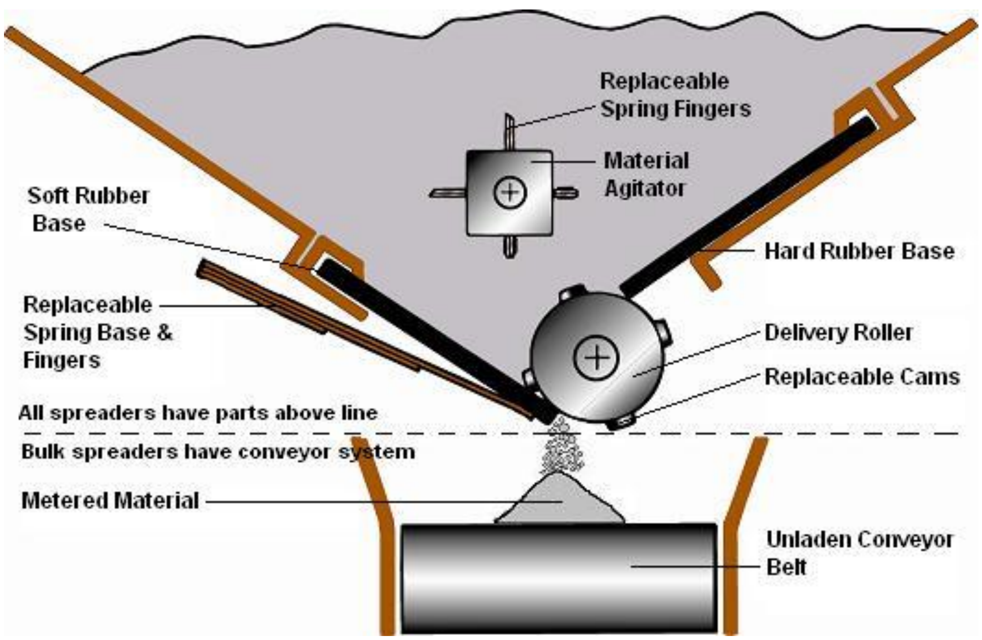
The standard ODOT spreader applies pre-wet material to a single lane. The spreader takes dry material from the bed of the plow truck and adds brine at the point of application to the dry material. An image of a standard ODOT plow truck and spreader is shown in Figure 3.3.

Figure 3.3: Standard ODOT Spreader on Tandem Axle Dump Truck.

The standard ODOT spreader is mounted on a tandem axle dump truck with a stainless steel bed. The spreader is center mounted and applies material to a single lane. The standard spreader used in this evaluation applies pre-wetted granular salt.

3.3.2 Epoke Theory

The concept of the Epoke system, which was developed in the 1950s, is to crush salt into fine grains and apply a liquid that allows it to stick to the road. The salt is loaded into the hopper as with a typical ODOT plow truck. Within the hopper is an agitator used to keep the material loose so that it will flow down into a roller, which crushes the salt into a powder. After the material is crushed, it falls onto a conveyor belt, where it is metered and fed into the salt spreader. The Epoke is equipped with tanks for storing liquids, which feed into the liquid nozzles. When the salt is spread, it is either covered with liquid creating a paste-like consistency or it may be pre-wetted, where 30% by weight of the salt is replaced with liquid. By mixing the salt with liquid, the amount of salt applied may be reduced. Please see section 5.4.1 of the report for additional information about the operation of the unit. Figure 3.4 presents a diagram that shows the process taking place in the Epoke.



Note: This figure is provided by Epoke and "All spreaders…" refers to Epoke products.
Figure 3.4: Diagram of Epoke System Process.

The Epoke process crushes the salt at the roller and drops it onto the conveyor belt, which delivers the salt to the spreader. Figure 3.5 shows photographs of the crushed salt that is spread by the Epoke and the standard salt found in an ODOT stockpile.

Epoke Crushed Salt

Standard Salt

Figure 3.5: Salt Consistency after Crushing by Epoke and Standard Salt.

Figure 3.5 shows the difference in the consistency of salt from the Epoke and the stockpile. After the salt travels through the Epoke and is dispensed, it is finer and consists of smaller grains than the salt dispensed by the standard truck.

The Epoke is also capable of spreading material over multiple lanes. It will spread up to three lanes and may be adjusted to spray behind, to the left, or to the right of the truck. When selecting to spray to the left or right, the material is also being spread in the lane the truck is traveling in. The Epoke reports the application rates of salt and liquid in the metric system. The dry material is reported in grams per meter-squared (g/m^2), while the liquid rates are reported in milliliter per meter-squared (mL/m^2). These values are easily converted to pounds per lane mile (lbs/ln-ml) and gallons per lane mile (gal/ln-ml) for the dry and liquid rates respectively. A conversion table is provided in section 7.3.1.

3.3.3 Epoke Sirius AST Combi S4902

The Sirius AST Combi S4902 is the spreader utilized for evaluation in this study, and is capable of spreading dry material, liquid, or both in combination over multiple lanes. An image of the spreader as installed on an ODOT truck is shown in Figure 3.6.

Figure 3.6: Epoke Sirius AST Combi S4902 Spreader.

The grey tanks on the Epoke are used for storing liquid material, which for ODOT is typically brine, while the orange hopper stores the salt. The Epoke is placed on a tandem axle hook lift truck equipped with a front plow.

One main advantage of the Epoke Sirius AST Combi S4902 is the ability to spread material over multiple lanes, which may result in cost savings due to reduced treatment times. Figure 3.7 shows an image of the spreader on the rear of the Epoke.

Figure 3.7: Dry Material Spreader and Liquid Nozzles on the Epoke.

The dry material spreader is the round disk between the liquid nozzles. The nozzles allow for liquid to be spread over one, two, or three lanes in either direction. The selection of width and direction for spreading the material is made using the Epoke controller in the cab of the truck, which is a separate panel from the one that controls the plow. Figure 3.8 shows the Pengwyn plow controller and the Epoke controller in the cab of the ODOT plow truck.

Figure 3.8: Pengwyn and Epoke Controllers.

The controller allows the operators to vary the amount of salt and liquid being applied, as well as the number of lanes treated and the direction of the spreading. In addition to the spreading control, the Epoke controller has the capability to record and navigate multiple routes. With the additional purchase of the EpoSat, which provides global positioning system (GPS) capabilities, the unit is capable of recording routes and spreader controls on the routes. The routes may be used with navigation to control the spreader while the operator focuses on the roadway and plowing activities.

In order to record the routes, a memory card is placed into the controller. While in record mode, the operator drives the route normally, including using the controller to apply dry and liquid material as needed. When the route is complete and recording is finished, the memory card is removed and inserted into an external drive, which loads the data into the EpoSat program on a computer. The program allows changes to be made to the route, including the addition of an audible turn approach warning further away from an intersection, adjusting the width of material being spread, and changing the direction that the material is being spread. Once complete, the changes may be loaded back into the EpoSat controller via the memory card. When beginning their route, the operator may use the controller to which route they will be maintaining. Once the GPS signal is acquired, the unit will provide turn by turn directions to the operator and will control the spreading operations based on the previously recorded operations.

3.3.4 Epoke Virtus Spreader

Along with the spreader for the snow plow truck, ODOT purchased an additional Epoke Virtus Spreader (Epoke tanker) to mount on the back of a 5000 gallon tanker trailer. The tanker truck is used to spread liquid, which for ODOT is typically a brine solution, for anti-icing of routes prior to snow events. ODOT typically deploys this tanker, which had previously been able to treat only one lane at a time, along with standard trucks with liquid tanks. Figures 3.9 and 3.10 show the tanker truck with the Epoke tanker in place and the liquid spray nozzles, respectively.

Figure 3.9: 5000 Gallon Tanker Truck Equipped with Epoke Tanker.

Liquid Nozzles

Figure 3.10: Epoke Tanker Spray Bar.

By placing the Epoke tanker on the tanker truck, it will have the capability to spread liquid over multiple lanes. In addition to the Epoke spreader on the snow plow truck, the Epoke tanker spreader will be evaluated against the standard method for anti-icing that is currently used by ODOT.

CHAPTER IV

DATA COLLECTION METHODOLOGY

For winter maintenance purposes, the evaluation focuses around five areas of data collection. Accordingly, this methodology chapter is divided into five sections:

- Section One – Weather Data Collection,
- Section Two – Speed Data Collection,
- Section Three – Snow Plow Truck Data Collection,
- Section Four – Winter Deployment Strategies, and
- Section Five – Summer Use of the Epoke.

4.1 Weather Data Collection

Weather data are identified by the research team as being required to evaluate the Epoke, in order to determine the amount of snowfall and the hourly snowfall rate for each event occurring in the two winters of the study. These data are used to make comparisons based on the severity of winter storms.

Several sources providing weather data are considered and evaluated based on the amount of data provided and the temporal deviations of the data. With the frequency of which weather changes, hourly data is set as the minimum timeframe to which data needs to be reported. A longer time interval between snowfall measurements will not provide the desired temporal deviations for this study. This requirement is a limiting factor for many weather data sources, as they only provide daily reporting. A list of the weather data sources evaluated by the research team is presented in Table 4.1.

Table 4.1: Weather Data Sources.

Data Source	Reporting Interval
National Oceanic and Atmospheric Administration (NOAA)	Hourly
Weather Underground	Daily
Weather Warehouse	Monthly

Note: The NOAA has sub agencies that were evaluated for weather data including the National Climatic Data Center and the National Weather Service. Many online weather providers were also evaluated, but they were either not reliable enough or did not possess an hourly reporting interval.

The NOAA's National Operational Hydrologic Remote Sensing Center is used to collect the weather data for this project, since it provides interactive snow information from weather stations near the study area. The research team selected the two weather stations nearest the study areas on SR-8 and I-271, which are located in Cuyahoga Falls and Macedonia. Using the two closest stations will ensure that data may be continuously acquired in the event that one station becomes nonfunctional.

A matrix of storms is created to evaluate the Epoke under various weather conditions. The matrix, which includes storm intensity classifications based on the weather conditions observed during this study, are as follows:

- Anti-icing – Appling anti-icing liquid before a storm or when there is a chance for a storm,
- Light Snowfall – Less than two inches of total accumulation and with peak snowfall rates less than 0.25 inches per hour,
- Moderate Snowfall – Between two and six inches of total accumulation and with peak snowfall rates between 0.25 and 0.75 inches per hour, and
- Heavy Snowfall – Greater than six inches of total accumulation and with peak snowfall rates greater than 0.75 inches per hour.

If a storm meets one of the two criteria and is near the minimum requirement for the next category, it may be placed in the more severe matrix category. The matrix classification is created observationally from the weather patterns experienced during the study. Please note that the two winters during this study were both milder than usual for Ohio.

4.2 Speed Data Collection

Motorists will drive at a speed at which they feel comfortable based on the conditions, so by maintaining one direction of travel with the Epoke and the other side of the roadway with a standard truck, a comparison of the effectiveness of snow and ice removal and prevention is determined. The vehicle speeds are used as surrogate measures of road conditions and any differences will depict the differences in the capabilities of the Epoke and standard truck. The Epoke is evaluated for two winter seasons: the 2011 to 2012 season and the 2012 to 2013 season. For each season, vehicle speed data is collected using Bluetooth nodes placed alongside the selected roadway. In order to describe the speed data collection process, this section is divided into three subsections:

- Subsection One – Description of the Bluetooth Data Collection System,
- Subsection Two – Winter 2011 to 2012 Deployment, and
- Subsection Three – Winter 2012 to 2013 Deployment.

4.2.1 Description of the Bluetooth Data Collection System

The Bluetooth data collection system remains the same for both winter seasons; however, the exact locations of the nodes may change between seasons. The system utilized for speed data collection is a system developed by the research team; it consists of several individual Bluetooth nodes in the field and a server that processes the data collected from the roadway segments.

The Bluetooth nodes consists of a Bluetooth radio, computer board with universal serial bus (USB) interfaces, Bluetooth antennae, 3G wireless card, power regulator, and batteries. The computer board, Bluetooth radio, and 3G wireless card are housed within a plastic enclosure. This enclosure and the remaining components are placed within a lockable weather proof case. A photograph of one such case deployed in the field is shown in Figure 4.1.

Figure 4.1: Bluetooth Node Located on Interstate 271.

Also in this figure, it may be noted that a guardrail attachment is used to secure the nodes to a permanent structure. Before placing the Bluetooth nodes in the field, the research team acquired all the permits required by ODOT. Additionally, all local and state law enforcement agencies are contacted to alert them of the purpose and placement of the nodes. Included in the email to the law enforcement agencies is a photograph of a node and a description of what the system is used for.

By housing the Bluetooth antenna within the enclosure, it is possible that the signal sensitivity may be reduced. However, given the risk of moisture impacting the nodes and the temporary nature of the node locations, the team decided against mounting the antenna on a pole, as this method would require drilling a hole through the case. If a hole is not properly sealed, moisture may compromise the integrity of the system. For more information about the node placement for this study, see Schneider et al., 2012.

Each node placed in the field is designed to record the media access control (MAC) address of a passing Bluetooth enabled devices, accompanied by a timestamp. When several nodes are placed alongside a roadway, a vehicle’s speed may be calculated by matching a MAC address on multiple nodes and dividing the distance between the nodes by the difference in the timestamps. Maintaining a database of the exact distances between each set of nodes is imperative for the accuracy of the speed calculations.

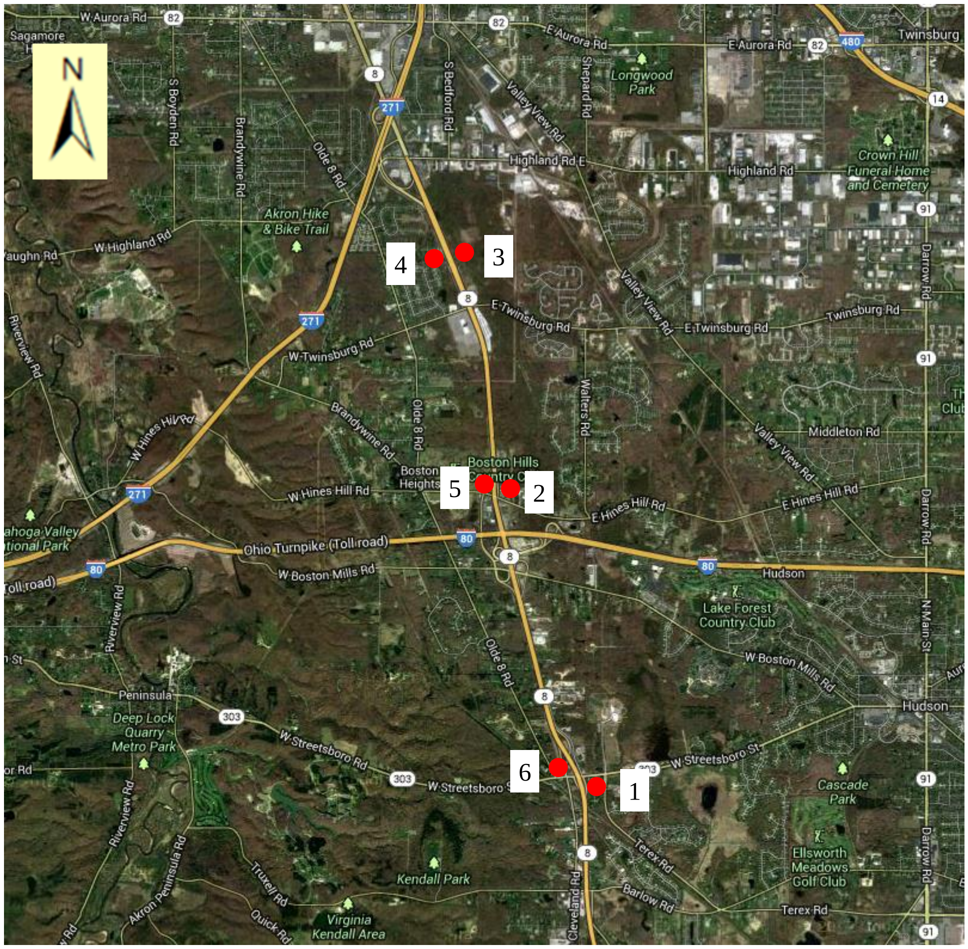
In order for the speed calculations to be accomplished in real-time, each node needs to have wireless internet access for uploading its data to a server. This central server collects all the data from each node and processes it in two steps, cleaning and matching. Again, for additional information about the Bluetooth nodes and details about the system utilized in this project, see Schneider et. al. 2012.

Bluetooth nodes are used to ascertain the vehicle speeds in both directions of travel on the selected roadways in order to evaluate the effectiveness of the Epoke as compared to a standard ODOT snow plow hopper.

4.2.2 Winter 2011 to 2012 Deployment

The first year of this study began in December of 2011, when the research team completed the deployment of Bluetooth nodes on SR-8. Accordingly, six nodes were placed along the roadway from mile marker 13 through the interchange with I-271. In this area, SR-8 varies between four and six lanes divided by a barrier wall, with two and three lanes in each direction.

Typically, the Bluetooth nodes are placed in the median in order to balance the amount of target radios recorded in each direction. However, with no divided median present, the research team decided to place the nodes off the shoulder of the highway, to ensure the safety of the research team while maintaining the nodes. The locations of the nodes along SR-8 are shown in Figure 4.2.



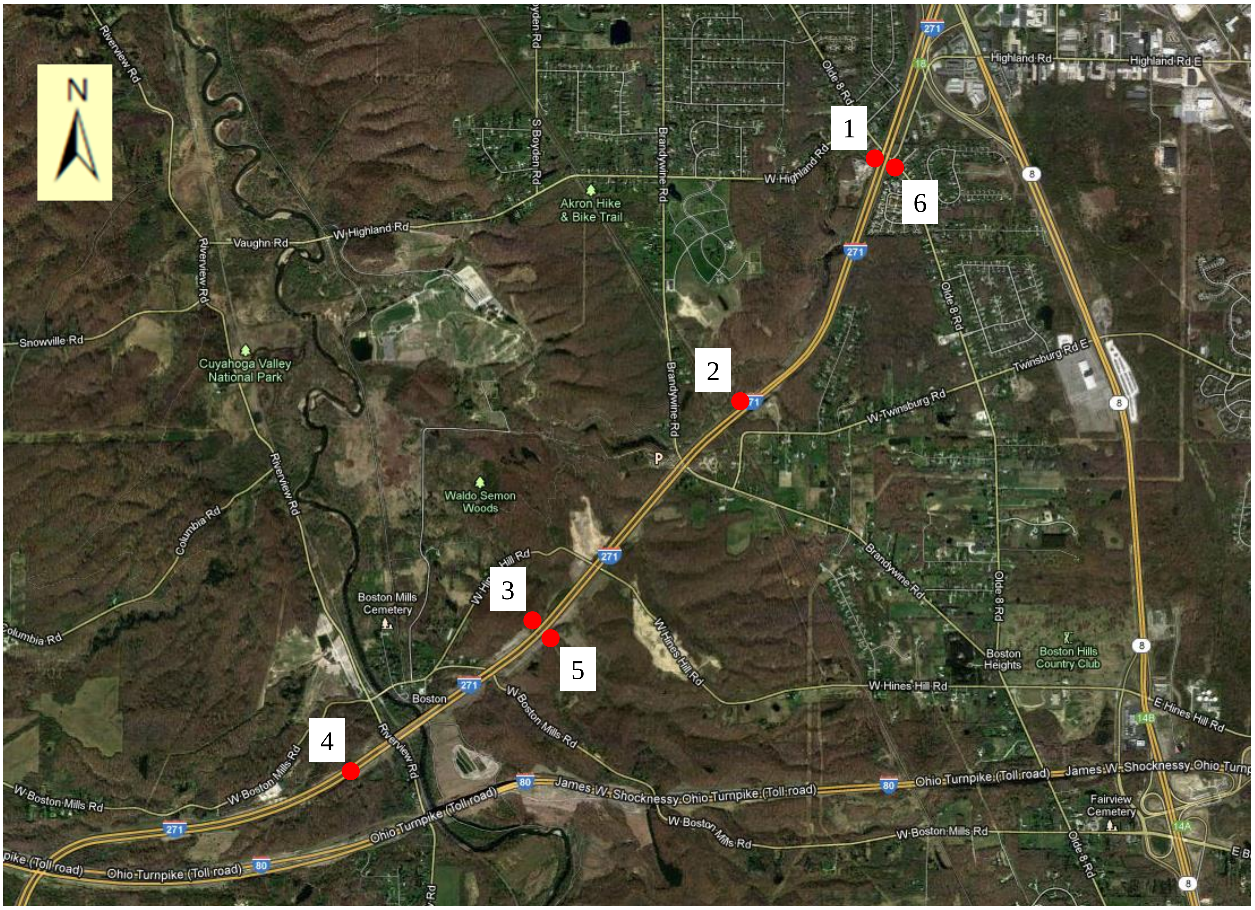
Note: This figure was retrieved from Google Earth and modified on 2/11/13.
Figure 4.2: Location of Bluetooth Nodes for Winter 2011 - 2012.

The nodes were placed from mile marker 13 to mile marker 18 on SR-8. Initially, the nodes were all placed on the northbound (NB) shoulder; however, the locations were quickly adjusted due to the lower sample count from the vehicles traveling in the opposite direction of travel. The nodes were subsequently moved to the deployment shown in Figure 4.2, with nodes just off the shoulders on each direction of the roadway. By placing the nodes on opposite sides of the highway, the amount of hits are balanced between the northbound and southbound (SB) directions, resulting in more comprehensive speed estimations for both directions of travel.

The Bluetooth nodes remained in this deployment from December 2011 to April 2012 in order to gather speeds from all the winter events as well as baseline speeds from days when no weather event occurs. This is especially important to compare the weather events with reoccurring congestion.

4.2.3 Winter 2012 to 2013 Deployment

After the limited amount of snowfall during the first winter of the study, the research team and ODOT decided to extend the project for a second winter. As a result of a meeting before the winter season with the technical liaison committee, the study area is moved to I-271 for the 2012 – 2013 winter season. It is decided that using a smaller area for the study zone will allow for a more accurate side by side comparison of the Epoke to a standard snow plow. The locations of the nodes for the second winter season are shown in Figure 4.3.



Note: This figure was retrieved from Google Earth and modified on 2/11/13.
Figure 4.3: Bluetooth Node Locations for Winter 2012 - 2013.

The study zone is located between nodes one and six at the northern end and nodes three and five at the southern end, as shown in Figure 4.3. An additional node is placed south of this to obtain the speeds of vehicles traveling into and out of the study area. As with the previous deployment, the nodes are placed off the shoulders rather than in the median, as there are no adequate locations for securing the nodes in the median. The most southern node, number four, is placed in the median since there is a location in order to secure the node, i.e., a guardrail.

4.3 Snow Plow Truck Data Collection

In order to compare the Epoke to a standard ODOT truck, data needs to be collected based on the operation of the two trucks. Accordingly, this section is divided into the following subsections in order to provide details regarding the data collected and the methods used for collecting the data:

- Subsection One – Data Collected from the Trucks,
- Subsection Two – Methods Utilized to Collect Data from the Trucks, and
- Subsection Three – GPS Data.

4.3.1 Data Collected from the Trucks

To make comparisons between the Epoke and the standard ODOT winter maintenance plow truck, several categories of data need to be collected:

- Salt Usage,
- Brine Usage,
- Mileage Treated,
- Lanes Treated, and
- Plowing.

These data are collected from both the Epoke and the standard trucks in order to compare material usage and treatment operations. The rate of salt application is recorded in pounds per lane mile applied, and this rate is used to determine the difference in the total amount of salt applied by each truck. The brine application rate is recorded in gallons per lane mile and the rate is recorded as zero if no brine is being applied. The mileage treated is found by recording the start and end mile markers for each treated segment of the routes traveled. In order to collect the most accurate application data for the treated segments, the mile markers are also recorded each time there is a change in the application rate or the number of lanes treated. The number of lanes being treated is unique to the Epoke, which has the capability to treat multiple lanes, while the standard truck is only able to treat a single lane during each pass. Plowing is an indication that the plow is in the "down" position and the truck is engaged in plowing activities; this position is recorded so as to account for all maintenance actions aside from applying material.

The data collected from the trucks are used as the basis for the comparison between the Epoke and the standard truck, and these data are vital to the success of this research project. Accurate measures for the data in each category are required. The techniques used to collect accurate data are discussed in the following section.

4.3.2 Methods Utilized to Collect Data from the Trucks

. In order to collect the data from both plow trucks, the research team utilized various techniques at different stages of the project:

- Technique One – ODOT Maintenance and Repair (M&R) 661 forms filled out by operators,
- Technique Two – ODOT M&R 661 forms filled out by students riding in truck, and
- Technique Three – Use of an Epoke data collection program that was created by the research team.

Technique One

The first technique, the M&R 661 forms completed by the operators, are utilized during the beginning of the first winter season. The M&R 661 forms include the start and end time for each treated roadway, location of the treated roadway, road condition, type of treatment used, and treatment materials applied for each of the plow trucks. A sample of the ODOT M&R 661 form is shown in Figure 4.4.

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

Road Condition and Operation Report

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

Road Condition Key:

1= clear	5= icy
2= snow covered	6= icy in spots
3= snow covered in spots	7= slush covered
4= drifted	8= blocked

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

Page 1

Figure 4.4: Blank ODOT M&R 661 Form.

These forms are filled out periodically by the operators; but are not necessarily completed in detail for each segment of the route, as operators are focusing on the maintenance of the roadways. Requiring operators to frequently pull over to the side of the road to complete paperwork would allow the condition of the roads to deteriorate unnecessarily. Typically, an operator will report the total amount of material applied at the completion of a route, and the application rates are determined based on the distance traveled.

Technique Two

The second technique utilized is to place students in the snow plow trucks along with the operator, so that the students record the events as they occur. Application rates may change frequently, and the operator of the Epoke may change the number of lanes and direction that the Epoke is spreading; these changes need to be tracked meticulously in order to be useful for this study. By having researchers fill out the forms while the events are taking place, the resolution of the data is greatly increased, giving a more accurate tracking of application rate changes and the number of lanes being treated by the Epoke, which will aid in a thorough evaluation of the system.

Technique Three

The third technique utilized in the second winter season also involves placing students in the plow trucks, but the students use a simple data collection program installed on a laptop computer rather than a M&R 661 form. The research team created a simple, offline computer based program to facilitate data collection. By creating this program, the data are more organized and consistent, allowing for easier application of the results. A screenshot of the data collection program is shown in Figure 4.5.

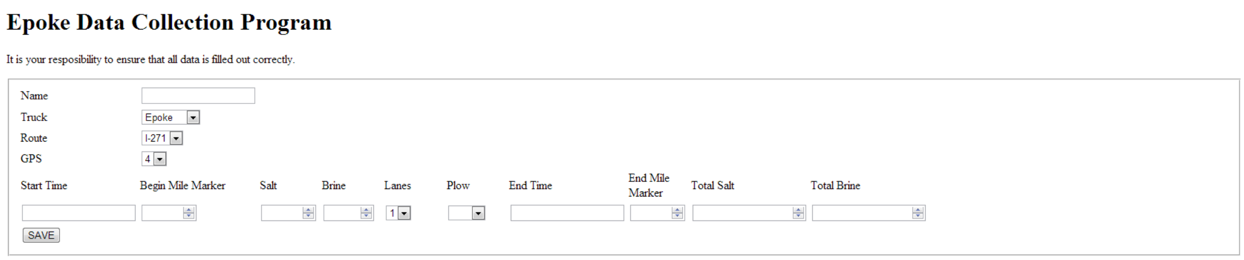


Figure 4.5: Screenshot of Epoke Data Collection Program.

This program is written in .php and contains a .sql connection to store the data locally to the laptop computer. The program records essentially the same information as the M&R 661 forms and is used to supplement the M&R 661 form for data collection purposes. Since the program is offline, it stores data locally to the laptop computer's hard drive rather than wirelessly uploading the data to a central server. By doing this, it ensures that there is no monthly data fee for wireless transmission. Once a route is completed, the data is downloaded from the laptop computer to the server for evaluation.

4.3.3 GPS Data

During the second winter season, the research team placed QStarz Travel Recorder XT GPS units inside the trucks to ensure the integrity of the locations associated with the salt application data, as well as to validate the route optimization model discussed in Chapter 7 of this report. A photograph of one of the GPS units is shown in Figure 4.6.

Note: The GPS units are numbered so that the unit number may be recorded along with the truck number it is placed in. This allows for the routes, which are downloaded after the events, to be matched with either a standard truck or the Epoke.
Figure 4.6: QStarz GPS Unit Deployed in the Maintenance Trucks.

The GPS units selected for this project are passive, meaning that they will simply record the location data rather than continuously upload it to a remote server. The truck operators were informed in advance that GPS units would be placed in the trucks and were briefed regarding the use of the data. It is emphasized that the units are not in place to track the operators' practices, but are in place to provide more accurate location data for the researchers to use in the route optimization model and to ensure the accuracy of the application data.

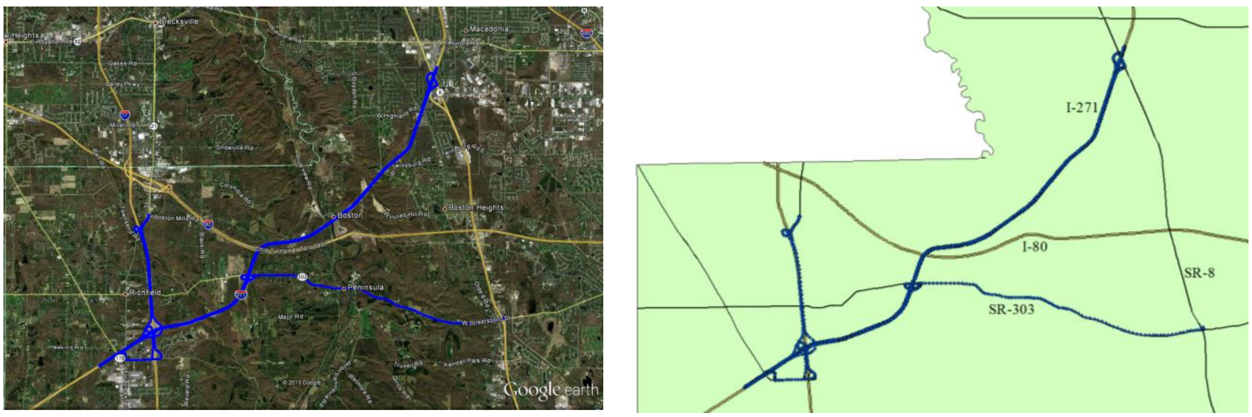
Similar to the handling of the data logged in the Epoke Data Collection Program, the GPS data are downloaded after each winter event. The GPS data are downloaded into two file formats:

- .kml file – This file type is used by Google Earth, which the research team employed to create maps presented to the truck operators for training purposes, and
- .csv file – This file type is used to import data into Microsoft Excel, where the data could be saved in .xls format and later imported to ArcGIS for analysis.

The Google Earth files are used to map the routes in order to show the truck operators how the GPS data was able to successfully document the routes they drove while treating their assigned routes. The .csv files are imported into Microsoft Excel in order to convert the speeds from kilometers per hour (kph) to miles per hour (mph), as well as to change the time format so it will import into ArcGIS. After the conversions in Microsoft Excel are complete, the file may be imported to ArcGIS for analysis. The researchers evaluate the times associated with the trucks on each route in order to determine the length of time required to complete winter maintenance tasks which are applied to the route optimization model discussed in Chapter 7.

A sample of the two GPS data output formats utilized by the research team are shown in Figure 4.7.

Google Earth **ArcGIS**



Note: These are samples of routes maintained on February 20, 2013.
Figure 4.7: Sample Routes Displayed in Google Earth and ArcGIS.

Figure 4.7 presents a visual display of the data in the Google Earth output; however, the ArcGIS maps provide more data analysis capabilities based on the ability to display the individual points and the accompanying attributes, including time and location of each point. These maps are used to educate the operators on the importance of maintaining the routes in a manner that facilitates accurate comparisons, as well as to ensure the accuracy of the salt application data recorded. The application data was validated by matching the times of applications entered into the data collection program with the GPS data to ensure that no mistakes are made with the location entered.

4.4 Winter Deployment Strategies

The research team, along with ODOT, utilized two deployment strategies for this research project. Accordingly, this section is divided into two subsections:

- <u>Subsection One</u> – Winter 2011 – 2012 Deployment, and
- <u>Subsection Two</u> – Winter 2012 – 2013 Deployment.

4.4.1 Winter 2011 – 2012 Deployment

During the first winter season, the Epoke is placed mainly on SR-8 for winter maintenance purposes and is accompanied by a typical ODOT plow truck on this route. In order to make valid comparisons between the Epoke and standard spreader, the two trucks must maintain exclusively opposite directions of the highway. Simply stated, the Epoke treats only the southbound lanes, while the standard truck treats only the northbound direction as shown in Figure 4.8.

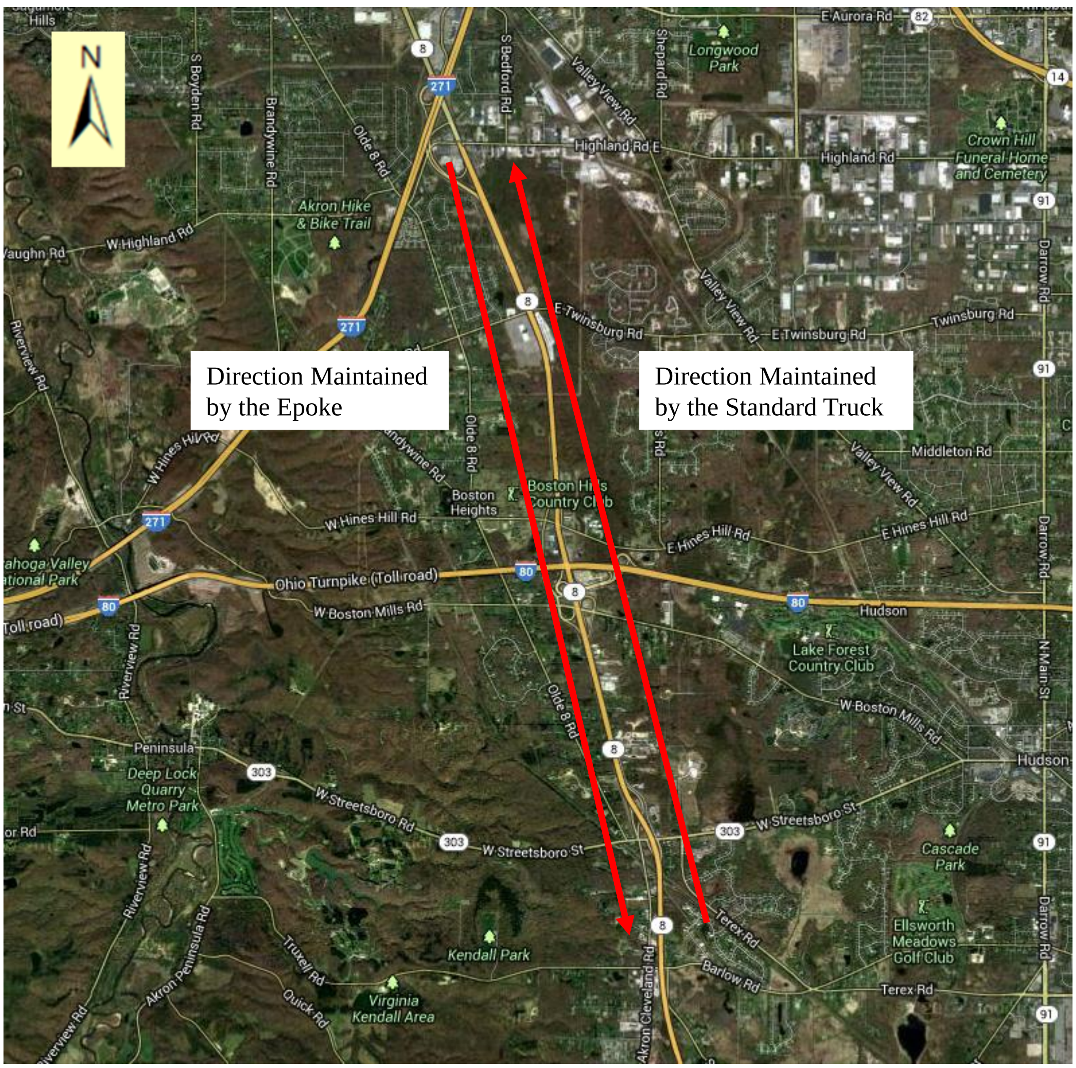


Figure 4.8: Directions Maintained by Each Truck on SR-8.

Initially, ODOT and the research team considered having the Epoke treat the southern end of the route and having the standard truck treat the northern end, with each truck maintaining both directions of travel. However, to ensure that no areas are left untreated and to minimize the changes to ODOT's current snow removal operations, it is decided to have the trucks treat opposite directions of travel over the entire length of the same highway section.

4.4.2 Winter 2012 – 2013 Deployment

During the first deployment strategy, it is found that the operators expressed concerns regarding the large amount of deadhead time while traveling in the direction they are not supposed to treat. The operators are uncomfortable with traveling such a distance and not treating the roadway. As a result, during the second winter season the evaluation area is moved to I-271, and the test area is shortened to encompass mile markers 15 to 18 as shown in Figure 4.9.

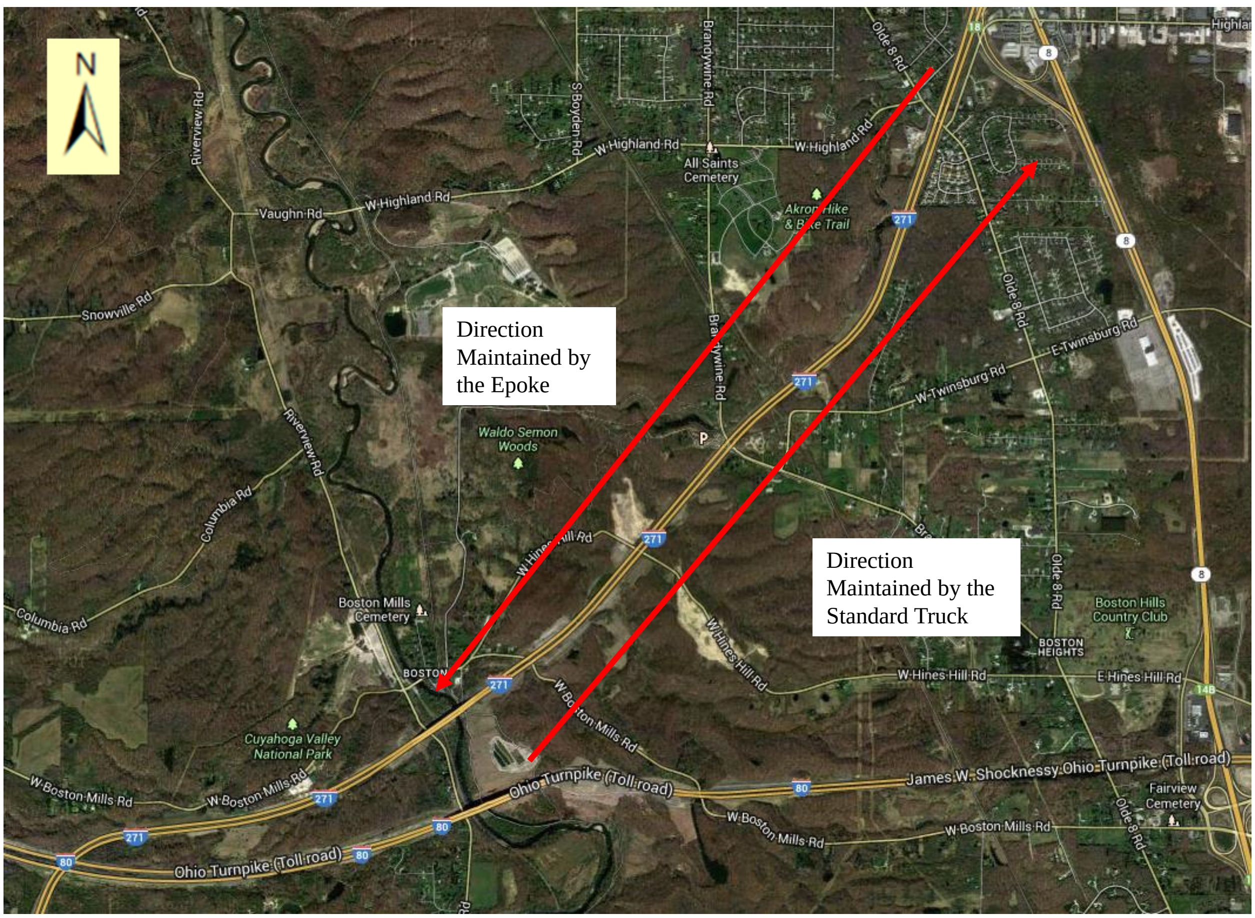


Figure 4.9: Directions Maintained by Each Truck on I-271.

As in the first deployment, the Epoke is to maintain one direction of travel while the standard truck maintains the opposite direction of travel. During the first winter season, this area is maintained by ODOT's Twinsburg Garage, but an agreement is made to have the Boston Heights Garage take over the route.

At the beginning of the second winter season, the two trucks are assigned to SR-8 and the operators maintained the study area on I-271 in addition to their normal route on SR-8. However, shortly into the season, the two trucks are moved exclusively to I-271. By shortening the study area and eliminating the need for the trucks to maintain the interchange ramps between SR-8 and I-271, better comparisons are made. Additionally, the instances where a truck treats a section it is not supposed to maintain are nearly eliminated, i.e. cases where the standard truck treats the direction that the Epoke is supposed to maintain or vice versa.

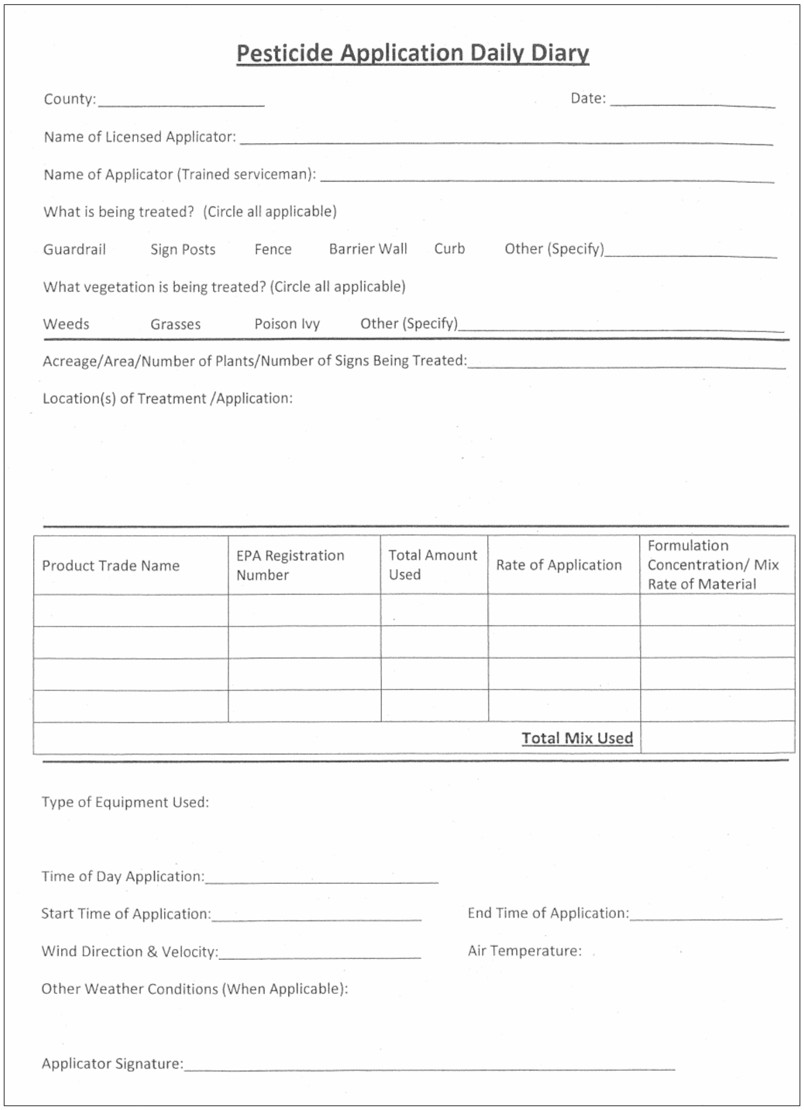
4.5 Summer Use of the Epoke

The Epoke is a multifaceted system, which after some minor modifications may be utilized for summer herbicide spraying. Since ODOT's operations are year round, having versatile equipment with a wide range of uses will make it more cost effective. As a result, the feasibility of using the Epoke to spray herbicide in the warmer months is evaluated. Accordingly, this section is divided into three subsections:

- <u>Subsection One</u> – Introduction to Herbicide Spraying,
- <u>Subsection Two</u> – Previous ODOT Herbicide Practices, and
- <u>Subsection Three</u> – Utilizing the Epoke for Herbicide Spraying.

4.5.1 Introduction to Herbicide Spraying

According to ODOT's website, ODOT maintains over 500,000 signs and 5,600 miles of barriers. One requirement for ODOT is to ensure that the signs and barriers do not become obstructed by vegetation. It is imperative for the safety of the traveling public to ensure that all signs and barriers are visible. During the spring and summer seasons, ODOT conducts herbicide spraying of guardrails, signs, fences, barrier walls, and curbs that are along the roadways that they are responsible for maintaining. Federal law dictates the environmental conditions during which spraying may occur, and ODOT exercises more strict limiting factors. ODOT conducts herbicide spraying when winds are below 12 mph and there is no chance of rain for at least three hours after applying herbicide. ODOT also follows other weather restrictions indicated on the label of the product being used. The main vegetation that ODOT sprays to limit are grasses, weeds, and poison ivy. Figure 4.10 shows the daily log sheet used by operators when spraying. Note that ODOT performs herbicide spraying even though the sheet indicates pesticide application.



Pesticide Application Daily Diary

County:____________________ Date: ____________________

Name of Licensed Applicator: ____________________

Name of Applicator (Trained serviceman): ____________________

What is being treated? (Circle all applicable)

Guardrail Sign Posts Fence Barrier Wall Curb Other (Specify)____________________

What vegetation is being treated? (Circle all applicable)

Weeds Grasses Poison Ivy Other (Specify)____________________

Acreage/Area/Number of Plants/Number of Signs Being Treated:____________________

Location(s) of Treatment /Application:

Product Trade Name	EPA Registration Number	Total Amount Used	Rate of Application	Formulation Concentration/ Mix Rate of Material
			Total Mix Used	

Type of Equipment Used:

Time of Day Application:____________________

Start Time of Application:____________________ End Time of Application:____________________

Wind Direction & Velocity:____________________ Air Temperature:

Other Weather Conditions (When Applicable):

Applicator Signature:____________________

Figure 4.10: Log Sheet used by Operators when Spraying.

The main product used for spraying over the last couple years is Prosecutor Pro. This product is mixed with water at a ratio of 2.5 ounces to 1 gallon of water. Figure 4.11 shows the label of the Prosecutor Pro.

Figure 4.11: Label of Prosecutor Pro used for Herbicide Spraying.

According to the Ohio Department of Agriculture (ODA), the label is the law which must be followed in order to prevent harm to people and the environment. All operators that conduct spraying at ODOT must be certified through the ODA.

4.5.2 Previous ODOT Herbicide Practices

In order to gather baseline data for the research team to make comparisons, the typical spraying operations are observed. A member of the research team traveled with ODOT personnel to spray on I-77 south of Akron. The purpose of this trip is to gather an understanding of the herbicide spraying process. A truck with a 130 gallon tank secured in the bed of a one ton truck is used during the standard spraying operation. For spraying vegetation not accessible by the vehicle, a person drove the vehicle while another walked outside spraying vegetation with a wand. It was common for the technician to refill the 130 gallon tank a couple times per day. The technician would carry the herbicide product in the truck and when the tank was empty, they would drive to closest ODOT garage or outpost with water access to mix the solution. This process is time consuming and inefficient. Figure 4.12 shows the tank used for herbicide spraying prior to using the Epoke.

Figure 4.12: The 130 Gallon Tank on One Ton Truck used for Herbicide Spraying prior to Epoke.

The tank in Figure 4.12 is 130 gallons and there is a spray wand attached to it.

4.5.3 Utilizing the Epoke for Herbicide Spraying

The Epoke has a 1,100 gallon liquid tank, which for this purpose is filled with the herbicide mixture. The ODOT Boston Heights Garage was able to modify the Epoke in order to spray herbicide from the front of the truck and use the Epoke controller to adjust the amount of herbicide being sprayed. A new hose was run to the front of the truck and a manually adjustable spray bar was fabricated to mimic the techniques needed to properly spray the herbicide. Safety is ODOT's main concern and using the Epoke to spray does not require the technician to leave the truck, except to set up the spray bar at the beginning and end of the route, which increases the safety for the technicians. With the Epoke's large tank, the technician does not need to stop to refill the tank throughout the day, thus saving time. The modified system installed on the ODOT truck is shown in Figure 4.13.

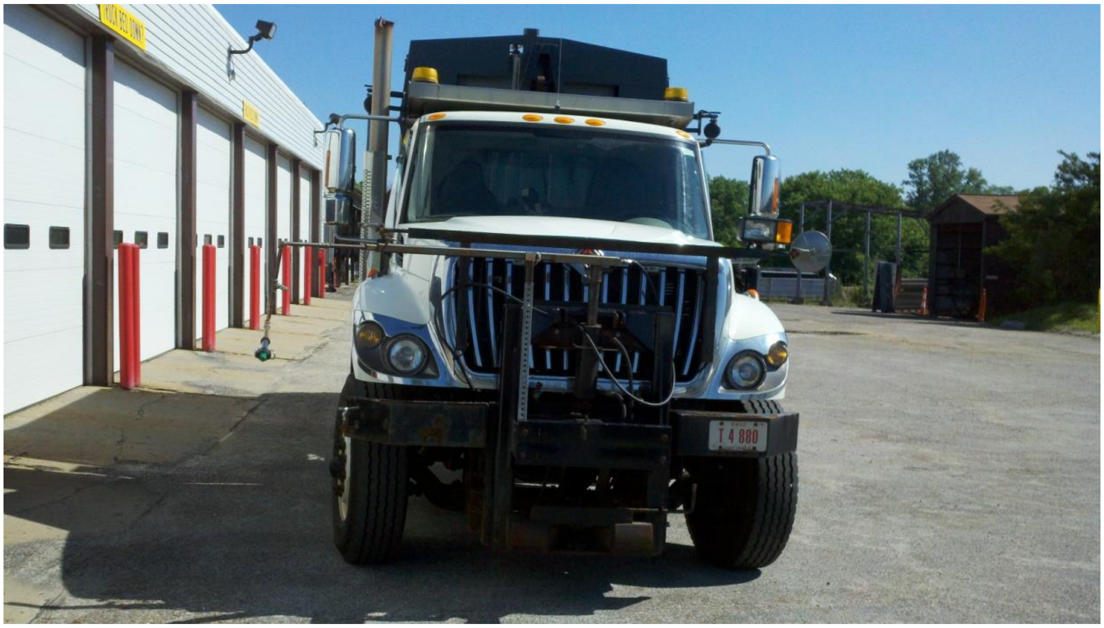


Figure 4.13: Completed Spray Arm on Epoke.

The arm is completed and used on a test run near the Boston Heights garage to ensure the working order of the system. The flow rate of the herbicide needs to be much less than that of the brine, so Epoke modified the flow rates and helped to install dampers.

The Epoke may be best utilized for guardrails, barriers and other walls along the mainline roadways. In order to conduct spot spraying, including signs, the other method with the wand may still be used at this time. Figure 4.14 shows the Epoke spraying a guardrail with herbicide.

Figure 4.14: Epoke Spraying Guardrail with Herbicide.

As shown in Figure 4.14 the Epoke is a much safer method for operators compared to the pervious method, since using the Epoke does not require the operators to get out of the truck for extended periods of time, and operators need to leave the truck less frequently.

Figure 4.15 shows some of the positive benefits and negatives of using the Epoke versus the previous method. There are major advantages to using the Epoke, the most important being the safety of the operators.

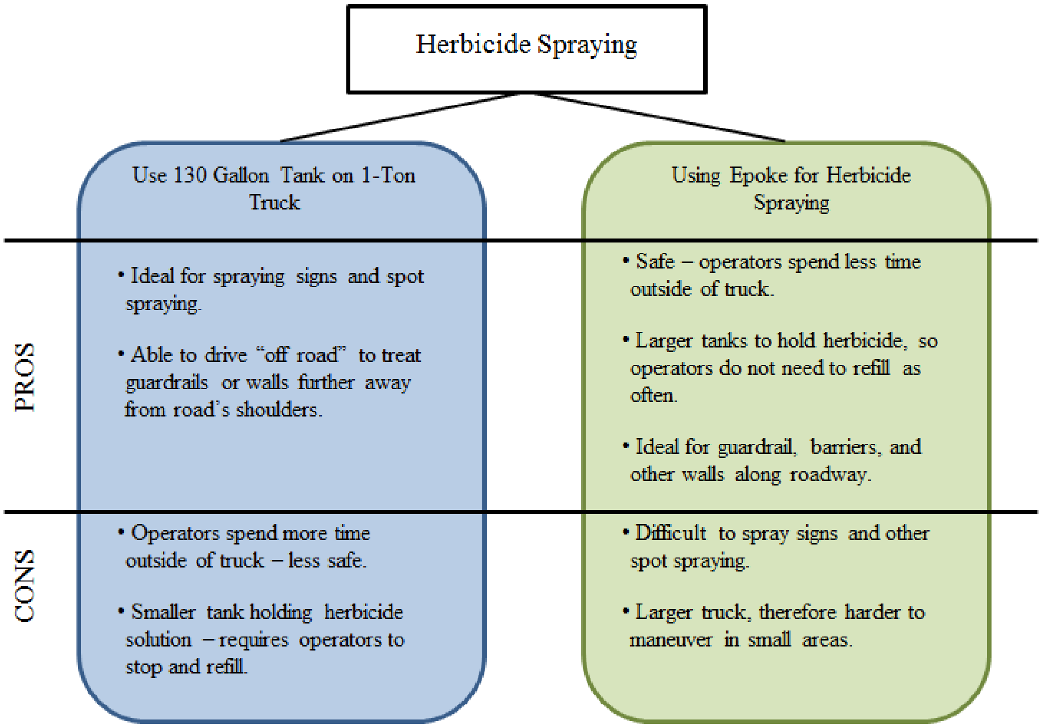


Figure 4.15: Pros and Cons of Two Methods for Herbicide Spraying.

The Epoke provides increased safety compared to the previous method by allowing the operators to stay in the truck. However, the Epoke is large and harder to maneuver, making it more difficult to spot spray signs. The Epoke is a great tool for herbicide spraying although other methods may still be used to treat the areas and objects that the Epoke cannot. The Boston Heights garage is always finding new ways to improve herbicide spraying with the Epoke that may address the negative issues that are seen with using the Epoke for herbicide spraying, such as spot spraying.

CHAPTER V

RESULTS

This chapter contains the results of the research efforts described previously in the methodology, and it is divided into eight sections:

- Section One – Introduction,
- Section Two – Truck Equipment,
- Section Three – Weather,
- Section Four – Salt Usage,
- Section Five – GPS Data,
- Section Six – Vehicle Speeds,
- Section Seven – Summary of Events, and
- Section Eight – Tanker Anti-icing.

Since the winter season that occurred during the first year of the project was unusually mild, the data from both winters are combined in the analysis and in the discussion of the outcomes.

5.1 Introduction

As discussed previously, the main data collection efforts are three-fold: weather, salt usage, and vehicle speeds. The flow of data for the project is presented in Figure 5.1.

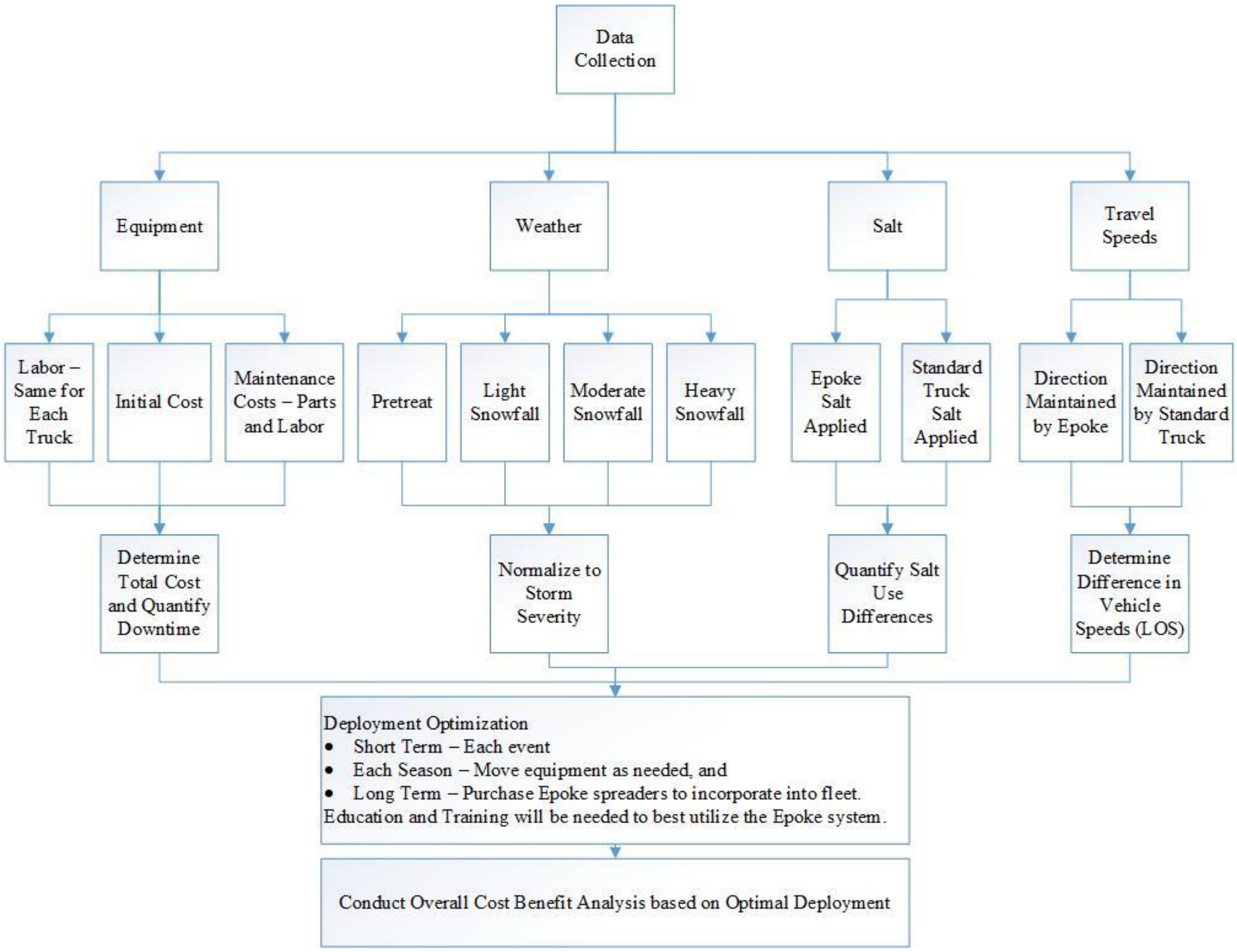


Figure 5.1: Flow of Data for the Project.

Along with the weather, salt usage, and vehicle speeds, data from the equipment are also collected for use in the analysis conducted during this project. The equipment data includes the initial purchase costs of all equipment, labor costs for the operators, and maintenance costs including parts and labor. All of the data collected are used in conducting the cost benefit analysis of the Epoke as well as for determining the optimal deployment strategy.

5.2 Truck Equipment

This section describes the equipment utilized in this research project, and it is divided into two subsections:

- Subsection One – Initial Equipment Acquisition, and
- Subsection Two – Maintenance of Equipment.

5.2.1 Initial Equipment Acquisition

All equipment utilized in this project is acquired by ODOT through the research project. Table 5.1 presents all the equipment purchased and the purchase price, as well as the cost of a standard spreader utilized by ODOT for comparison purposes.

Table 5.1: Equipment Costs.

Epoke Sirius AST Combi S4902	$110,000 for hook lift ($100,000 for slide in)
Epoke Virtus (Epoke Tanker)	$56,500
EpoSat	Included in S4902 purchase
Standard Hydraulic Spreader with Pre-wetting	$23,000

Note: Costs provided in this table are taken directly from purchase agreements or information provided by ODOT.

The total amount of equipment purchased for this project is $166,500, which includes optional equipment purchased for the evaluation. For the baseline comparison the Epoke Sirius AST Combi S4902 spreader is purchased for $110,000 whereas the standard hydraulic spreader used by ODOT has a purchase cost of $23,000. It should be noted that the $110,000 for the Epoke S4902 is for a hook lift spreader, while a more common insert spreader would be $100,000. When deciding between the purchase of a hook lift or slide-in spreader, it is recommended to match the majority of the fleet to minimize downtime in the event of a maintenance issue with the truck. By matching the majority of the fleet, the Epoke may be easily utilized with another truck.

5.2.2 Maintenance of Equipment

The Epoke is placed on one of ODOT’s hook lift trucks, which allows for interchanging applicable components, such as different bed types. The Epoke is designed as an insert that will slide in the bed of any plow truck, and accordingly the manufacturers warned against using the hook lift truck with the spreader. By modifying the Epoke to be picked up by the hook truck, it will lose the capability to be interchangeable with other plow trucks that do not have hook lifts. If a maintenance issue arose with the truck the Epoke is on, the Epoke would also be out of service even though the spreader itself is operational, since the majority of trucks in ODOT fleet do not have hook lifts. This presents a loss time on the Epoke when the truck maintenance is at fault; when examining the maintenance during this project, these situations are not applied to the Epoke but rather to the truck.

The maintenance of the Epoke is tracked in addition to the initial costs for the equipment. There are seven days on which the Epoke is not utilized due to a maintenance issue; however, the cause of the issue must be distinguished between the spreader or the truck. Of those seven missed event days, one is caused by the Epoke and six are caused by the truck. The one event day missed due to the spreader is the result of the Epoke rupturing a hose. This repair required the purchase of a new fitting, which ODOT did not have in stock.

5.3 Weather

Over the course of the two winter seasons, a total of 47 snow events occurred. These events are categorized into anti-icing, light snowfall, moderate snowfall, and heavy snowfall as described in the methodology section. A summary of the winter events is presented in Table 5.2.

Table 5.2: Summary of Winter Events by Snow Severity.

Pretreat			Light			Moderate			Heavy		
Date	Peak Snowfall (in/hr)	Accumulation (in)	Date	Peak Snowfall (in/hr)	Accumulation (in)	Date	Peak Snowfall (in/hr)	Accumulation (in)	Date	Peak Snowfall (in/hr)	Accumulation (in)
12/5/2012	0	0	2/14/2012	0.15	0.2	1/19/2012	0.38	1.98	12/26/2012	2.18	10.58
12/6/2012	0	0	1/21/2013	0.08	0.44	2/11/2012	0.29	3.12			
12/11/2012	0.03	0.13	1/24/2013	0.06	0.21	12/21/2012	0.27	2.96			
12/12/2012	0	0	1/26/2013	0.06	0.31	12/29/2012	0.65	3.41			
12/24/2012	0.03	0.03	1/31/2013	0.16	0.4	1/25/2013	0.44	2.56			
1/14/2013	0	0	2/1/2013	0.14	0.42	2/2/2013	0.26	2.03			
1/18/2013	0.04	0.05	2/3/2013	0.03	0.2	2/16/2013	0.53	2.22			
1/19/2013	0	0	2/4/2013	0.15	0.89	3/25/2013	0.46	2.09			
2/15/2013	0.01	0.05	2/5/2013	0.16	0.37						
3/5/2013	0	0	2/8/2013	0.12	0.56						
3/8/2013	0	0	2/17/2013	0.12	0.53						
3/12/2013	0	0	2/19/2013	0.08	0.34						
3/18/2013	0	0	2/20/2013	0.04	0.11						
3/19/2013	0	0	2/22/2013	0.24	0.38						
3/26/2013	0	0	2/28/2013	0.08	0.3						
3/27/2013	0	0	3/1/2013	0.09	0.81						
4/2/2013	0	0	3/6/2013	0.18	0.23						
			3/13/2013	0.08	0.36						
			3/16/2013	0	0						
			3/21/2013	0.05	0.36						
			3/22/2013	0.07	0.34						

Data for total and hourly snowfall is found using weather stations maintained by the NOAA as previously discussed in section 4.1. Of the 47 total events, 17 only required anti-icing treatment, 21 experienced light snowfall, eight experienced moderate snowfall, and one heavy snowfall event occurred. There was a significant difference in number of events between the two winter seasons; only three events occurred in the 2011 – 2012 winter season, while the remaining 44 occur during the 2012 – 2013 season.

Data are collected for every event, and Figure 5.2 shows the breakdown of data collection for the events.

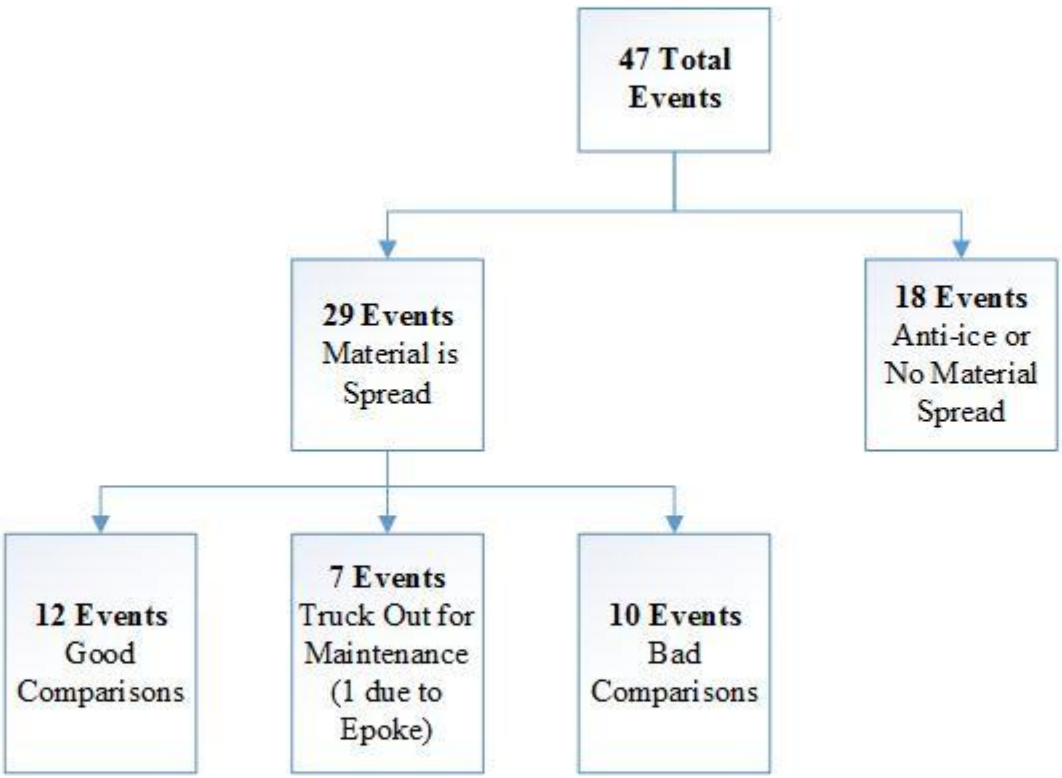


Figure 5.2: Breakdown of Winter Events.

There are 17 events where only anti-icing is utilized, and one event where no material is spread. These are days where snow is forecasted and trucks are sent out, while little snow fell and no material is required to maintain the roadway conditions. Of the 29 events where material is spread, 12 are good comparisons, meaning the Epoke and standard truck treated opposite directions of the highway. There are seven events where the Epoke is not used due to a maintenance issue, with six of these being an issue with the truck and one being an issue with the actual spreader. Additionally, there are ten events that are bad comparisons, where either the standard truck or Epoke spread on the opposite side of the study zone which they are assigned to maintain. These results are invalid and may not be used in the side-by-side evaluation of the Epoke and standard truck.

5.4 Salt Usage

The research team tracked the salt applied by both the Epoke and standard truck during all snow events using a computer based data collection platform. To quantify the salt usage data, this section is divided into three subsections as follows:

- Subsection One – Salt Calculations,
- Subsection Two – Salt Usage on Good Comparison Days, and
- Subsection Three – Salt Usage on Days when the Epoke is Out of Service.

The amount of salt applied will be presented for each situation.

5.4.1 Salt Calculations

In order to determine the amount of salt used by each spreader system, the total amount of salt applied must be calculated; this amount includes both the dry material and the salt from the brine liquid mixture used by ODOT. It is noted that while ODOT utilizes brine, the Epoke may use any type of liquid desired. The brine produced by ODOT is a mixture of water and salt, which contains 23.3% salt. The standard ODOT spreader considered in this evaluation applies dry material, with an additional seven gallons of brine per ton of salt applied, and the Epoke, which when in pre-wet mode will use a maximum dry-to-liquid ratio of 70:30. This ratio can be changed to a lower the amount of liquid in the ratio by changing the setting in the menu of the control panel, but ODOT uses the maximum 70:30 ratio.

The calculation of the salt applied by each truck may be explained visually as in Figure 5.3.

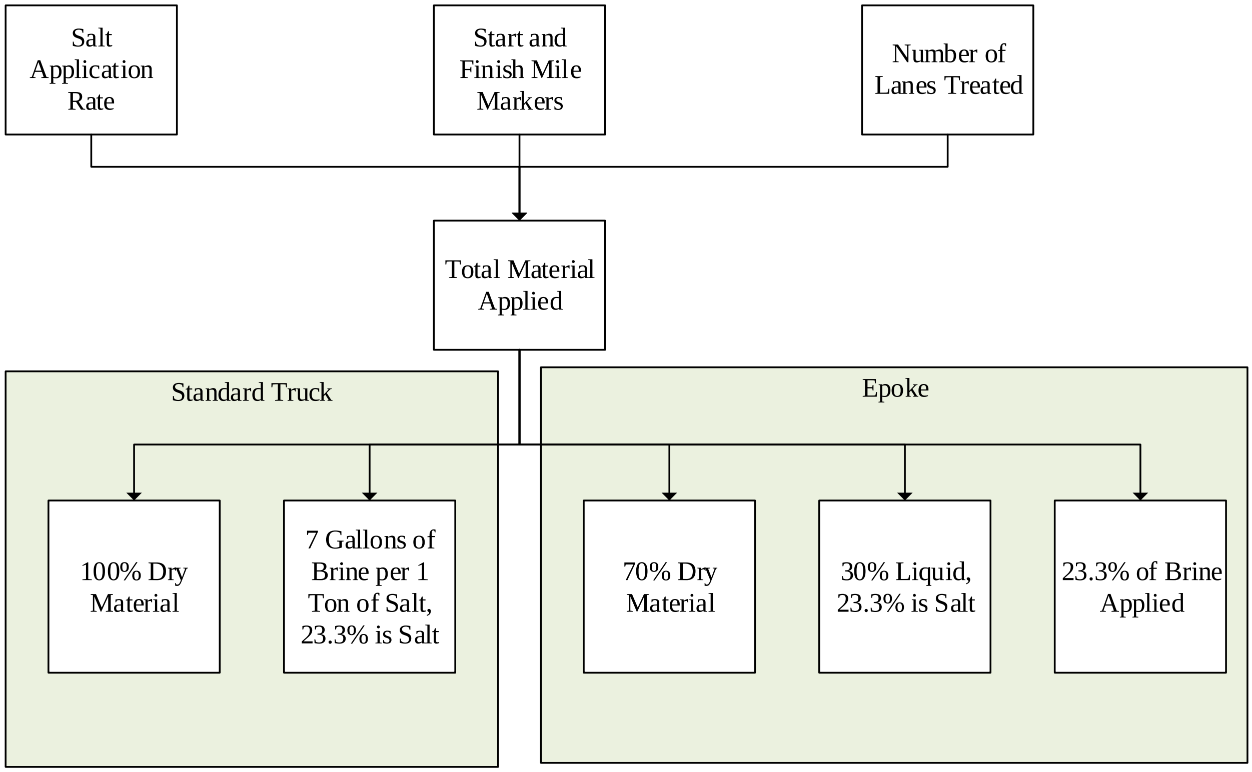


Figure 5.3: Calculation Components for Total Salt Applied by Each Truck.

The students in each truck record the salt application rates, the start and end mile markers, and the number of lanes treated which are used to calculate the total material applied is shown in Equation 5.1.

$$Total\ Material\ Applied\ (lbs) = Application\ Rate\ \left(\frac{lbs}{ln - ml}\right) x\ Number\ of\ Lanes\ Treated\ x\ Length\ of\ Application\ (miles)$$

Equation 5.1

The total material applied by each truck is found from the application rate, number of lanes treated, and the distance of application. This will result in a total value of dry material in pounds.

The amount of liquid applied by the Epoke is found similarly to the dry material as shown in Equation 5.2.

$$Total\ Liquid\ Applied\ (gallons)$$
$$= Application\ Rate\ \left(\frac{gal}{ln - ml}\right) x\ Number\ of\ Lanes\ Treated\ x\ Length\ of\ Application\ (miles)$$

Equation 5.2

The total amount of liquid applied is a function of the application rate, number of lanes, and length of application.

After finding the total material applied, the amount of salt applied may be found for the standard truck using Equation 5.3.

$$Total\ Salt\ Used = (Total\ Material\ Applied) + (Total\ Material\ Applied \times 0.008)$$

Equation 5.3

This equation shows the total salt used by the standard truck is equal to the total dry material applied plus the fraction of the brine applied that is salt. The value of 0.008 is found by converting the seven gallons of brine per ton of salt multiplied by the pounds of salt per gallon of brine, as shown in Appendix A.

Similarly, the amount of salt applied by the Epoke may be found using Equation 5.4.

$$\begin{aligned} Total\ Salt\ Used \\ &= (Total\ Pre\text{-}wetted\ Material\ Applied \times 0.7) \\ &+ (Total\ Pre\text{-}wetted\ Material\ Applied \times 0.3 \times 0.233) \\ &+ (\text{Total Liquid Applied} \times 0.233) \end{aligned}$$

Equation 5.4

The total salt used by the Epoke is equal to 70% of the dry material plus the fraction of salt in the brine from the 30% split and any additional liquid applied.

An example of how these equations are applied is shown in Appendix A. Using these equations, the total amount of salt applied by each system may be found. Additionally, all figures and salt values include total salt regardless of application type or vehicle.

5.4.2 Salt Usage on Good Comparison Days

As previously stated, there are 12 days on which the Epoke and standard truck were both operational and treated exclusively opposite directions of the study zone. However, February 16, 2013, is removed as an outlier due to the over treatment with the Epoke, resulting in inflated salt application values. On February 16, 2013, the Epoke treated the study zone seven times, while the standard truck treated six times. With the similar number of times spread, it is expected the salt usage would be similar. However, the Epoke spreads material over multiple lanes on each pass; it applied 6670 pounds of salt to the study zone, while the standard truck applied 3303 pounds. This large disparity in the amount of salt applied emphasizes the need for proper training of operators when implementing new equipment; this topic will be discussed in more detail in section 7.3. When the data for this day is removed, the Epoke applied a total of 9757 pounds of salt while the standard truck applied 11,103 pounds. The amount of salt applied on these days is shown in Figure 5.4.

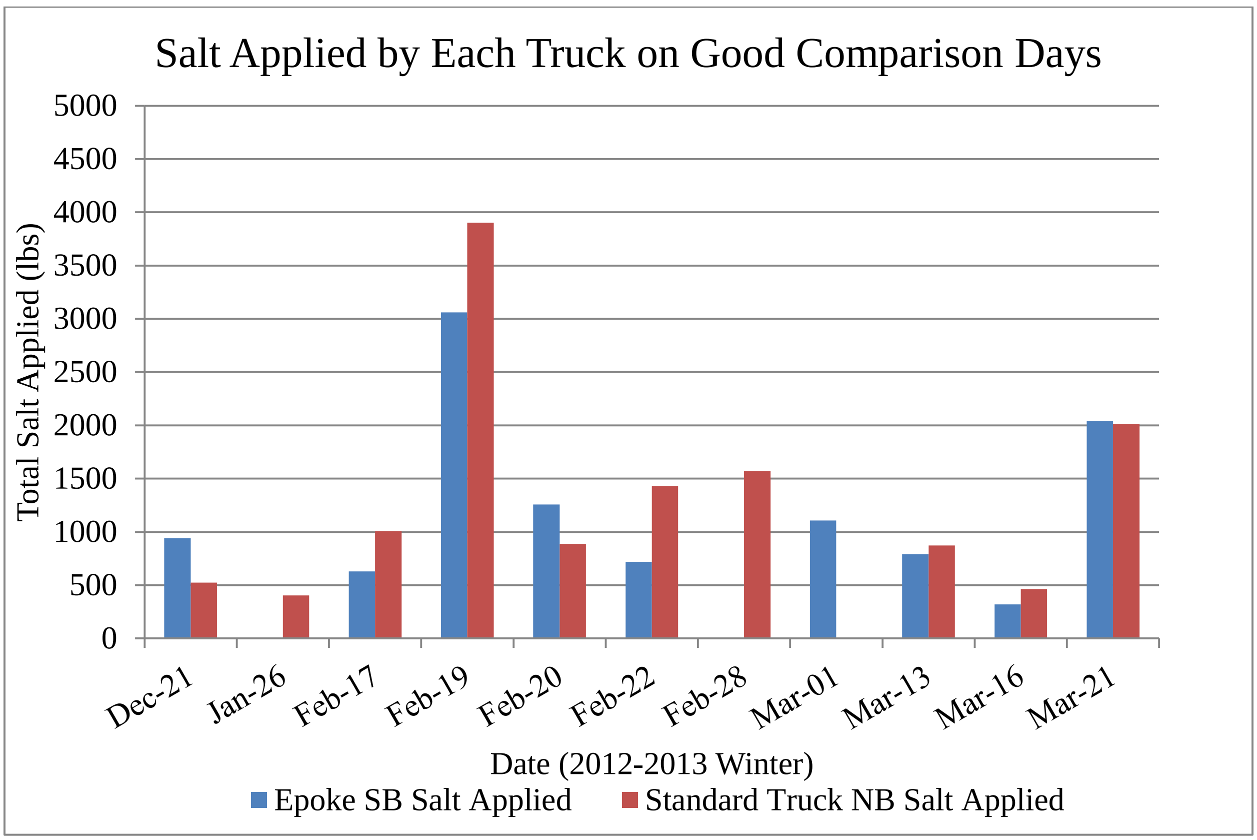


Figure 5.4: Salt Applied by Each Truck on Good Comparison Days.

A summary of the amount of salt applied by each truck is presented in Figure 5.4 is shown in Table 5.3.

Table 5.3: Comparison of Salt Applied by Each Truck in Opposite Directions.

	Epoke Salt Used in Study Zone (lbs)	Standard Truck Salt Used in Study Zone (lbs)
NB	0	11,103
SB	9,757	0

Note: on February 16, 2013, the Epoke applied 6,670 pounds of salt compared to 3,303 pounds of salt by the standard truck and is not included in this table. January 26, 2013, February 28, 2013, and March 1, 2013 are not included, as discussed below.

On January 26, 2013, and February 28, 2013, the Epoke did not treat in the study zone but did make several passes through the area; while on March 1, 2013, the standard truck did not treat the study zone but did make several passes, which are confirmed by the GPS units. This suggests that the operators felt it was unnecessary to treat the roadway during these events. During preliminary meetings with ODOT, it is decided to remove the days in which only one of the trucks treated for the cost analysis, since these days are not a true side-by-side comparison. Removing the three events where only one truck treated the study zone may alleviate some of the human variability in the analysis. Comparing the amount of salt applied by the Epoke and standard truck on the remaining good comparison days, it was determined that the Epoke used 12% less salt than the standard truck while treating the same segment of roadway.

5.4.3 Salt Usage on Days when Epoke is Out of Service

There are seven days during which the Epoke is out of service for a maintenance issue at the time a snow event occurred. These days are treated in a similar manner to the days when the Epoke and standard truck are both operational and treating the study zone. However, two standard trucks maintain both directions of travel in the study zone on these days in order to determine the amount of salt applied during the event. If any differences arise in salt usage, this may need to be accounted for when comparing the Epoke and standard truck. Figure 5.5 shows the amount of salt applied by the standard truck in the northbound and southbound directions in the study zone.

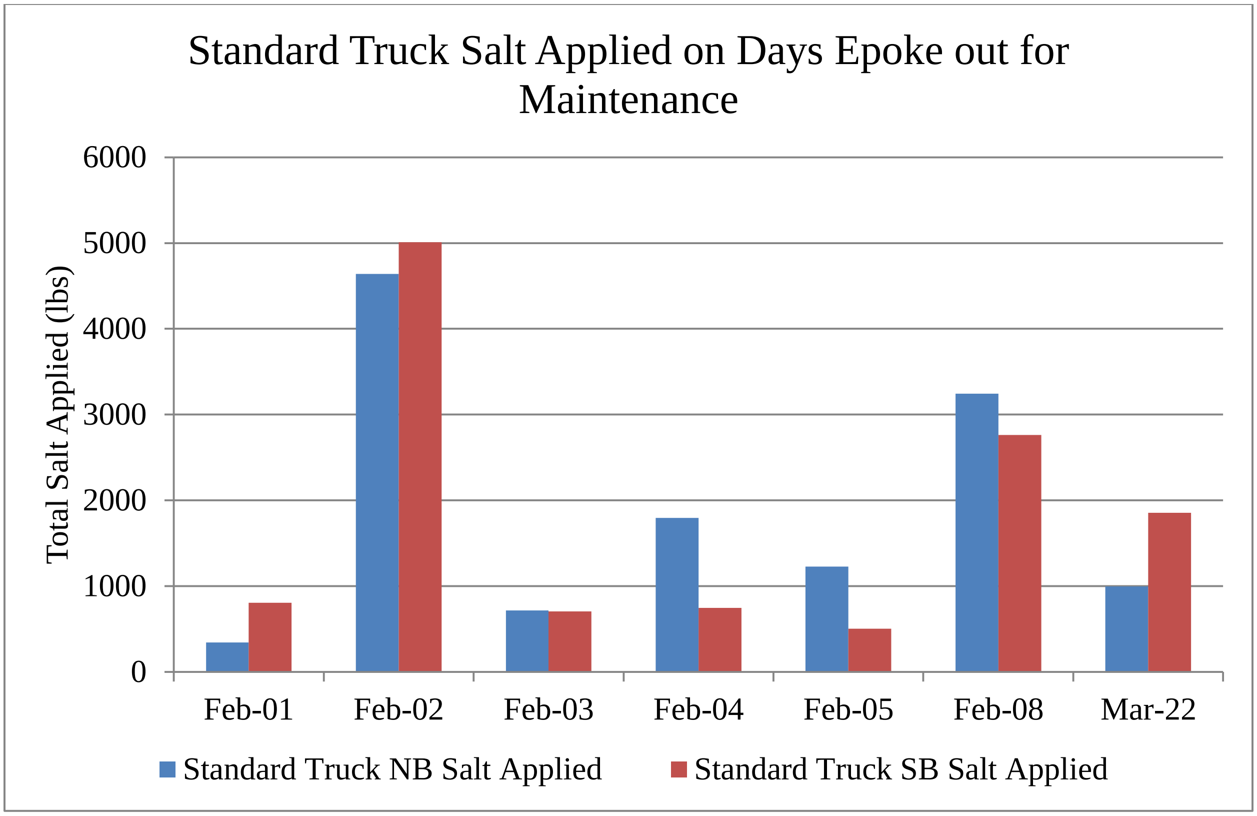


Figure 5.5: Salt Applied by the Standard Truck on Days when the Epoke is Out of Service.

For the majority of the events, the amount of salt applied in each direction is similar. To summarize this figure, Table 5.4 shows the amount of salt applied in each direction.

Table 5.4: Amount of Salt Applied on Days when the Epoke is Out of Service.

	Epoke Salt Used in Study Zone (lbs)	**Standard Truck Salt Used in Study Zone (lbs)**
NB	0	12,968
SB	0	12,388

Note: The Epoke was out for service, and two different standard trucks maintained the study zone.

Since the Epoke is not operational for these seven days, the standard truck is required to maintain both directions of the highway. It should be noted that the maintenance issues causing the Epoke to be out of service are not exclusively related to the spreader but predominately to the truck, as discussed in section 5.2.2. The amount of salt applied by the standard truck is similar in each direction, indicating no need to account for a directional bias in the amount of salt applied.

5.5 GPS Data

While collecting the salt data, the students brought the GPS units in the plow trucks during the winter events. These GPS units record the location, time, speed, and heading of the trucks. These data are used to validate the salt application data, as well as to record the amount of time required to maintain the routes, which aids in determining the total times for a route optimization model developed. One additional advantage of the GPS units is that in the instance that the salt data shows the standard truck is treating both directions, the GPS routes are used to determine why this is occurring and where the Epoke is traveling. This occurred several times at the beginning of the season, and as a result the Epoke is moved exclusively to I-271 to maintain the study zone with a standard truck.

The GPS data are exported into ArcGIS to determine the amount of time required to maintain certain routes. These times are used to validate and adjust the route optimization model developed to optimize the deployment of the Epoke. The route optimization model is discussed in further detail in Chapter 7 of this report. The GPS units are used to find any time differences in treatments between the Epoke and the standard truck. The researchers will look exclusively at interchanges as well as times when the Epoke treats multiple lanes in the study zone and is then able to treat other areas.

5.6 Vehicle Speeds

The research team utilized Bluetooth nodes to record the vehicle speeds in the study area on I-271. This section is divided into two subsections:

- Subsection One – Speed Trends, and
- Subsection Two – Regain Time.

These sections will detail two of the applications of the Bluetooth data collection system utilized in this project.

5.6.1 Speed Trends

The researchers compared the speeds in the northbound and southbound directions to determine any differences between the two spreader systems. A speed difference between the southbound direction maintained by the Epoke and the northbound direction maintained by the standard truck may indicate a difference in the quality of treatment between the two systems. In order to conclusively state that there is a difference between the two systems, the speeds will have to be the same during baseline conditions while being consistently different from one another during winter events.

The speeds are monitored continuously from December 2011 to April 2012 and from December 2012 until April 2013 in order to determine the baseline speeds in the study area as well as the speeds during each winter event. For I-271, the baseline conditions result in speeds of 67 miles per hour in each direction, while the average speeds during winter events are shown in Table 5.5.

Table 5.5: Vehicle Speeds in Both Directions during Winter Events.

Event Date	Northbound		Southbound		Length of Storm (hr)	Total Snowfall (in)
	Vehicle Speeds (mph)	Standard Deviation	Vehicle Speeds (mph)	Standard Deviation		
12/21/2012	49	18	51	17	23	2.96
12/26/2012	42	8	43	10	12	10.72
12/29/2012	58	9	62	12	20	3.55
1/21/2013	63	8	66	8	13	0.48
1/24/2013	59	8	63	8	10	0.22
1/25/2013	58	9	59	10	13	2.57
1/26/2013	62	7	67	8	9	0.31
1/31/2013	62	8	63	7	5	0.45
2/1/2013	61	8	58	14	12	0.50
2/2/2013	55	8	57	10	15	1.79
2/3/2013	62	8	66	7	12	0.22
2/4/2013	60	7	62	8	16	0.98
2/5/2013	49	10	60	9	7	0.43
2/8/2013	59	9	64	9	12	0.56
2/16/2013	56	14	64	14	15	2.25
2/17/2013	57	12	60	14	12	0.58
2/19/2013	60	8	60	9	7	0.34
2/20/2013	61	9	62	11	8	0.18
2/22/2013	64	11	66	13	6	0.39
2/28/2013	56	11	63	5	5	0.30
3/1/2013	63	8	65	7	23	0.81
3/6/2013	61	4	65	4	2	0.23
3/13/2013	63	7	65	6	12	0.43
3/21/2013	64	7	66	8	14	0.37

3/22/2013	61	11	64	7	11	0.40
3/25/2013	59	8	63	7	16	2.56

Note: on March 15, 16, and 24 of 2013 snow was forecasted and crews were deployed; however, no snowfall occurred.

In general, the speeds are similar in both the northbound and southbound directions, which indicates that the level of treatment is similar between the standard spreader and the Epoke. Therefore, the Epoke presents no improvement in travel speeds, while safety improvements will need to be further evaluated to determine if any time savings make the Epoke more efficient at treating roadways.

5.6.2 Regain Time

Regain time is one performance metric currently used by ODOT to evaluate the successes of winter maintenance operations. Regain time is the amount of time required to return vehicle speeds to within ten miles per hour of the baseline speeds once a winter storm has ended. Through data fusion of the speeds from Bluetooth nodes and snowfall data from NOAA, the researchers are able to determine the baseline speeds during normal conditions, as well as the regain time for each event. By taking the directional split from the nodes, the regain time may be determined for each direction of travel, facilitating comparisons between the Epoke and standard truck in terms of regain time. Figure 5.6 shows the vehicle speeds and snowfall rates during the winter event on December 29, 2012 demonstrating the regain time achieved on this day.

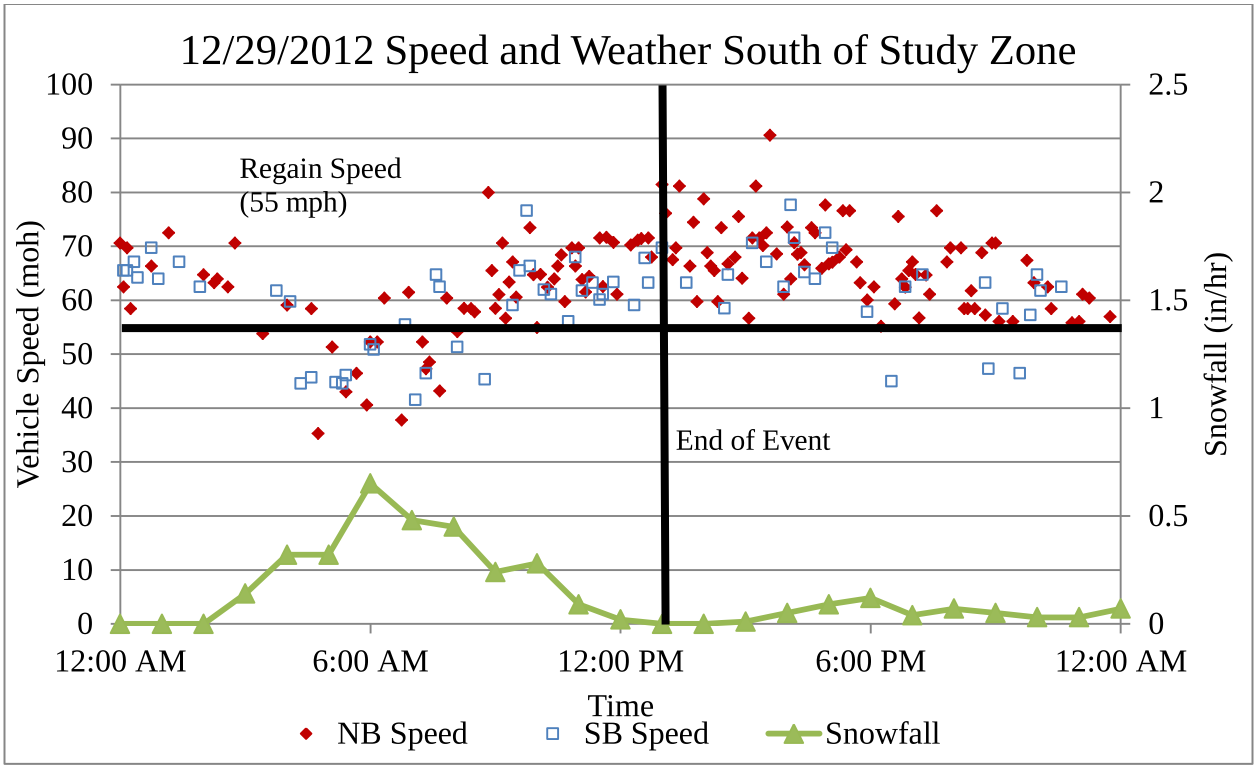


Figure 5.6: Vehicle Speeds and Regain Time on December 29, 2012.

The baseline conditions indicate that the average speeds are slightly above the speed limit; however, the target speed is set based on the speed limit. This figure shows that by the time the snowfall ends at 1:00 PM, the vehicle speeds are not only above the target regain speed of 55 mph, but are at the speed limit of 65 mph. This day is chosen as an example for illustrating the regain time, since moderate snowfall ends early in the day, this provides the research team with a higher level of Bluetooth responses as compared to events that end late in the evening.

The regain time is evaluated for each direction in every winter event for the second season. Table 5.6 summarizes the results for regain time.

Table 5.6: Regain Time in Both Directions for Winter Events.

Event Date	Northbound Regain Time (minutes)	Southbound Regain Time (minutes)
12/21/2012	198	294
12/26/2012	54	0
1/21/2013	40	0
2/16/2013	150	60

Note: A regain time of zero minutes indicates that speeds are above 55 mph by the time snowfall ends. The remaining winter events have a regain time of zero minutes.

The remaining events all have a regain time of zero minutes, meaning that speeds are within 10 mph of the baseline speeds by the time the snowfall ends. The average regain time in the northbound direction is 26 minutes, and 18 minutes in the southbound direction.

5.7 Summary of Events

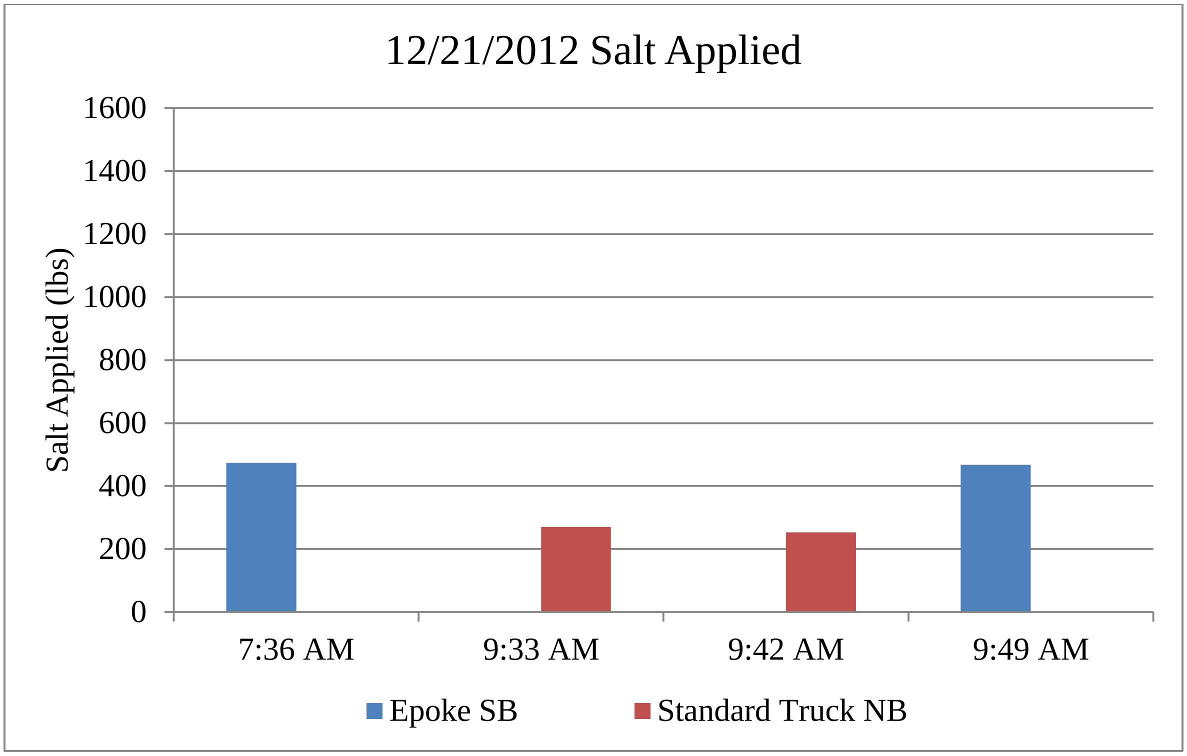
By combining the weather, salt usage, GPS data, and vehicle speeds, the research team is able to summarize every winter event. One event from each month is shown in the following sections, while the data for all events are shown are Appendix B. This section is divided into the following subsections to display the data associated with each date:

- Subsection One – December 21, 2012,
- Subsection Two – January 24, 2013,
- Subsection Three – February 17, 2013, and
- Subsection Four – March 13, 2013.

A synopsis of winter maintenance activities is provided with the data for each event.

5.7.1 December 21, 2012

The first event of the winter season occurred on December 21, 2012. The amount of salt applied by the Epoke and the standard truck is shown in Figures 5.7.



Note: Times corresponded to when the study zone was treated.

Figure 5.7: Salt Applied by Each Truck on December 21, 2012.

Both trucks treated the roadway in the study area twice on this day, and the amount of salt applied by each truck is shown in Table 5.7.

Table 5.7: Total Salt Applied by Each Truck on December 21, 2012.

	Epoke Salt Used in Study Zone (lbs)	**Standard Truck Salt Used in Study Zone (lbs)**
NB	0	524
SB	942	0

The Epoke and the standard truck applied salt at a rate of 150 pounds per lane mile (lbs/ln-ml). However, the Epoke treated two lanes on each of its passes and the standard truck started spreading a half mile into the study zone on each pass. This generated a disparity in the amount of salt applied, both of which are resolved through communication with operators and further training.

The vehicle speeds and snowfall on this day are shown in Figure 5.8.

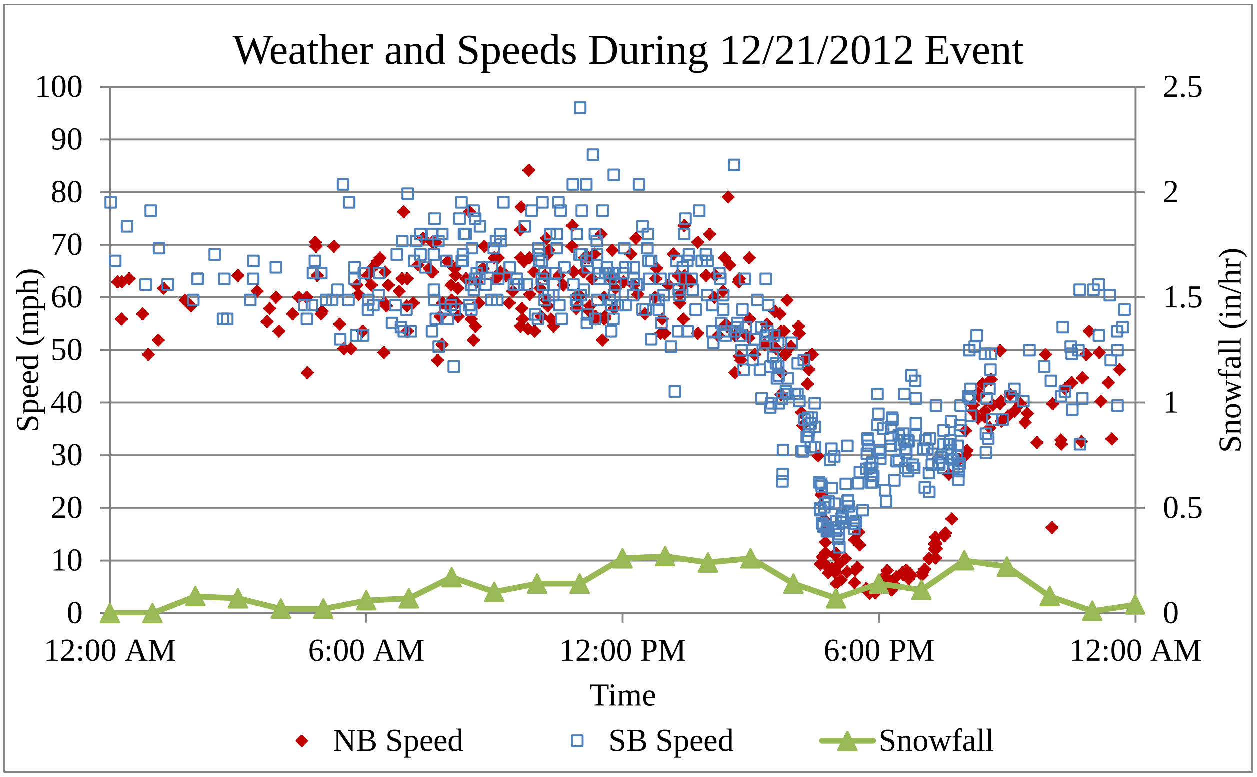


Figure 5.8: Speeds and Weather on December 21, 2012.

The peak snowfall on this day is 0.26 inches per hour (in/hr), but snowfall is continuous for most of the day, accumulating 2.96 inches. The vehicle speeds are similar for the majority of the day, until at 4:30 PM the northbound speeds are slower than the southbound speeds as a result of a crash. Figure 5.9 shows the speeds and weather during this event from 3:30 PM to 9:30 PM.

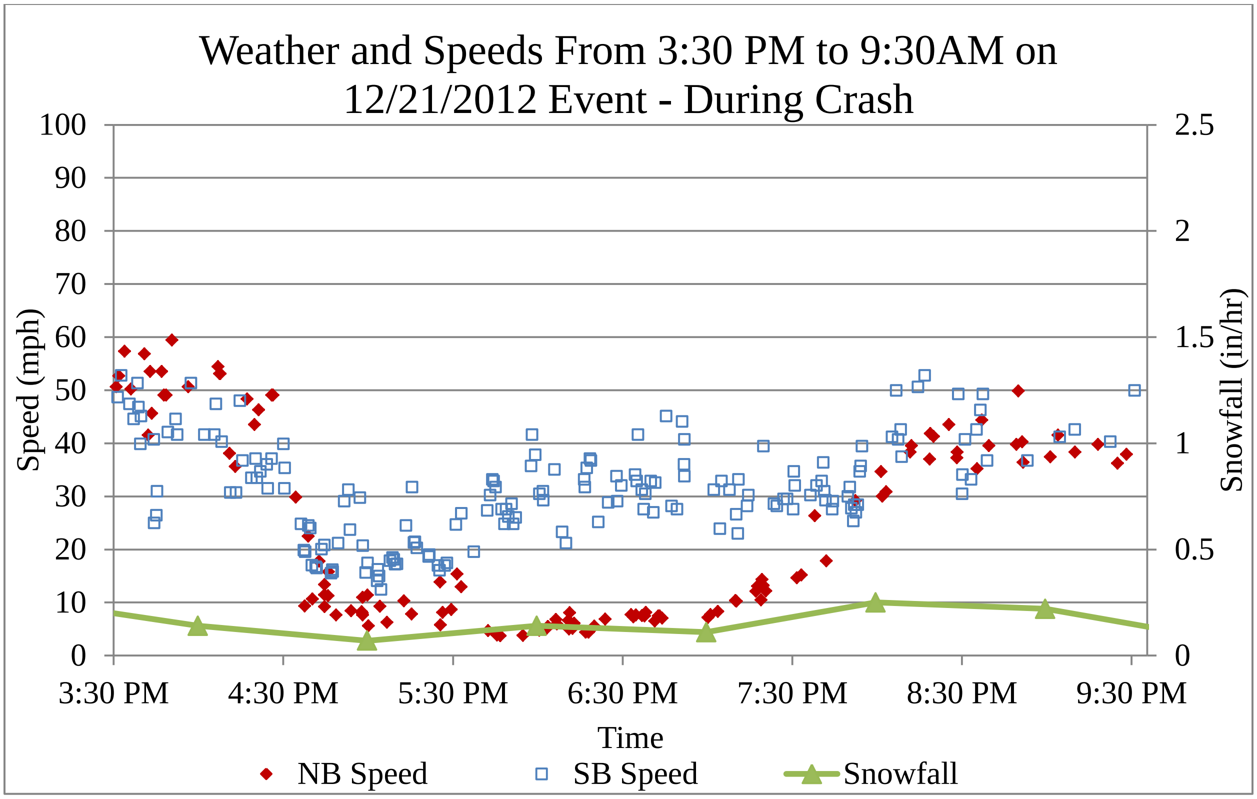


Figure 5.9: Weather and Speeds During Crash on December 21, 2012.

The difference in the speeds on December 21, 2012, is caused by a crash occurring north of the study area in the northbound direction. Crash reports obtained through the Ohio Department of Public Safety indicate that two crashes occurred near mile marker 21 just after 3:30 PM, which corresponds to the time where reduced speeds on I-271 were noted.

On the day of this winter event, the Epoke and the standard truck treat the study area until noon, after which the two trucks only treat SR-8. After this time, a separate truck maintains I-271. This event is before the Epoke is moved exclusively to I-271, so the trucks are responsible for maintaining a portion of SR-8 as well.

The GPS routes of the Epoke and the standard truck are shown in Figures 5.10 and 5.11, respectively.

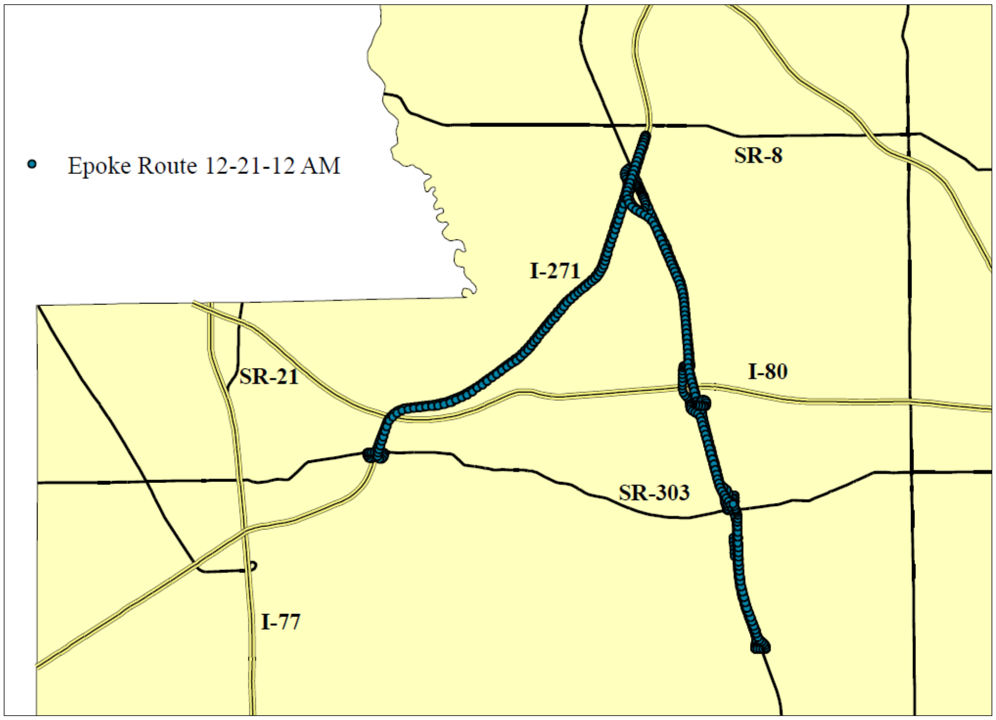


Figure 5.10: Route of Epoke on the Morning of December 21, 2012.

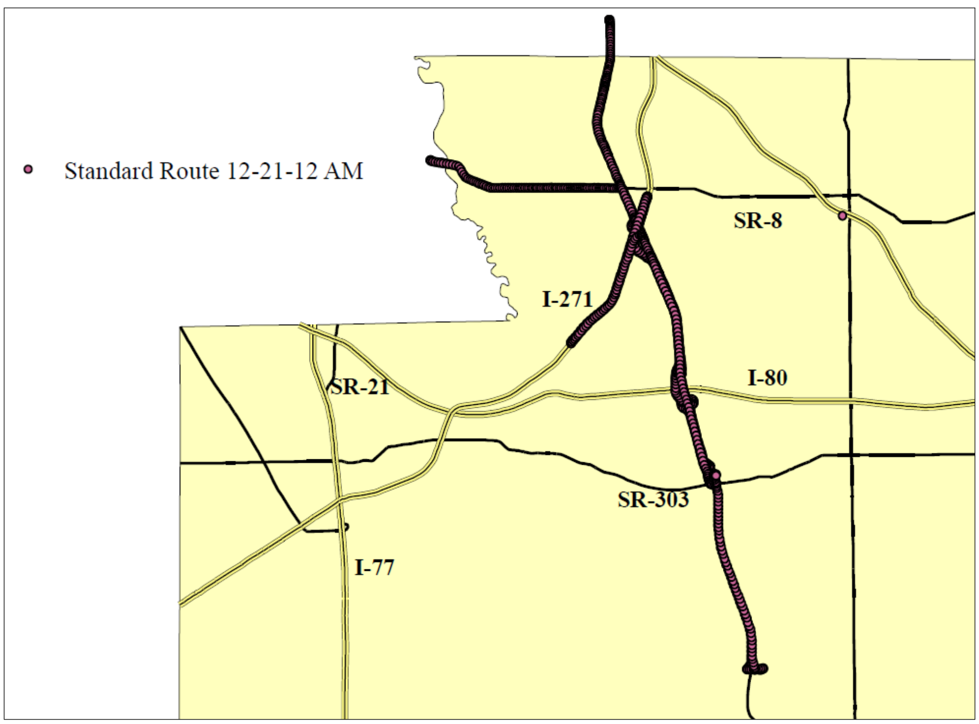
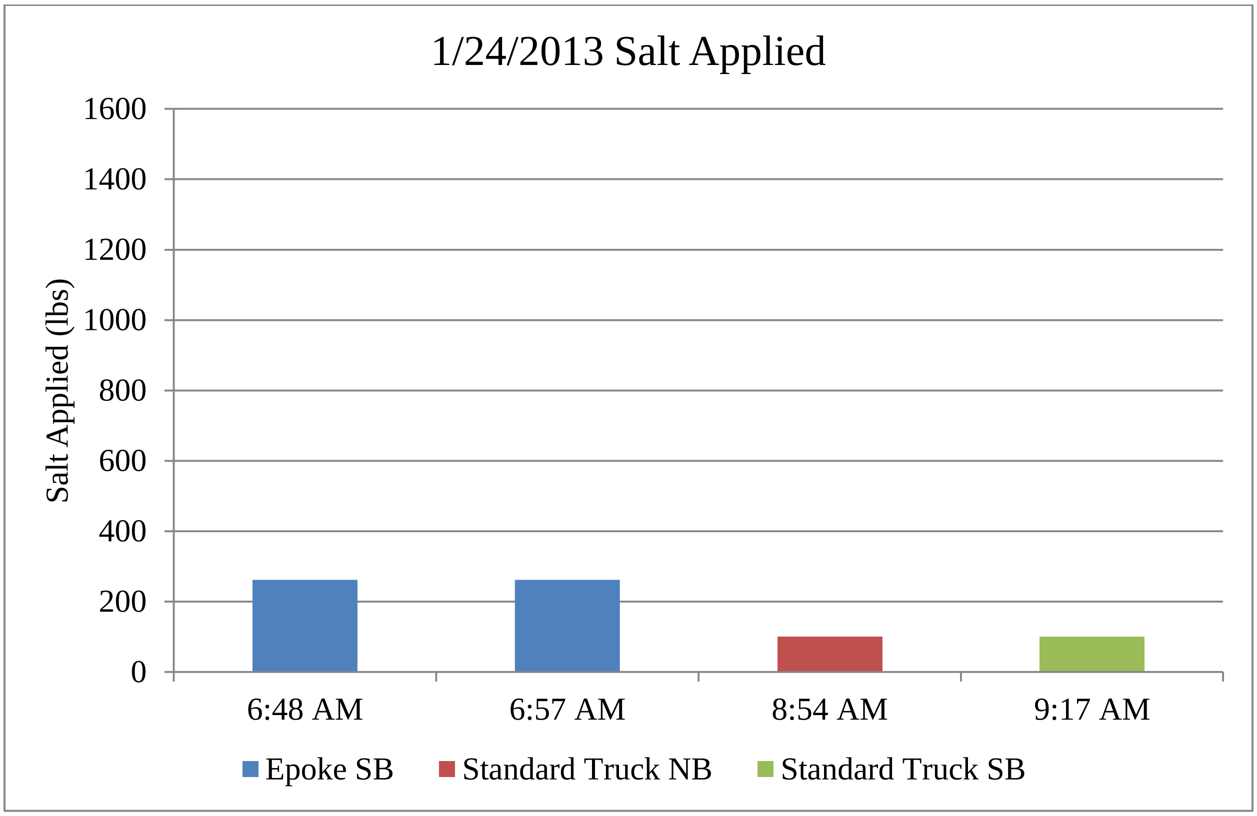


Figure 5.11: Route of the Standard Truck on the Morning of December 21, 2012.

As stated previously, the two trucks maintain similar routes including SR-8 and I-271. This is the first event of the season, and the decision to move the trucks exclusively to I-271 had not been made at that time. The standard truck maintained additional routes including SR-82 and the northern portion of SR-8. However, the Epoke treated a total of 253 lane miles compared to 119 lane miles treated by the standard truck.

5.7.2 January 24, 2013

The amount of salt applied by the Epoke and standard truck on January 24, 2013, is shown in Figure 5.12.



Note: Times corresponded to when the study zone was treated.

Figure 5.12: Salt Applied by Each Truck on January 24, 2013.

On January 24, 2013, the Epoke treated the study area twice in the southbound direction, while the standard truck treated once in each the northbound and southbound directions, and the amount of salt applied by each truck is shown in Table 5.8.

Table 5.8: Total Salt Applied by Each Truck on January 24, 2013.

	Epoke Salt Used in Study Zone (lbs)	Standard Truck Salt Used in Study Zone (lbs)
NB	0	100
SB	524	100

The Epoke treated two lanes at a rate of 100 lbs/ln-ml on both passes, while the standard truck treated a single lane at a rate of 50 lbs/ln-ml plus the salt in the brine used for pre-wetting.

The vehicle speeds and snowfall occurring on January 24, 2013, are shown in Figure 5.13.

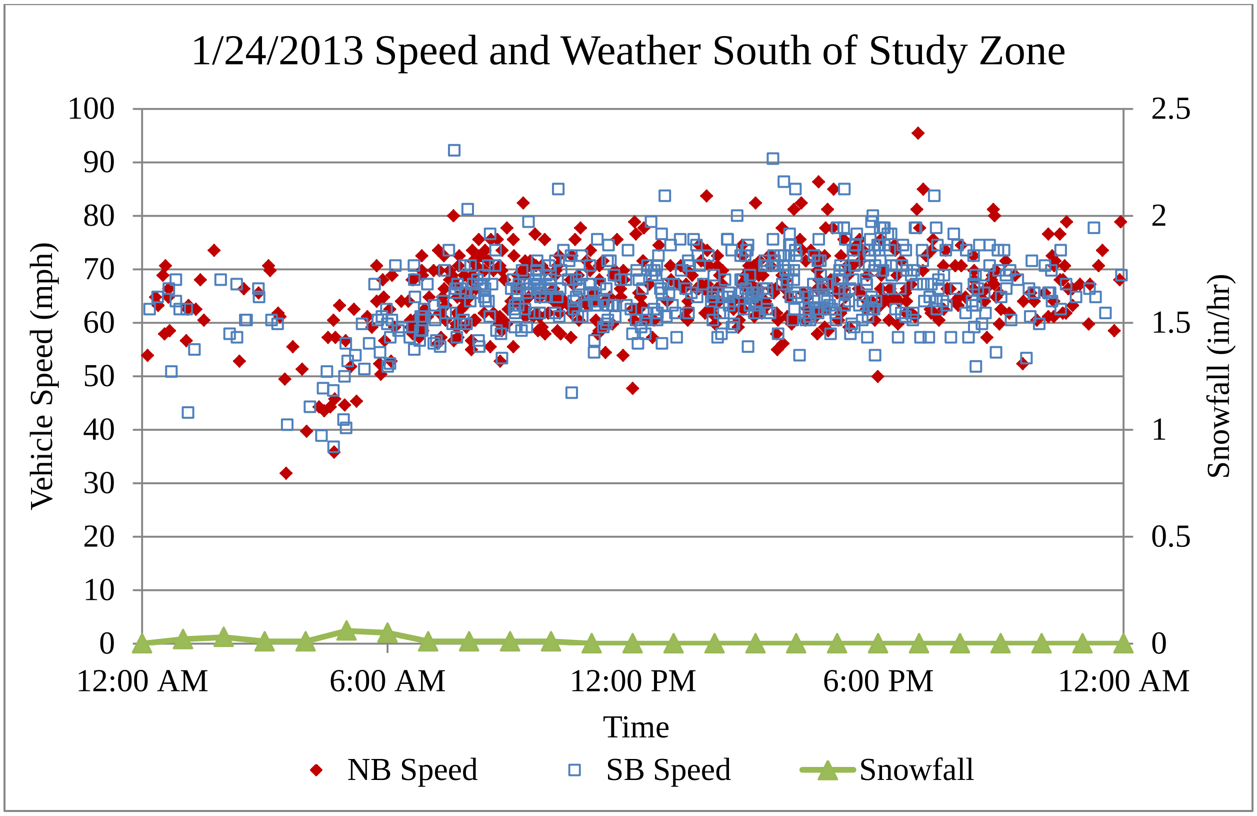


Figure 5.13: Speeds and Weather on January 24, 2013.

The peak snowfall on this day is 0.06 in/hr with a total accumulation of 0.21 inches. There is no discernible difference between speeds in the northbound and southbound directions, which indicates similar levels of road quality for the two directions of travel. Even with the light snowfall occurring at 5:00 AM, there is a 25 mph speed reduction at the peak snowfall.

The GPS routes of the Epoke and standard truck are shown in Figures 5.14 and 5.15, respectively.

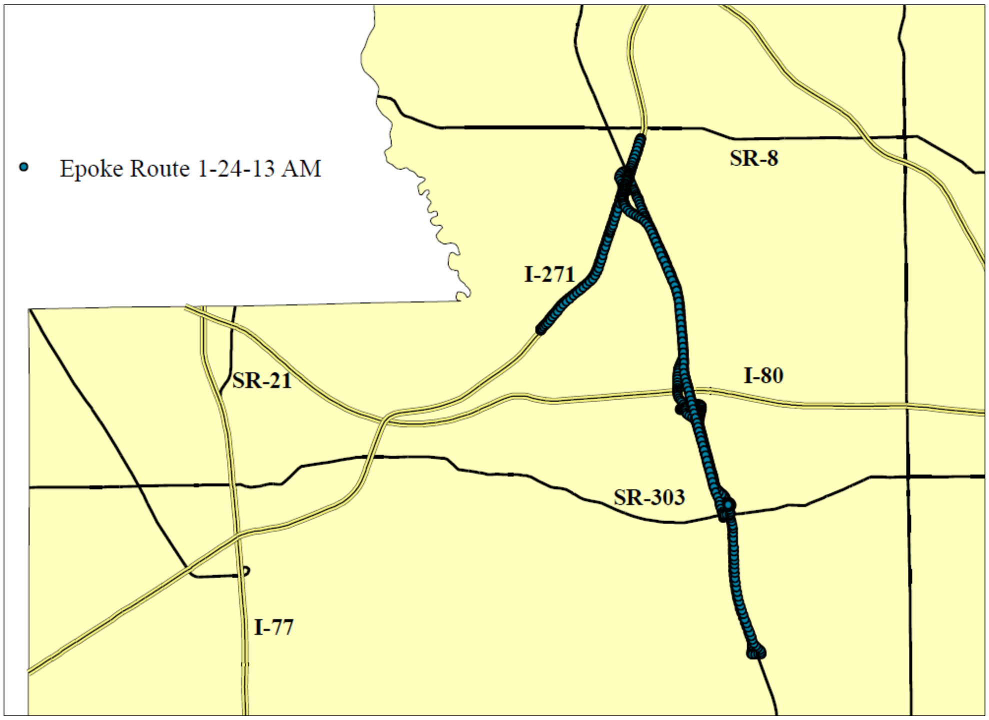


Figure 5.14: Route of Epoke on the Morning of January 24, 2013.

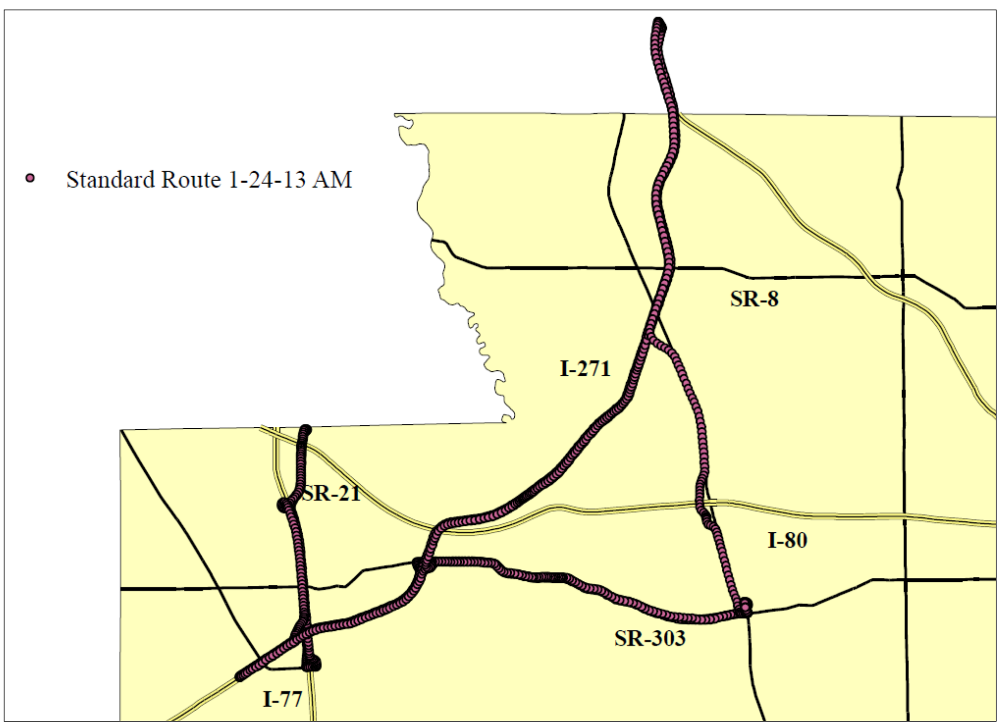
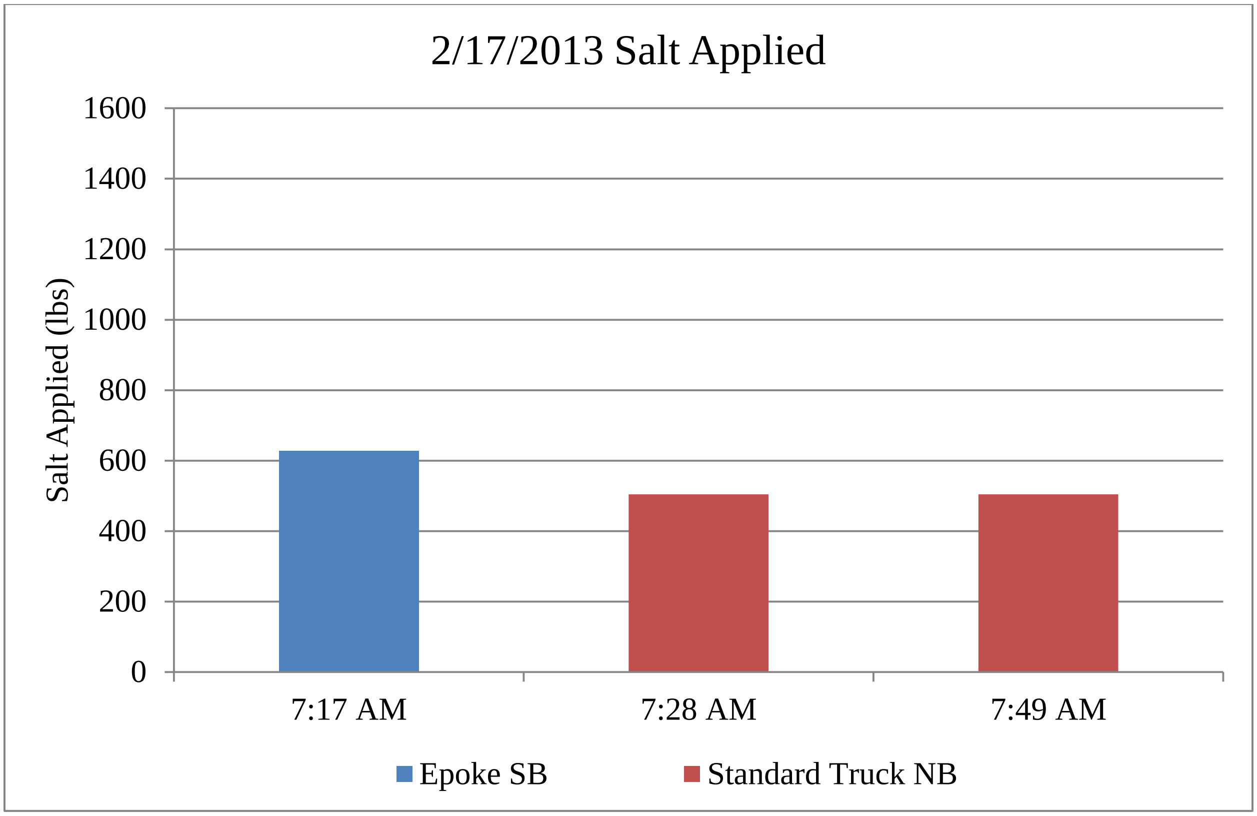


Figure 5.15: Route of the Standard Truck on the Morning of January 24, 2013.

The Epoke maintained only SR-8 and the study area of I-271, while the standard truck maintained SR-8, SR- 303, SR-21, I-271, and I-77.

5.7.3 February 17, 2013

The amount of salt applied by the Epoke and standard truck is shown in Figures 5.16.



Note: Times corresponded to when the study zone was treated.

Figure 5.16: Salt Applied by Each Truck on February 17, 2013.

The Epoke treated once in the study area, while the standard truck treated twice, and the total amount of salt applied by each truck on this day is shown in Table 5.9.

Table 5.9: Total Salt Applied by Each Truck on February 17, 2013.

	Epoke Salt Used in Study Zone (lbs)	**Standard Truck Salt Used in Study Zone (lbs)**
NB	0	1008
SB	628	0

On its single pass, the Epoke treated two lanes at a rate of 200 lbs/ln-ml, while the standard truck also treated at a rate of 200 lbs/ln-ml on both passes. With the capability of the Epoke to spread material over multiple lanes, it makes one pass compared to two passes for the standard truck. This allows the Epoke to treat other areas while the standard truck continues to maintain I-271 additional times. This presents a time savings for the Epoke, which is evaluated in depth in section 6.2. A limiting factor of spreading material over multiple lanes in one pass is seen when snow accumulates on the road to the point where it must be plowed off. In these situations, the Epoke will need to make additional trips to plow all lanes on a multi-lane road.

The vehicle speeds and snowfall occurring on February 17, 2013, are shown in Figure 5.17.

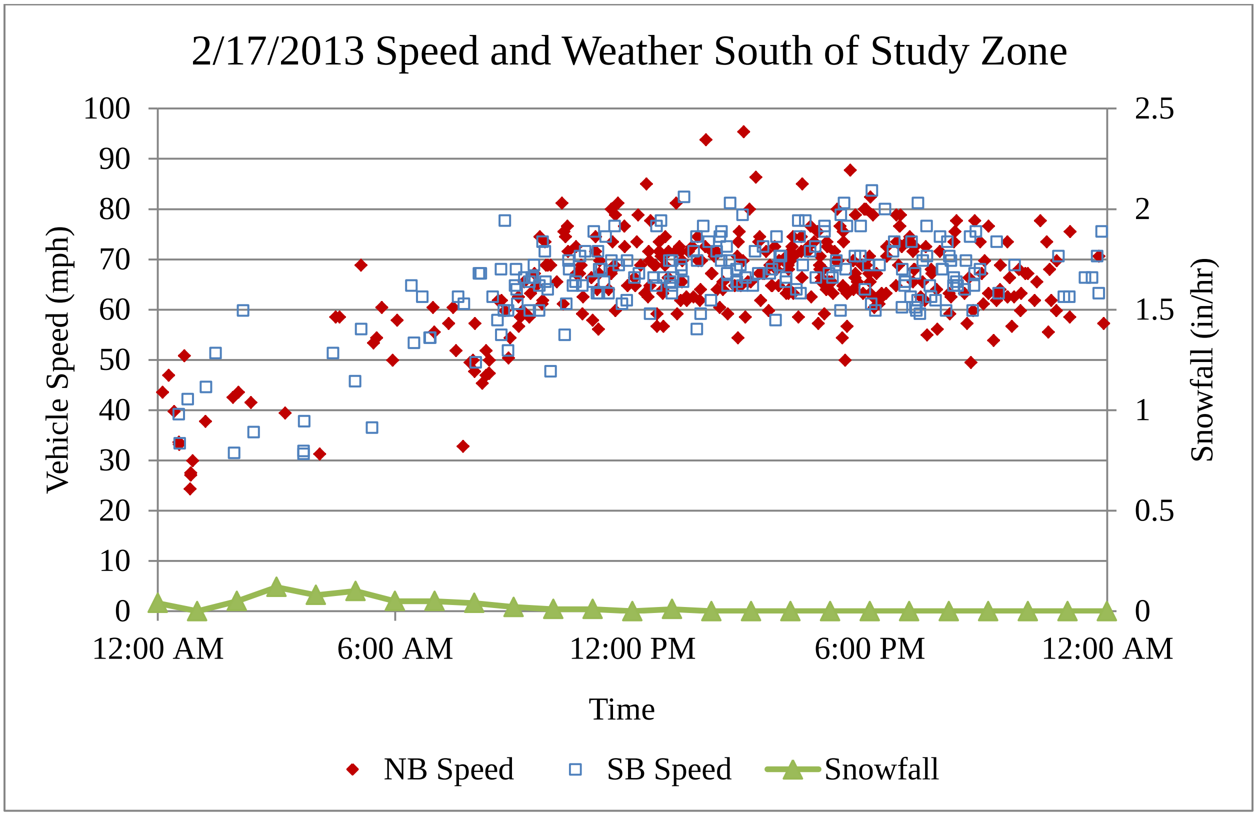


Figure 5.17: Speeds and Weather on February 17, 2013.

The peak snowfall on this day is 0.12 in/hr with a total accumulation of 0.53 inches. Again, the speeds are similar in the northbound and southbound directions. There are slight amounts of snowfall in the morning, but it is extended over several hours resulting in a speed reduction lasting until around 8:00 AM when the snowfall subsides.

The GPS routes of the Epoke and standard truck on February 17, 2013 are shown in Figures 5.18 and 5.19, respectively.

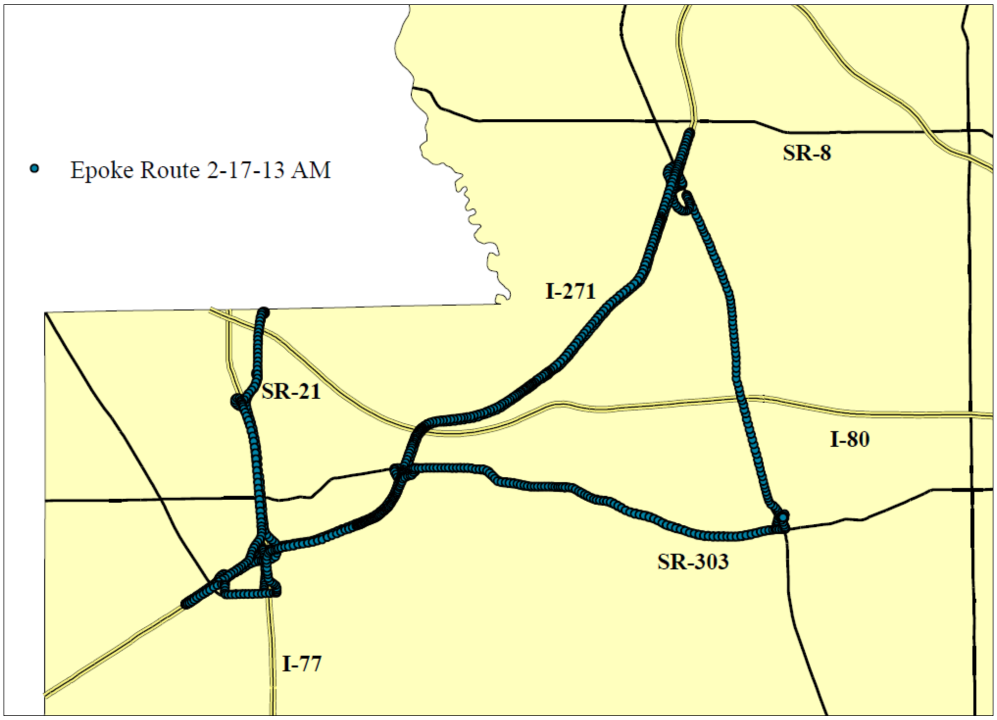


Figure 5.18: Route of Epoke on the Morning of February 17, 2013.

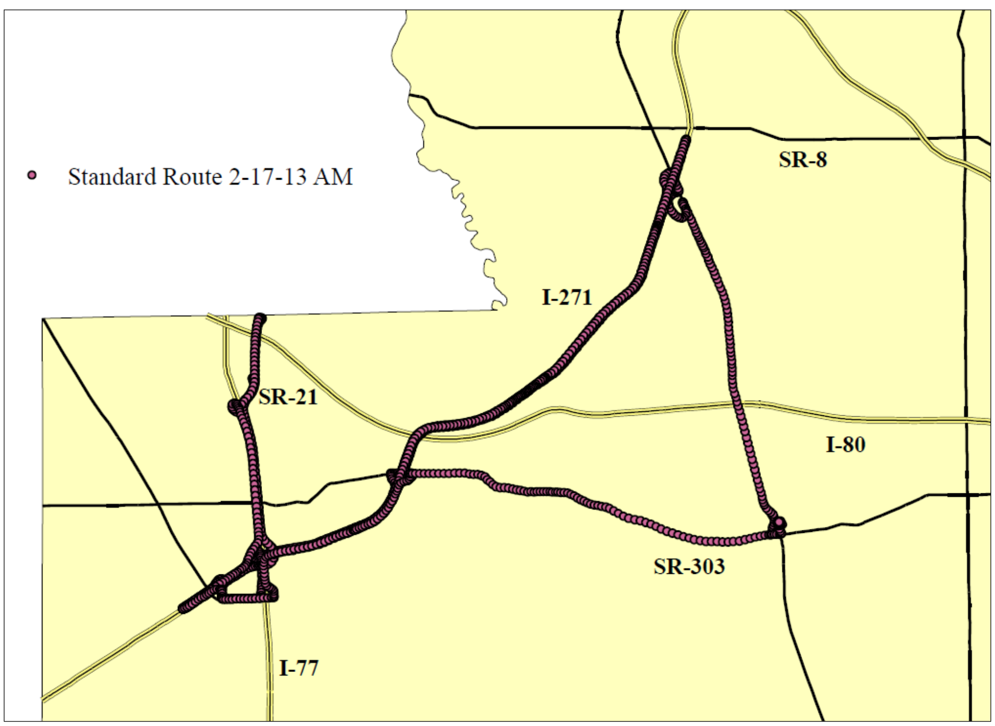
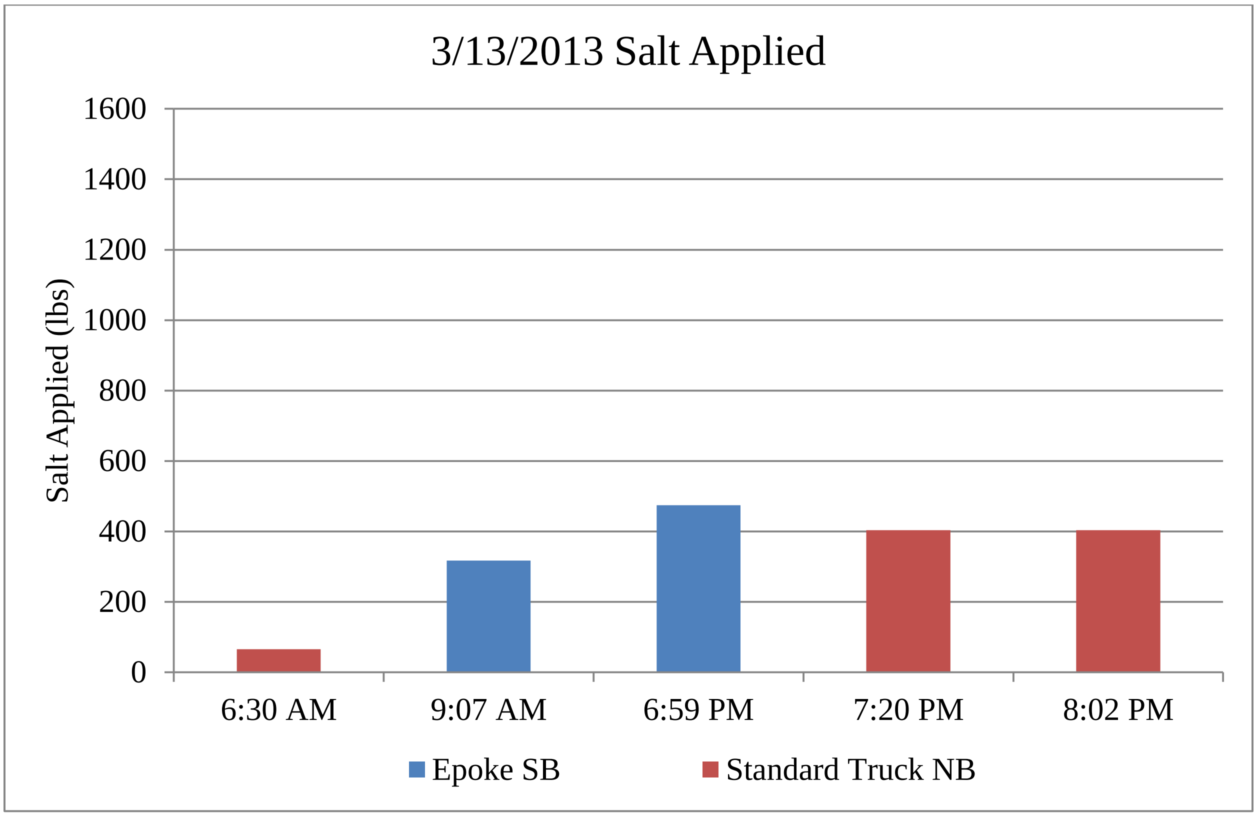


Figure 5.19: Route of the Standard Truck on the Morning of February 17, 2013.

This winter event is after the trucks are moved to I-271 exclusively. The trucks still travel on SR-8, but this is required to get from the garage to I-271 where they spend the majority of the shift. The two trucks maintained similar routes on this day.

5.7.4 March 13, 2013

The amount of salt applied by the Epoke and standard truck on March 13, 2013, is shown in Figures 5.20.



Note: Times corresponded to when the study zone was treated.

Figure 5.20: Salt Applied by Each Truck on March 13, 2013.

The Epoke treated twice in the study area, while the standard truck treated three times, and the total amount of salt applied by each truck is shown in Table 5.10.

Table 5.10: Total Salt Applied by Each Truck on March 13, 2013.

	Epoke Salt Used in Study Zone (lbs)	**Standard Truck Salt Used in Study Zone (lbs)**
NB	0	872
SB	792	0

On each pass the Epoke treated two lanes, while on the first pass the Epoke applied salt at a rate of 100 lbs/ln-ml, and on the second pass at a rate of 250 lbs/ln-ml. The standard truck treated at a rate of 130 lbs/ln-ml during the first pass and at a rate of 200 lbs/ln-ml on the two subsequent passes. On the first pass, the standard truck only treated the final half mile of the study area, resulting in the little amount of salt applied.

The vehicle speeds and snowfall occurring on March 13, 2013, are shown in Figure 5.21.

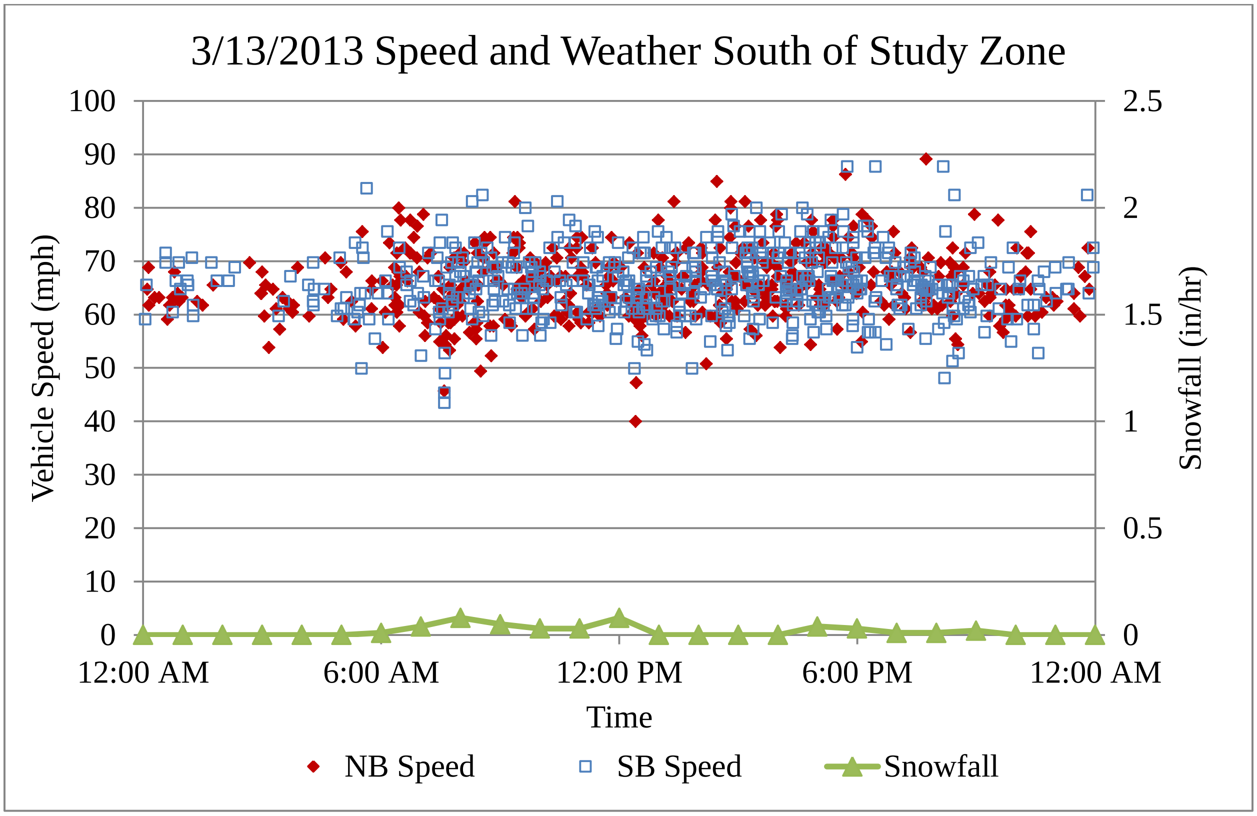


Figure 5.21: Speeds and Weather on March 13, 2013.

The peak hourly snowfall rate on this day is 0.08 in/hr resulting in a total accumulation of 0.36 inches. The speeds are similar for both directions of travel, indicating that the Epoke and standard truck are clearing the roads to the same level of effectiveness. Additionally, the scarce amount of snowfall does not lead to any speed reductions.

The GPS routes of the Epoke and standard truck are shown in Figures 5.22 and 5.23, respectively.

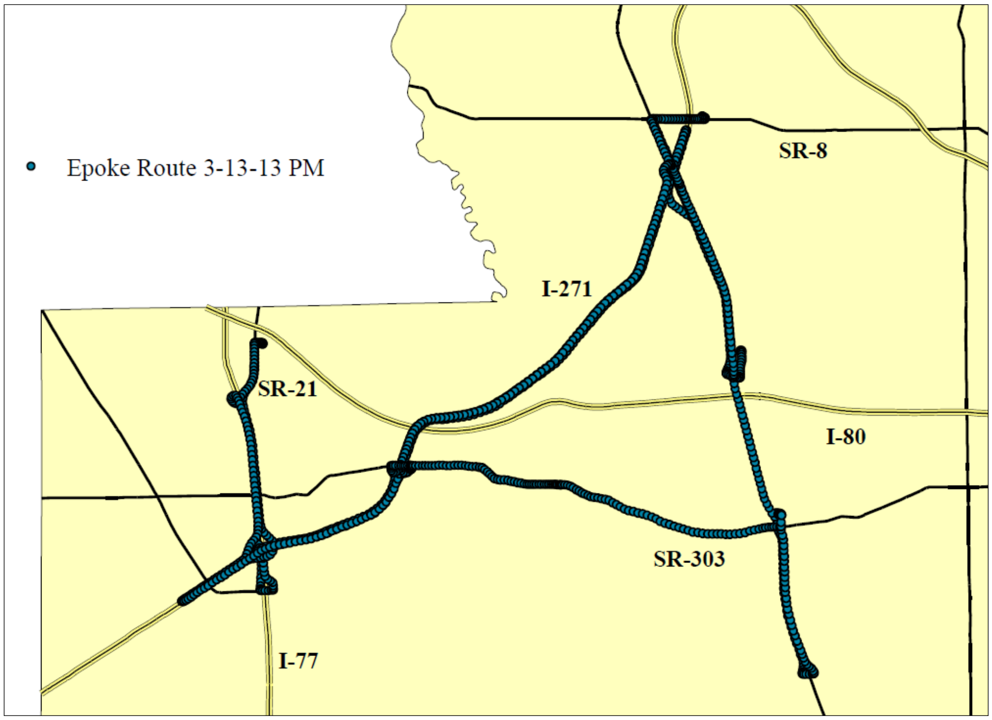


Figure 5.22: Route of Epoke on the Evening of March 13, 2013.

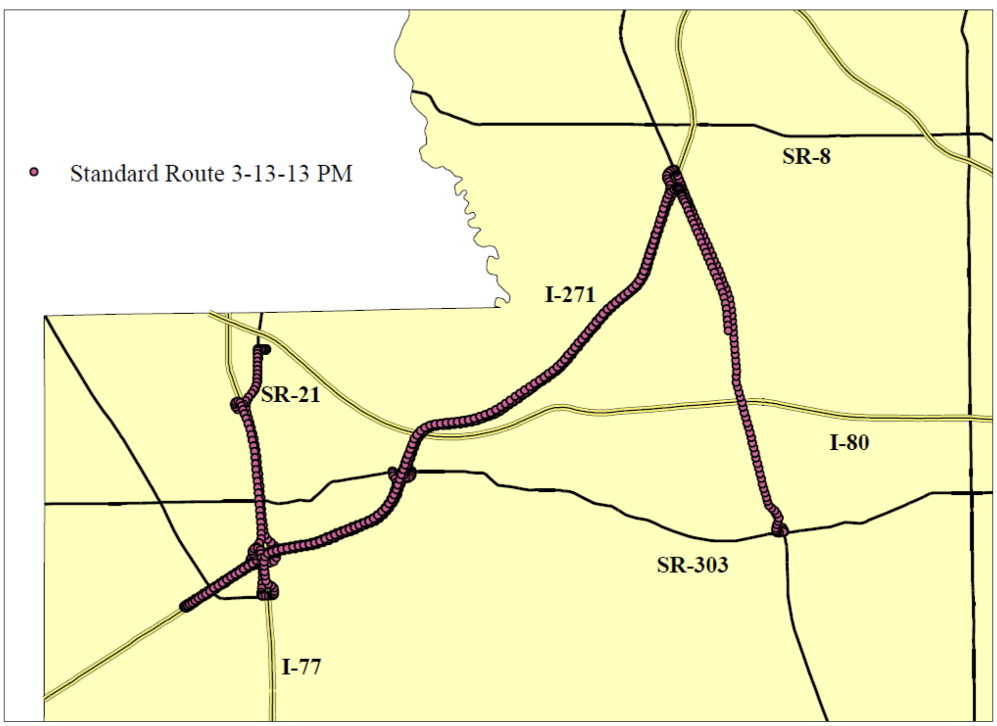


Figure 5.23: Route of the Standard Truck on the Evening of March 13, 2013.

On this day, the trucks treat similar routes. However, the Epoke did maintain SR-303 while the standard truck did not.

5.8 Tanker Anti-icing

Along with the spreader placed on the snow plow truck, ODOT also mounted an Epoke spreader on their 5000 gallon tanker truck used for anti-icing. Previously, ODOT would use four trucks for anti-icing, which required 12 to 14 hours to treat all of Summit County in this manner.

The tanker truck is only equipped with the Epoke for the second winter season, and there were 27 events where the Epoke tanker is exclusively performing anti-icing as shown in Table 5.2. Of the anti-icing events, 17 require only anti-ice. While the 10 additional events required additional material to be spread during the events, and are grouped into the comparison events in Table 5.2.

Accordingly, this section is divided into three subsections:

- <u>Subsection One</u> – December 6, 2012 Anti-icing,
- <u>Subsection Two</u> – December 11, 2012 Anti-icing, and
- <u>Subsection Three</u> – Summary of All Anti-icing Events.

5.8.1 December 6, 2012 Anti-icing

On December 6, 2012, snow was in the forecast, but none accumulated. Two trucks are deployed for anti-icing purposes on this day, the Epoke tanker truck and a standard truck. The routes for the two trucks are shown in Figures 5.24 and 5.25.

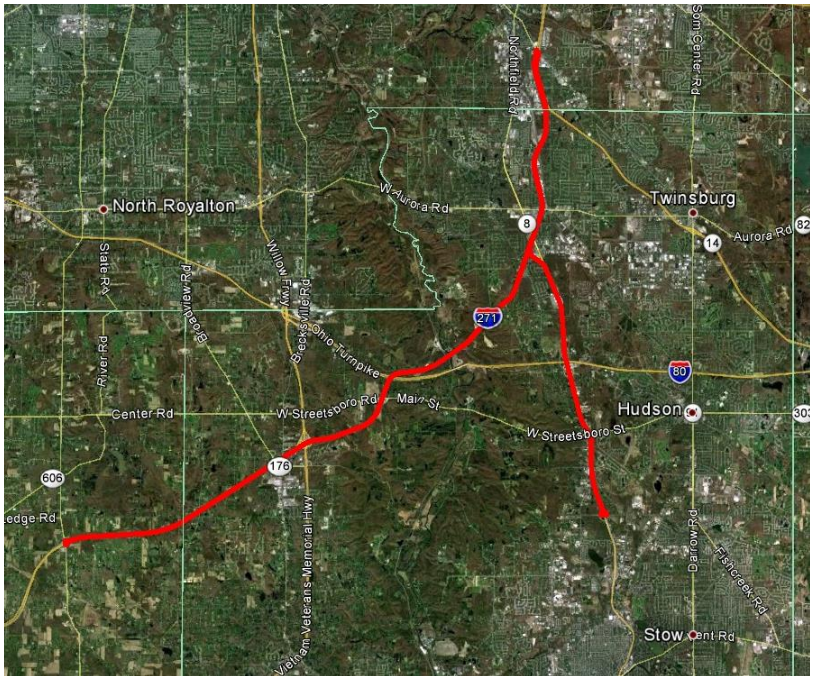


Figure 5.24: Route of Epoke Tanker Truck for Anti-icing on December 6, 2012.

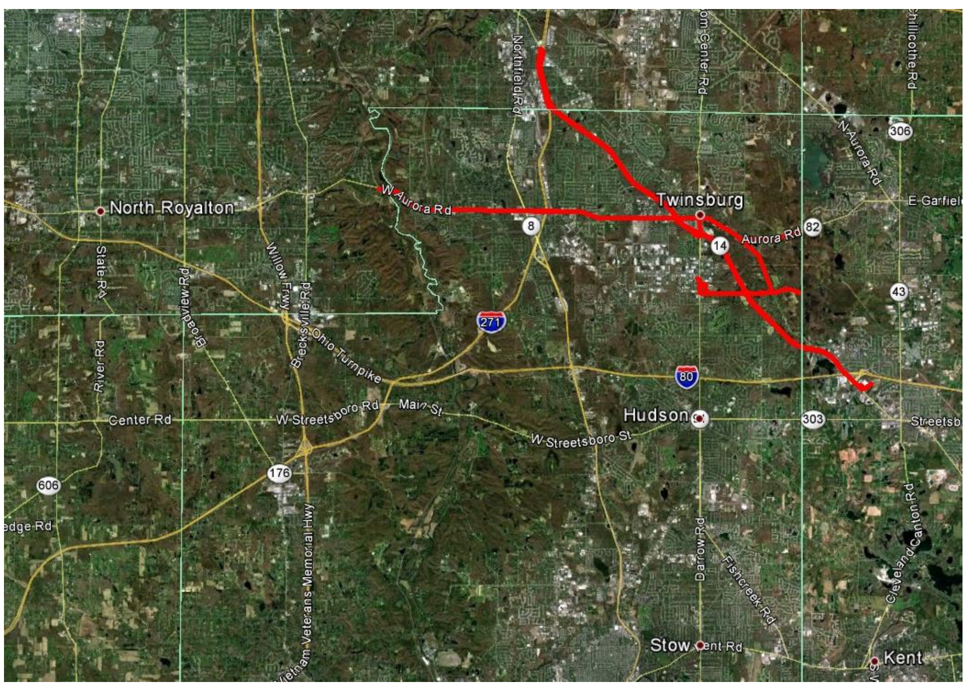


Figure 5.25: Route of Standard Truck for Anti-icing on December 6, 2012.

The Epoke tanker truck traveled 73 miles while treating all bridges on the route with 1000 gallons of brine, which took one hour and 45 minutes. The standard truck traveled 101 miles while treating 58.2 lane miles with 400 gallons of brine, which took two hours and 20 minutes.

5.8.2 December 11, 2012 Anti-icing

On December 11, 2012, the Epoke tanker and a standard truck were deployed for anti-icing. On this day, the peak snowfall was 0.03 in/hr and 0.13 inches accumulated. The routes for the tanker and the standard truck are shown in Figures 5.26 and 5.27, respectively.

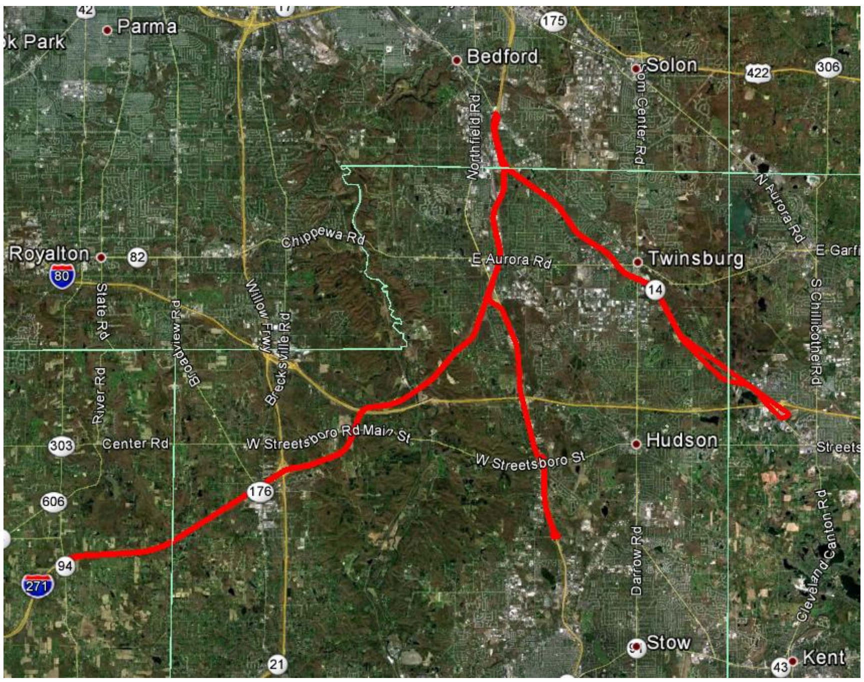


Figure 5.26: Route of Tanker Truck for Anti-icing on December 11, 2012.

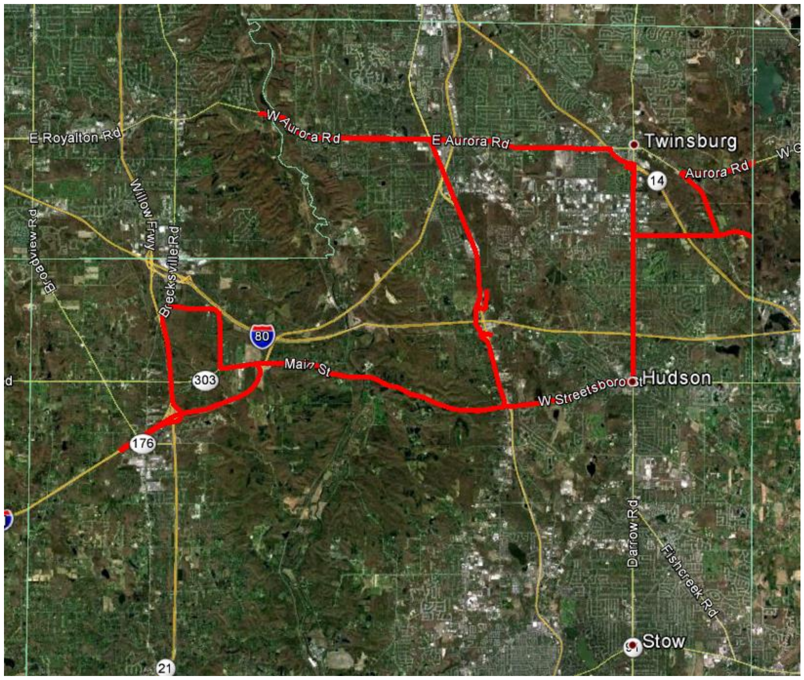


Figure 5.27: Route of Standard Truck for Anti-icing on December 11, 2012.

The Epoke tanker traveled 95 miles while treating 152 lane miles with 1253 gallons of brine, which took three hours and 15 minutes. The standard truck traveled 109 miles while treating 54 lane miles with 300 gallons of brine, which took four hours and 50 minutes.

5.6.3 Summary of All Anti-icing Events

All days on which the Epoke tanker is utilized for anti-icing are analyzed to determine the miles traveled, lane miles treated, time, and amount of salt used by the tanker truck. These data are summarized in Table 5.11.

Table 5.11: Summary of Anti-icing Events Utilizing the Tanker Truck.

Date	Miles Traveled	Lane Miles Treated	Time (hours)	Brine Applied (gallons)	Areas Treated
12/5/2012	122	56	3.00	1,400	I-77, I-277
12/6/2012	73	Bridges Only	1.25	1,000	SR-8, I-271
12/11/2012	95	152	3.25	1,253	SR-8, I-271, I-480
12/12/2012	162	Bridges Only	3.75	3,700	SR-8, SR-21, I-271, I-77, I-76
12/21/2012	171	118	8.50	19,035	SR-8, I-271, I-480, I-77
12/24/2012	195	Bridges Only	5.00	1,500	SR-8, SR-21, SR-82, I-271, I-480, I-77, I-76
12/26/2012	135	Bridges Only	3.50	2,212	SR-8, SR-21, I-271, I-77, I-76
1/14/2013	77	Bridges Only	1.75	892	SR-8, I-271, I-480
1/18/2013	191	Bridges Only	6.00	2,088	SR-8, SR-21, I-271, I-480, I-77, I-76,
1/19/2013	173	255	5.50	9,162	SR-8, SR-21, I-271, I-77, I-76
1/21/2013	NA	105	3.5	10,000	SR-8, I-480, I-271
2/15/2013	127	222	5.00	9,800	SR-8, SR-21, I-271, I-77, I-76
2/20/2013	154	140	NA	14,500	SR-8, I-271, SR-303, I-77
2/22/2013	46	53	2.50	3,800	SR-8, I-271
2/28/2013	37	54	1.25	12,094	SR-8, I-271
3/5/2013	64	81	2.50	NA	I-480, I-271
3/6/2013	51	57	1.00	3,000	I-77
3/8/2013	60	Bridges Only	2.00	500	I-480, I-271. SR-8
3/12/2013	170	268	7.00	18,000	I-76, I-77, SR-21, I-271, I-480, SR-8
3/16/2013	82	40	5.50	8,000	SR-8
3/18/2013	151	150	4.50	10,000	I-77, SR-8, I-480, I-271, SR-21
3/19/2013	51	75	2.00	3,500	SR-8, I-77, I-271
3/22/2013	162	213	7.50	12,700	SR-8
3/25/2013	NA	264	8.50	17,500	SR-8, I-271
3/26/2013	73	150	5.00	5,000	SR-8
3/27/2013	146	157	5.00	13,000	SR-8, I-271, I-480
4/2/2013	154	Bridges Only	3.50	1,500	SR-8, I-480, I-271, I-77, I-76, SR-21

Note: “Bridges Only” signifies that the tanker was only treating the bridges on the routes.

ODOT frequently treats only the bridges on routes, since they typically freeze before the road surface. By using the Epoke tanker, ODOT has the capability to spread material over two or three lanes, which presents a great time savings. Unlike the plow truck, which may need to return to a route multiple times to plow each lane, the Epoke tanker has no need to make multiple passes since it is simply applying material and has the ability to treat multiple lanes.

The two days of interest for the anti-icing are January 19, 2013 and February 15, 2013 since they treated a high amount of lane miles. The route of the Epoke tanker on February 15, 2013 is shown in Figure 5.28.

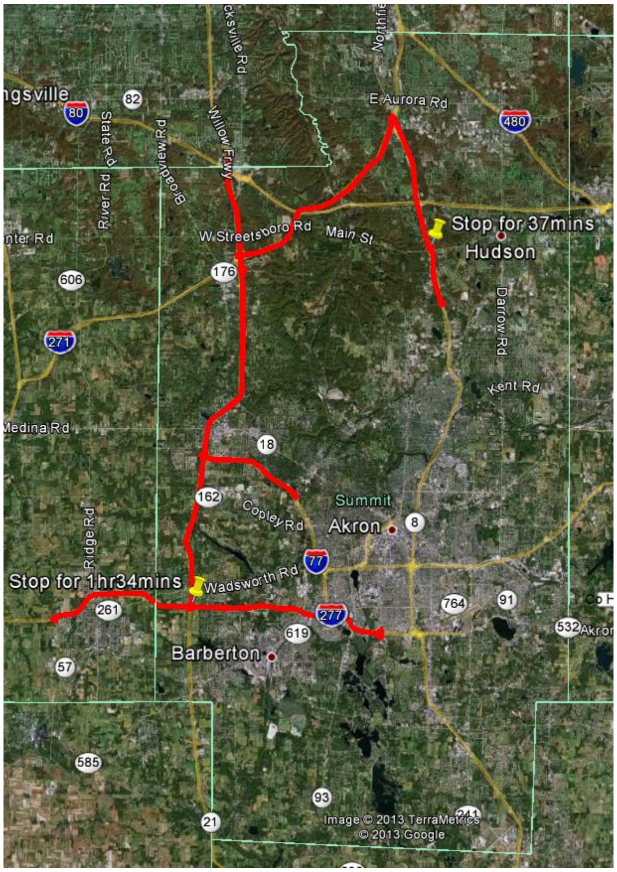


Figure 5.28: Route of Tanker on February 15, 2013.

On this day, the Epoke tanker treats 222 lane miles in five hours. When using typical equipment, this anti-icing would have taken approximately eight hours to complete. This presents a time savings of three hours total, as well as reducing the number of vehicles required from four to one. These labor savings will be quantified along with all the costs in the cost analysis Chapter 6.

CHAPTER VI

COST ANALYSIS

This chapter describes the overall cost benefit analysis of the Epoke spreader and tanker, and it is divided into four sections.

- Section One – Maintenance,
- Section Two – Labor,
- Section Three – Benefit to Cost Analysis, and
- Section Four – Cost Calculations.

6.1 Maintenance

Throughout the course of every winter operation, maintenance of equipment will become a factor, which may result in downtime during a winter event. Accordingly, the research team and ODOT tracked all the maintenance performed on the Epoke in order to include downtime and maintenance costs in the cost benefit analysis. When applicable, the reason for the maintenance and downtime will be discussed.

The first maintenance concern in the project arose in the process of mounting the Epoke on the ODOT truck. Since the system is installed on a truck that is set up for a standard snow plow and salt spreader, the concern is that the hydraulics are not sufficient to sustain the increased operations of the Epoke. The downtime and maintenance of the typical ODOT hopper over the last few seasons was reviewed with ODOT during a preliminary meeting. The research team contacted other Epoke users to gather the typical maintenance cost for the Epoke. The labor and stock were used to determine the cost of the maintenance. The overhead and deprecation costs were not a part of the maintenance analysis. Through this review, it shows that the Epoke has a maintenance cost of $876 per year, while the standard ODOT hopper has a maintenance cost of $296 per year.

6.2 Labor

Upon examination of the salt application data and the GPS routes for the trucks, the researchers found that the Epoke is capable of treating an area more quickly than the standard truck, which may result in a savings in labor costs. To quantify the savings, the events where the Epoke and standard truck are treating the study zone are compared, and the routes are analyzed to determine what areas the two trucks treated during these times.

Three different labor savings evaluations were reviewed and compared. Accordingly, the section is separated into four subsections.

- Subsection One – Labor Savings Based on Good Comparison Events,
- Subsection Two – Labor Savings Based on Model,
- Subsection Three – Maximum Theoretical Labor Savings at Boston Heights Garage, and
- Subsection Four – Summary.

6.2.1 Labor Savings Based on Good Comparison Events

In the analysis based on good comparison events, a total of eight snow events occurred in which both trucks are running and treating exclusively opposite directions in the study zone, these days are listed previously in section 5.4.2. The study zone is treated 17 times in the southbound direction by the Epoke and 26 times in the northbound direction by the standard truck. The LOS on both routes is found to be similar by analyzing the Bluetooth speed data acquired in the study zone. When comparing the number of passes each truck made to keep the road clear it is determined that one Epoke is equal to 1.6 standard trucks. This time savings ratio is used in calculating the labor savings of the Epoke, which is shown in Table 6.2 in section 6.2.4. Based on this ratio, an operator may not be eliminated; however the labor savings is based on the fact that additional work may be completed which may help reduce overtime or seasonal operator's hours.

Figure 6.1 is the process used to calculate the time saved in minutes on a per mile basis from the data collected during the final eight good comparison days. The minutes saved are based on the study zone, which is a four lane divided highway, with two lanes in each direction. Each truck is responsible for treating one direction of travel; therefore each truck maintains a two lane segment in the study zone. The minutes saved per mile may increase if treating three lanes and decrease if treating one lane in one pass.

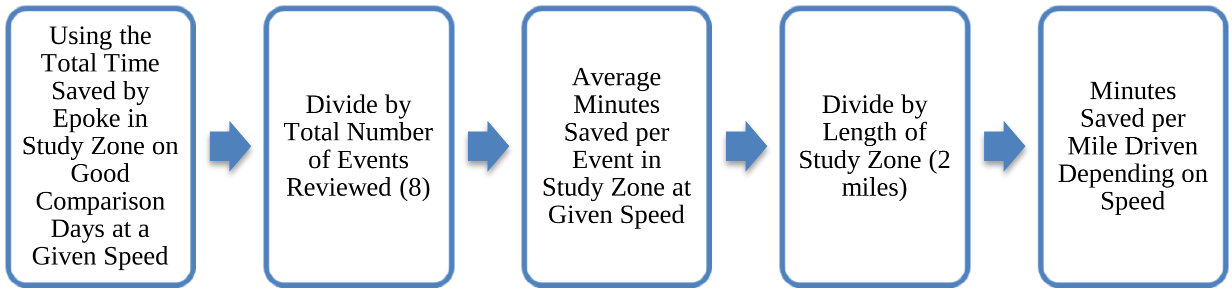


Figure 6.1: Time Savings per Mile Process.

Using the process described in Figure 6.1, Figure 6.2 is produced to show the minutes saved per mile by using the Epoke compared to the standard truck at various rates of speeds.

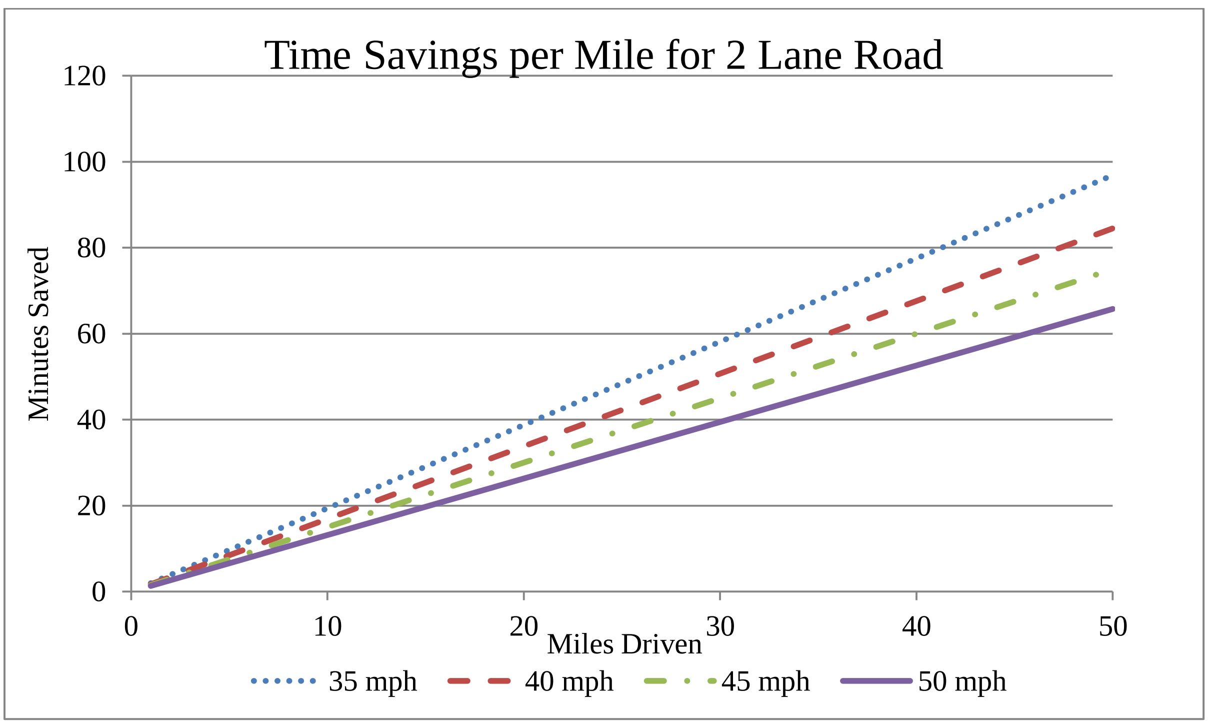


Figure 6.2: Time Savings vs. Miles Driven.

Using the amount of time saved through the study zone on the good comparison days, the average time saved over the eight events is determined in order to calculate the average time saved per mile on a two lane road. The time savings represent the amount of time that is expected to be saved when using the Epoke instead of the standard truck.

6.2.2 Labor Savings based on Route Optimization Model

A route optimization model is developed to aid in the optimal deployment strategy of the Epoke, and is described in Chapter 7. One outcome of the model is the labor savings created by utilizing the Epoke. Through the analysis of the total time required to complete each route, it is found that on average the Epoke is equivalent to 1.3 standard trucks. This ratio is used to calculate a labor savings as shown in Table 6.2 in section 6.2.4. This ratio is a result of the Epoke being capable of maintaining routes more quickly than the standard truck, based on its ability to treat multiple lanes at once.

6.2.3 Maximum Theoretical Labor Savings for Boston Heights Garage

The research team determined that the Boston Heights garage is responsible for maintaining 136 total lane miles. Table 6.1 shows the breakdown of the total miles for each multilane roadway for routes maintained by the Boston Height's Garage. Using this information the total number of passes required by the standard truck and Epoke are determined. The Epoke's number of passes is determined using the assumption that it is treating as many lanes as possible in one pass. The medians were considered when looking at the Epoke's ability to treat multiple lanes: on an undivided road with one lane in each direction the Epoke is capable of treating both lanes.

Table 6.1: Boston Heights Lane Distribution.

	Two Lanes	**Four Lanes**	**Five Lanes**	**Six Lanes**
Length of Segment (miles)	20	18	1.2	3
Total Lane-Miles	40	72	6	18

The Epoke is able to treat all of the Boston Heights routes by traveling a total of 64 miles, while the standard truck would have to travel a total of 136 miles to treat all the lanes. This demonstrates that at a maximum value, for the Boston Heights garage routes, one Epoke is equivalent to 2.1 standard trucks. This is a theoretical value, and it is found using the assumption that the Epoke is treating all the routes. This ratio is unique to the Boston Heights Garage. Equivalence ratios will vary depending on the roadway characteristics of the routes maintained by other garages.

6.2.4 Summary

The labor savings is calculated by using the following values: the equivalence ratio for the Epoke to a standard truck, an assumption of 56 winter events per year with a length of 12 hours each, and a labor rate of $17.60/hour. The hourly operator rate of $17.60/hr is the average rate provided by ODOT. Based on discussions with the technical liaison committee, overtime is not included in the cost analysis. Equation 6.1 is an example of the labor savings calculated using the ratio observed in the field of one Epoke equal to 1.6 standard trucks.

$$Labor\ Savings = (Epoke\ Ratio - 1) \times Number\ of\ Events \times Time\ Duration\ of\ Event \times Labor\ Rate$$

Equation 6.1

$$= (1.6 - 1) \times \left(56 \frac{Events}{Year}\right) \times \left(12 \frac{Hour}{Event}\right) \times \left(17.60\ \frac{Dollar}{Hour}\right)$$

$$= \$\ 7{,}096\ \frac{Labor\ Savings}{Year}$$

Equation 6.1 is used to solve for all three labor savings ratios discussed in this section. The labor savings that is observed in the field is the value used in the cost analysis of this evaluation.

Table 6.2 shows the labor savings of the Epoke. Three different labor saving ratios are evaluated: the 1.6:1 ratio is based on what was observed in the evaluation, 1.3:1 is the ratio found from the route optimization model, and 2.1:1 is the theoretical maximum savings that will be seen at the Boston Heights garage if the Epoke treats as many lanes as possible on this garage's routes.

Table 6.2: Labor Saved from Epoke.

Labor Savings			
	Good Comparison Evaluation	**Route Optimization Model**	**Boston Height Maximum**
Epoke to Standard Labor Savings Ratio	1.6:1	1.3:1	2.1:1
Number of Events per Year	56	56	56
Duration of Event (hr)	12	12	12
Labor Rate Straight Time ($/hr)	$17.60	$17.60	$17.60
Labor Savings ($/year)	$7,096	$3,548	$13,010

Note: The number of events, duration of events, and labor rate is set in accordance to discussions with ODOT.

The total labor saved in the Boston Heights garage during this study would generate a cost savings of $7,096 annually, as shown in Table 6.2. This value was found from using Equation 6.1, shown above. As a result of the Epoke's ability to treat multiple lanes in one pass, it is able to help treat other areas or complete other tasks, which results in a time savings. Again, it is important to note that the number of operators may not be reduced; however, time savings may be realized, since operators may work on other routes or tasks.

6.3 Benefit to Cost Analysis

The total salt saved from using the Epoke is shown to be 12%, as previously shown in section 5.4.2, which is determined by comparing the total salt applied to the study zone by each truck on the good comparison days. The total amount of salt saved based on this study is shown in Table 6.3 and from this table, the price of salt is $37.13 per ton based on information provided by Summit County. The total cost saved is shown for an annual salt use of 20,000 tons and 10,000 tons.

Table 6.3: Salt Saved by Epoke Depending on Annual Salt Usage.

Salt Savings – Based on Good Comparison Evaluation		
	20K Tons Annual Salt Used	**10K Tons Annual Salt Used**
Saved from Epoke (%)	12	12
Salt Used by Epoke* (tons)	3333	1667
Total Salt Saved (tons)	400	200
Price of Salt	$37.13	$37.13
Salt Savings	$14,852	$7,426

*Note: For a garage with 1 Epoke and 5 Standard Trucks, using an equal amount of salt.

The total amount of salt saved is 400 tons for an annual usage of 20,000 tons, and 200 tons for an annual usage of 10,000 tons. The 12% savings is for an ODOT garage which treated with pre-wetted salt in their standard trucks, and operates with one Epoke and five standard trucks, using the same amount of salt per season. This results in a cost saving of $14,852 when using 20,000 tons per year and a savings of $7,426 when using 10,000 tons per year.

6.4 Cost Calculations

In order to determine the feasibility of implementation of the Epoke, the costs and expenses of the system must be quantified. To accomplish this, the following three subsections are considered:

- Subsection One – Net Present Value,

- Subsection Two – Payback Period, and
- Subsection Three – Tanker Anti-icing Savings.

The combination of these sections will result in a summary of the costs and benefits of using the Epoke. Figure 6.3 shows the assumptions made when determining the cost analysis.

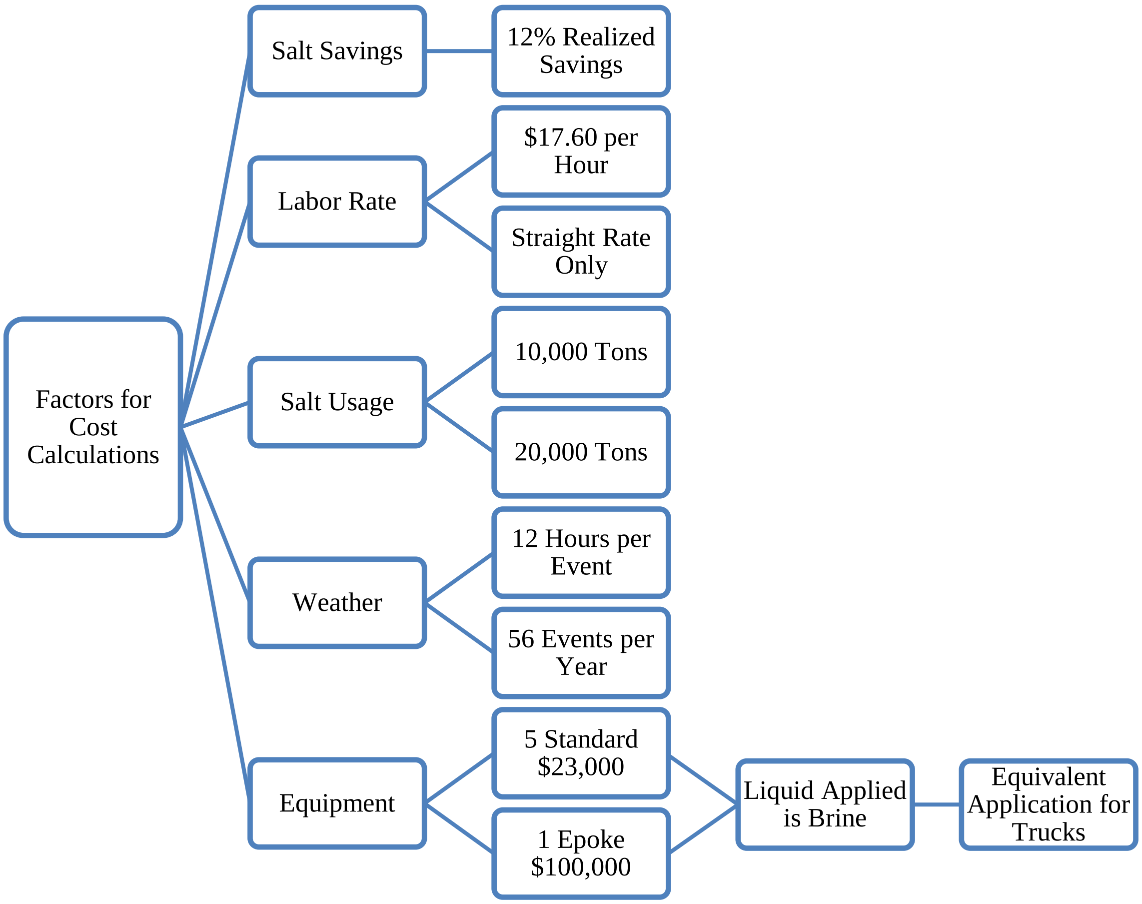


Figure 6.3: Assumptions Made for Cost Calculations.

The assumptions made for this cost analysis are formulated in a preliminary meeting between the research team and ODOT.

6.4.1 Net Present Value

The net present value (NPV) is determined given a time series of cash flows, both incoming and outgoing. The NPV is determined for each truck, the Epoke and the standard truck, then compared to determine the NPV of the Epoke's potential savings. The variables that are used to solve for the NPV of the Epoke and standard truck are: the initial cost, the maintenance costs per year, the cost of the salt usage of the truck per year, and the labor cost per year. The Epoke has a higher initial cost than the standard truck; however the Epoke has a 12% salt savings and a 1 to 1.6 labor savings ratio as discussed in section 6.2.1.

The equation for NPV is:

$$NPV = \frac{R}{(1+i)^n}$$

Equation 6.2

Where,

R = net cash flow (incoming – outgoing),

i = inflation rate, and

n = time of the cash flow (period of inflation rate).

The amount of salt used annually and the inflation rate are varied to capture the different potential NPVs of the Epoke. It is ODOT's preference to view the NPV after 8 years, which is the expected life span of an ODOT truck, additionally the NPV after 10 and 12 years are also provided for comparison purposes. The NPV of the Epoke is solved by using a salt savings of 12% and the 1.6:1 ratio to calculate a labor savings per year, which is observed in this evaluation. The labor savings are shown in section 6.2.4, and the salt savings calculations are shown in section 5.4.1. Table 6.4 shows the comparison of the NPV of the standard truck and the Epoke.

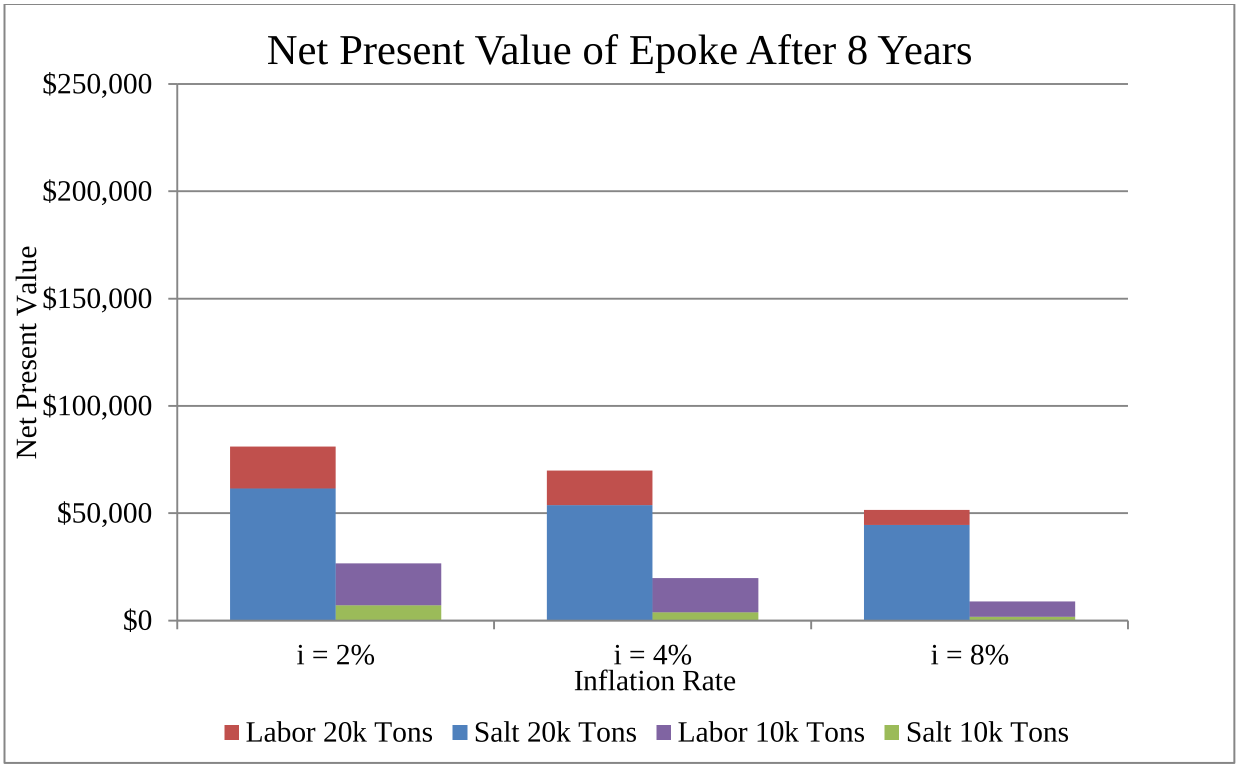
Table 6.4: Net Present Value Comparison.

	20,000 Tons of Salt / Year			10,000 Tons of Salt / Year		
	Standard	**Epoke**	**Difference**	**Standard**	**Epoke**	**Difference**
	2% Inflation			*2% Inflation*		
8 Years	($1,018,008)	($936,965)	$81,043	($564,683)	($538,038)	$26,644
10 Years	($1,243,191)	($1,126,739)	$116,453	($687,319)	($637,571)	$49,748
12 Years	($1,459,631)	($1,309,144)	$150,487	($805,193)	($733,239)	$71,955
	4% Inflation			*4% Inflation*		
8 Years	($937,027)	($867,198)	$69,829	($520,382)	($500,551)	$19,832
10 Years	($1,124,304)	($1,025,026)	$99,278	($622,375)	($583,328)	$39,046
12 Years	($1,297,452)	($1,170,947)	$126,505	($716,672)	($659,861)	$56,811
	8% Inflation			*8% Inflation*		
8 Years	($802,206)	($750,707)	$51,500	($446,585)	($437,760)	$8,825
10 Years	($933,128)	($861,041)	$72,087	($517,886)	($495,628)	$22,258
12 Years	($1,045,373)	($955,636)	$89,737	($579,015)	($545,241)	$33,774

Note: () indicates a negative number. Epoke has salt savings of 12% and labor savings of 1.6 standard trucks to 1 Epoke. Price of salt is $37.17/ton. 56 winter events per year at 12 hours each. Labor rate of $17.60/hour. In garage with six trucks using equivalent amount of salt per year. Initial cost of Epoke is $100,000, and the standard truck is $23,000.

The difference shown in Table 6.4 is the NPV of the Epoke compared to the standard truck. Table 6.4 shows the outgoing expenses of each truck. Since the Epoke has a salt savings of 12% and a labor savings, the outgoing cost of the Epoke after eight, ten, and twelve years is less than the outgoing expenses of the standard truck.

The NPV of the Epoke may be calculated using a net cash flow of the initial increased cost of the Epoke and the yearly maintenance costs minus the annual salt and labor savings, the results are the same as comparing each truck as in Table 6.4. The extra cost of the Epoke will vary depending on which Epoke system and which standard truck system are being compared. The extra cost of purchasing the Epoke instead of the standard truck was set at $77,000 for the NPV calculations. The labor rate is held constant for the two annual salt usages, since the amount of salt being used does not dictate whether or not the operators are working. However, the NPV from the labor savings will be different for each inflation rate due to the fact that the expenses stay constant while the savings do not, resulting in the varied labor saving proportions as the savings are subtracted from the expenses. Three different inflation rates and two different annual salt usage amounts are used in cost calculations in Figures 6.4 to 6.6, in order to capture a range of scenarios. Figure 6.4 shows the NPV after 8 years.

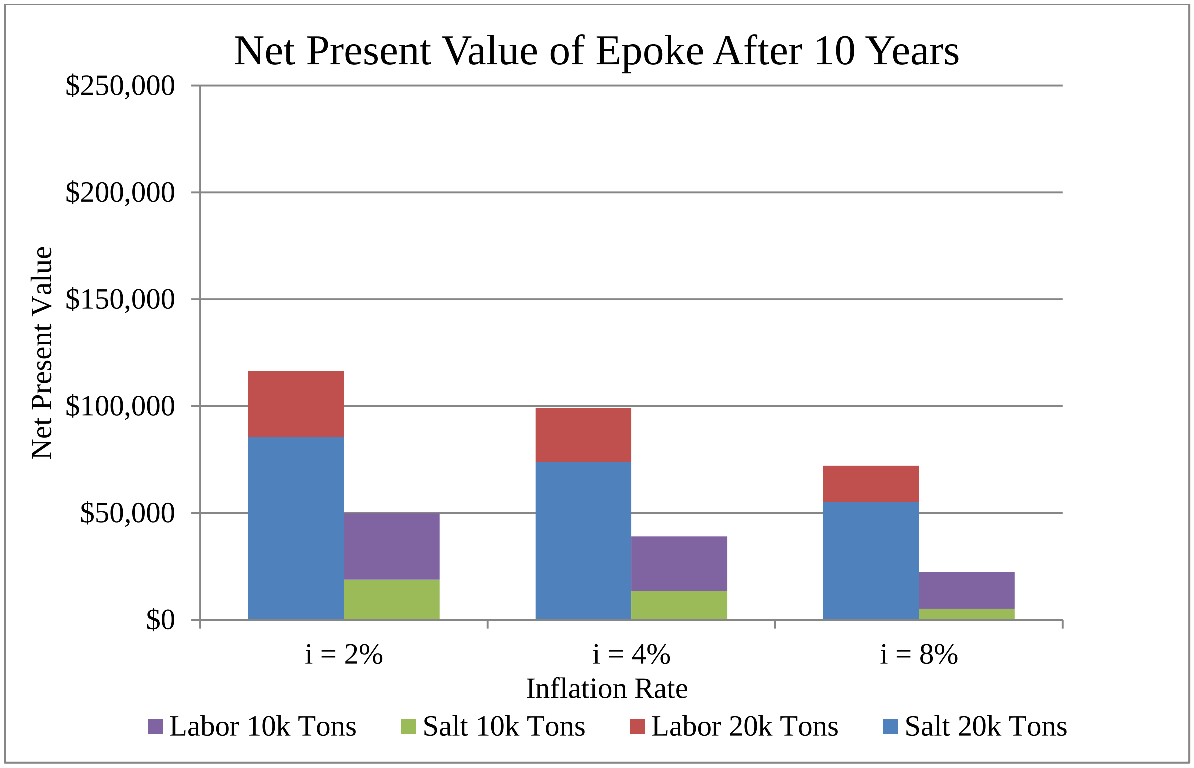


Note:
Salt Savings of 12%
Labor Rate of $17.60 /hr Straight Time
56 Winter Events at 12 Hours Each

Expenses of $77,000 – Difference in Epoke and Standard
Maintenance Difference of $580 per Year
1.6 Standard ODOT Truck are equivalent to 1 Epoke
Garage with 1 Epoke and 5 Standard Trucks
Price of Salt $37.17/ton

Figure 6.4: Net Present Value of Epoke after 8 Years.

Figure 6.4 indicates that ODOT will see a NPV between $51,500 and $150,487 for an annual salt usage of 20,000 tons and a NPV between $8,825 and $71,955 for an annual salt usage of 10,000 tons, depending on the inflation rate. Figure 6.5, shows the NPV after 10 years. The same assumptions are maintained for the NPVs under all scenarios, with only the time period being varied for each analysis.

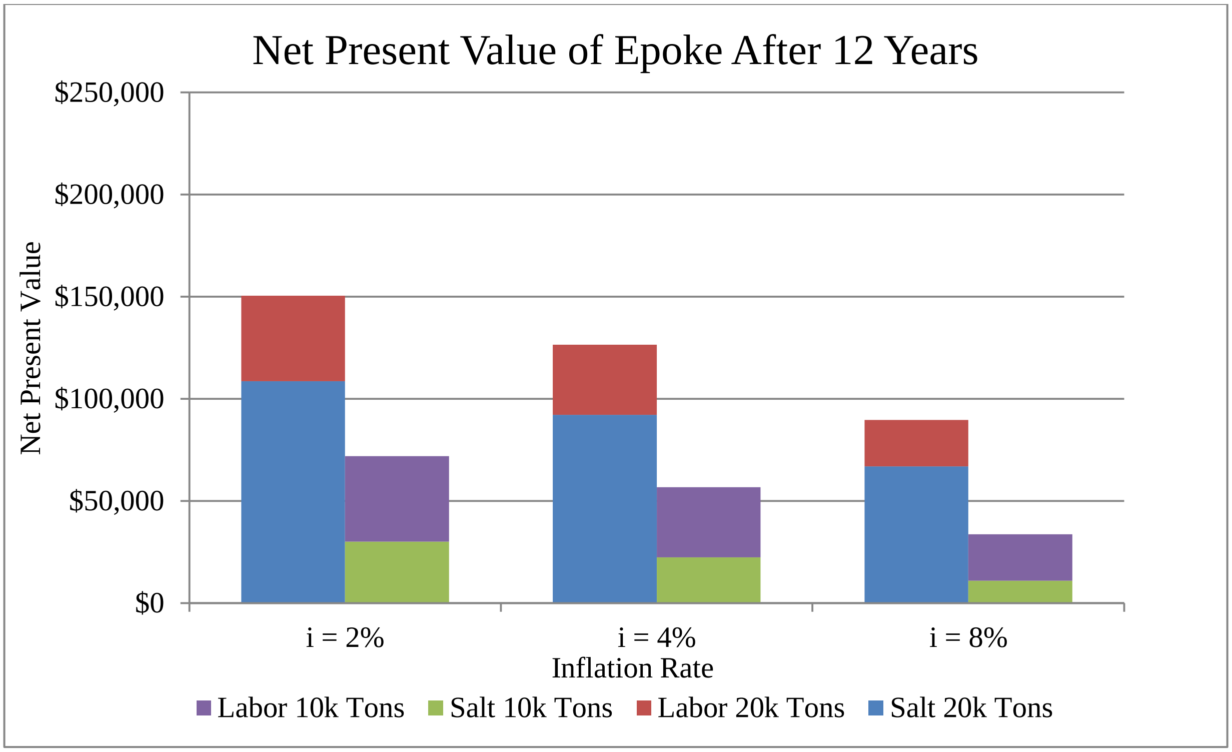


Note:
Salt Savings of 12%
Labor Rate of $17.60 /hr Straight Time
56 Winter Events at 12 Hours Each

Expenses of $77,000 – Difference in Epoke and Standard
Maintenance Difference of $580 per Year
1.6 Standard ODOT Truck are equivalent to 1 Epoke
Garage with 1 Epoke and 5 Standard Trucks
Price of Salt $37.17/ton

Figure 6.5: Net Present Value of Epoke after 10 Years.

Comparing the NPV of 8 years to 10 years, there is about a 31-37% increase for 20,000 tons per year and a 57-62% increase for 10,000 tons per year, depending on the inflation rate used. Figure 6.6 shows the NVP after 12 years.



Note:
Salt Savings of 12%
Labor Rate of $17.60 /hr Straight Time
56 Winter Events at 12 Hours Each

Expenses of $77,000 – Difference in Epoke and Standard
Maintenance Difference of $580 per Year
1.6 Standard ODOT Truck are equivalent to 1 Epoke
Garage with 1 Epoke and 5 Standard Trucks
Price of Salt $37.17/ton

Figure 6.6: Net Present Value of Epoke after 12 Years.

Comparing the NPV of 10 years to 12 years there is about a 20-26% increase for 20,000 tons per year and a 33-35% increase for 10,000 tons per year depending on the inflation rate used.

As shown in Figures 6.4 to 6.6, the more salt used annually and the lower the inflation rate, the greater the saving will be. Table 6.5 shows a summary of the NPV after 8, 10, and 12 years. This is based on the salt and time saved during the evaluation.

Table 6.5: Net Present Value of Epoke.

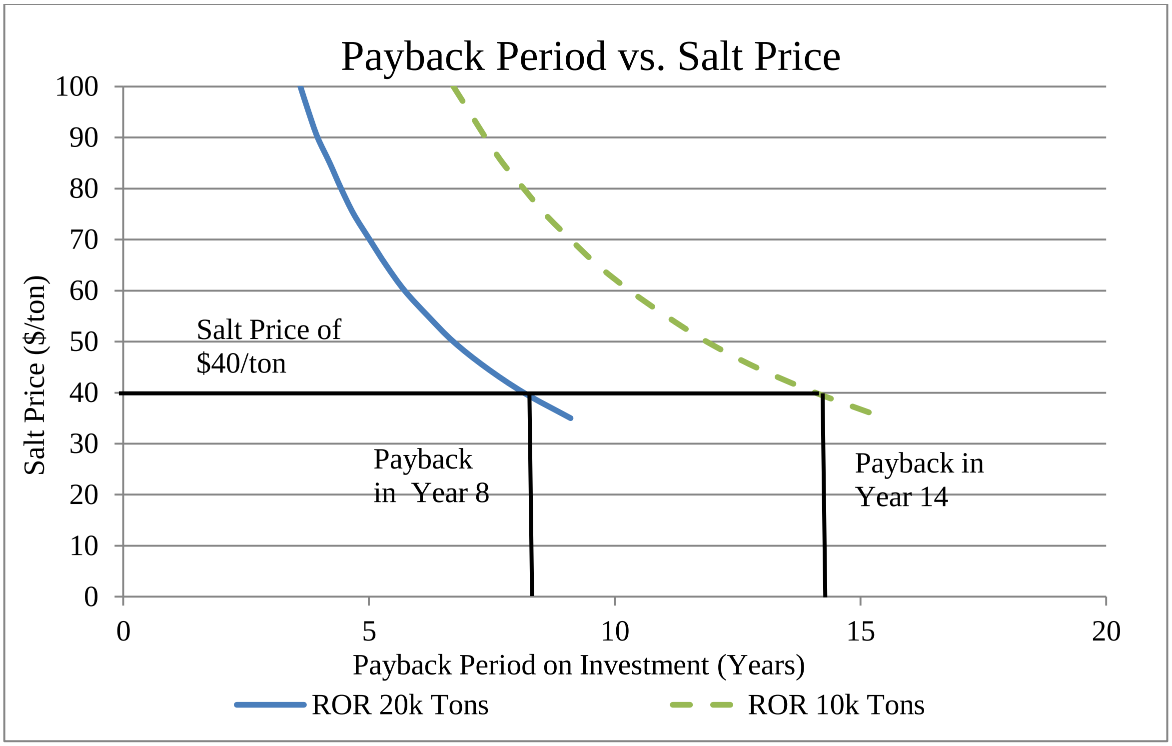
Net Present Value		
Inflation Rate	**20,000 Ton / Year**	**10,000 Tons / Year**
After 8 Years		
2%	$81,043	$26,644
4%	$69,829	$19,832
8%	$51,500	$8,825
After 10 Years		
2%	$116,453	$49,748
4%	$99,278	$39,046
8%	$72,087	$22,258
After 12 Years		
2%	$150,487	$71,955
4%	$126,505	$56,811
8%	$89,737	$33,774

Note: Salt Saving of 12%, maintenance difference of $580, price of salt $37.13/ton, and labor rate of $17.60/hr

As seen in Table 6.5, the NPV after 8 years is between $51,500 and $81,043 for 20,000 tons of salt spread per year and between $8,825 and $26,644 for 10,000 tons of salt spread per year, depending on the inflation rate. After 8 years, the Epoke will save more than the initial capital cost with an inflation rate up to 8%.

6.4.2 Payback Period

The payback period on an investment is time until money gained on an investment exceeds the amount of money invested. The investment in this case is $77,000 dollars, which is the difference in cost between the Epoke and the standard truck that ODOT currently uses, and the yearly maintenance cost difference of $580. The savings from the Epoke are based on the 12% annual salt savings and the annual labor savings found from the 1.6:1 labor savings ratio as seen in this evaluation. Figure 6.7 shows the payback period with varying prices of salt.



Note:
Inflation Rate of 4%
Salt Savings of 16%
Labor Rate of $17.60/hr Straight Time
56 Winter Events at 12 Hours Each

Expenses of $77,000 and $580 Maintenance per Year
1.6 Standard ODOT Truck are equivalent to 1 Epoke
Garage with 1 Epoke and 5 Standard Trucks

Figure 6.7: Payback Period on Epoke depending on Salt Prices.

The variables used in determining the payback period, found in the notes of Figure 6.7, are applied based on discussions with ODOT. As shown in Figure 6.7, the payback period may be seen during year eight, if salt prices are around $40/ton and the annual salt used in 20,000 tons. If only using 10,000 tons per year the payback period will be in year 14 with salt prices of $40/ton. Higher the salt prices and labor costs will result in a faster the payback period on the investment.

Table 6.6 is a summary of the payback period for the Epoke depending on the price of salt and the annual salt usage. This is based on the salt and time saved during the evaluation.

Table 6.6: Payback Period of Epoke depending on Salt Price.

Price of Salt per Ton	Payback Period Year 20,000 Ton / Year	Payback Period Year 10,000 Ton / Year
30	10.31	17.27
35	9.10	15.50
40	8.15	14.08
45	7.37	12.87
50	6.72	11.87
55	6.20	11.05
60	5.72	10.31
65	5.35	9.65
70	5.01	9.10
75	4.69	8.58
80	4.43	8.15
85	4.20	7.72
90	3.95	7.37
95	3.77	7.04
100	3.60	6.72

Note: These values are based on a salt savings of 12% and labor rate of $17.60/hr.

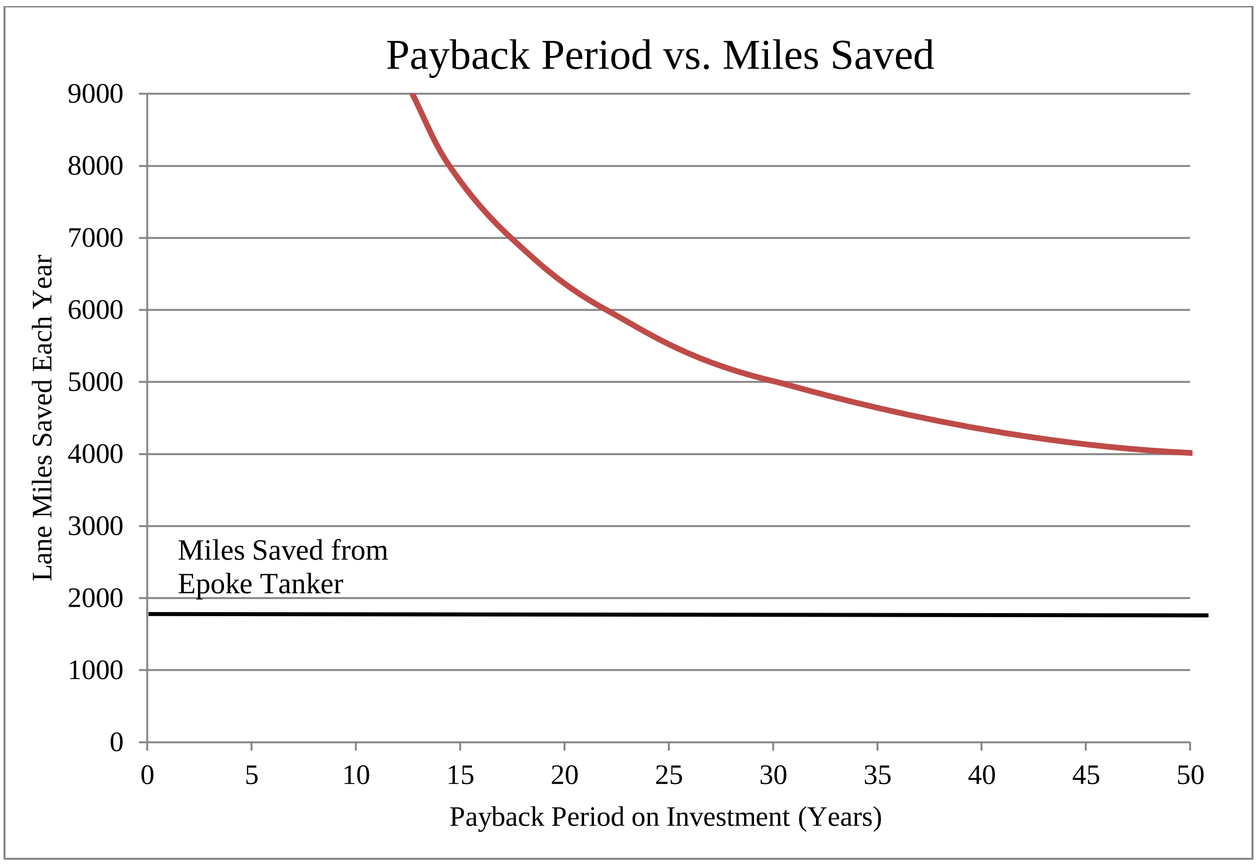
As shown in Table 6.6, the payback period will be seen during year six based on a salt price of $37.13 per ton and an operator rate of $17.60/hr. The higher the price of salt and the amount of salt used per year, the sooner the payback period will be realized.

6.4.3 Tanker Anti-icing Savings

Prior to the Epoke being installed on the tanker, it would take four trucks, including a tanker, a total of 12 to14 hours to complete anti-icing treatment of ODOT maintained roads in Summit County. With the total number of lane miles and the Epoke tanker's ability to treat multiple lanes, the number of passes that the Epoke tanker would require to treat all of Summit County is found. Using this information and the GPS data from anti-icing events, it is found that it requires the Epoke tanker 6 to 8 hours to anti-ice all of the ODOT maintained roads in Summit County. The cost benefit of the Epoke tanker includes the labor savings and fuel savings. The labor rate was set at $17.60/hr, as discussed with ODOT. The fuel savings is based on a fuel cost of $4 per gallon.

When the Epoke tanker is deployed to anti-ice Summit County roads, rather than four standard trucks, it results in a savings of $258. The Epoke tanker saves 6 hours of labor costs and $152 in fuel savings. During the previous winter, anti-icing occurred 27 times, with some of the anti-icing for bridges only. However, bridge treatments still required having trucks travel on all of the routes in Summit County. Based on the 27 anti-icing events, the Epoke tanker on the 5,000 gallon tanker truck may save ODOT $6,955 if used to treat all possible routes in Summit County during each anti-icing event. Reviewing the locations the Epoke tanker anti-icing over the 27 events, determined that the Epoke tanker saved 1,700 miles over a standard truck which only treats one lane at a time.

Figure 6.8 shows the payback period of the Epoke tanker attached to the 5,000 gallon tanker truck. The Epoke tanker is able to treat all of ODOT's Summit County routes in less time and with less fuel than is required for the four standard anti-icing trucks.



Note: Capital cost of $56,500
Labor rate of $17.60/hour
Inflation rate of 4%
Fuel cost of $4 per gallon
Tanker fuel efficiency of 5 miles per gallon

Figure 6.8: Payback Period of Epoke Tanker attached to 5,000 Gallon Tanker Truck for Anti-icing

The payback period is dependent on the number of miles saved during anti-icing in a given season. Based on the number of anti-icing events during the previous winter season as well as the operator's pay rate and current fuel costs, the payback period will not be seen. However, the Boston Heights garage expressed other benefits to having the Epoke tanker in the fleet. Due to the larger size of the Epoke tankers, it is most optimal for areas with high numbers of interstates or multi-lane highways with available turn around locations. The Epoke tanker may save a high number of miles when located in an area with many two or more lane highways. Summit County has various amounts of lanes on the roadways that ODOT is responsible for maintaining, and Table 6.7 shows the percentage of each number of lanes on roadways in ODOT Summit County.

Table 6.7: Summit County ODOT Lane Percentages.

Summit County Lanes	
1 Lane and Ramps	16%
2 Lane	26%
3 Lane	0.09%
4 Lane	43%
5 Lane	2%
6 Lane	12%
7 Lane	0.43%
8 Lane	0.46%

As seen in Table 6.7, 43% of ODOTs roadways in Summit County have four lanes. The Epoke tanker may treat four lane roadways in two passes, while the standard truck, including tankers, requires four passes. Based on the number of lanes, it is found that 84% of the roadways in Summit County may be treated more quickly by using the Epoke tanker. Some of these roadways may be less ideal to treat with a tanker based of the length and difficulties maneuvering a tanker truck. However, this would be an issue for a tanker truck with or without an Epoke attached, and the Epoke tanker may not have to make as many turnarounds as the standard tanker. Other information to consider with regards to the Epoke tanker is shown in Figure 6.9.

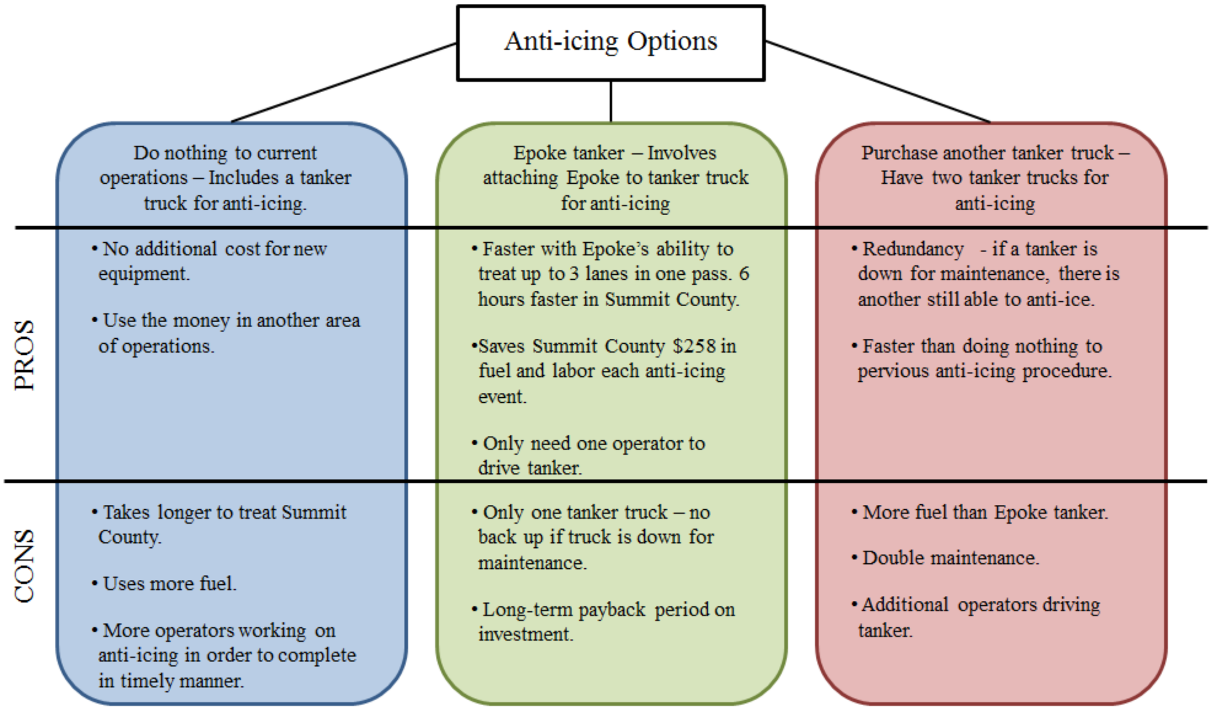


Figure 6.9: Epoke Tanker Pros and Cons List.

Figure 6.9 shows some of the potential benefits and drawbacks discussed during preliminary meetings with ODOT. Three options are analyzed: utilizing one tanker without an Epoke, placing an Epoke on the tanker, and purchasing an additional tanker for approximately the same price as placing an Epoke on a tanker. The cost of attaching the Epoke to a tanker is similar to the cost of purchasing another 5,000 gallon tanker.

As previously stated, the Epoke tanker resulted in time and fuel savings, as shown in Table 6.8.

Table 6.8: Anti-icing Savings.

Anti-icing Savings	
Hours Saved per Event	6
Labor Rate Straight Time ($/hr)	$17.60
Fuel Rate ($/gal)	$4
Fuel Saved per Event	$152
Cost Saved per Event	$258
Number of Events per Year	27
Total Cost that Anti-icing Saved	$6,955

Table 6.8 shows that the Epoke tanker saved $6,955 during this evaluation. Prior to the use of an Epoke tanker, it took four trucks a total of 12 to 14 hours to complete the anti-icing of Summit County, compared to the Epoke tanker, which only requires one operator 6 to 8 hours. However, based on the data from the evaluation, there is a long term payback period.

CHAPTER VII

IMPLEMENTATION

The proposed implementation plan includes the single Epoke that was purchased by ODOT for this project. While Epoke manufactures a number of spreaders with different capabilities and prices, the other Epoke products are not included in this implementation plan. Accordingly, this chapter is divided into five sections.

- Section One – Evaluation of M&R 661 Forms,
- Section Two – Route Optimization Model,
- Section Three – Operator Training on Use of Epoke,
- Section Four – Survey of Epoke Implementation and Training, and
- Section Five – Implementation Plan.

7.1 Evaluation of M&R 661 Forms

As previously stated in section 4.3.2, the M&R 661 is the standard form utilized by ODOT to track salt usage and winter maintenance activities. All M&R 661 forms for the past three winter seasons have been analyzed to determine operations during the period prior to implementation of the Epoke. One outcome of this analysis is the determination of the amount of time spent plowing by winter maintenance vehicles. Since the Epoke's ability to spread over multiple lanes is limited by plowing, knowing how often a truck will be expected to plow is a key piece of information. From the M&R 661 forms there are five road treatment categories:

1 – Plowing and applying chemicals,
2 – Applying chemicals only,
3 – Plowing only,
4 – Plowing back, center and turn lanes, and

5 – Roadway patrol only.

These categories are used to determine the amount of time that the trucks spend performing treatment activities in each category. Several forms have no information for road treatment, and these are left as blanks during the analysis. Figure 7.1 shows the percent time for each treatment category.

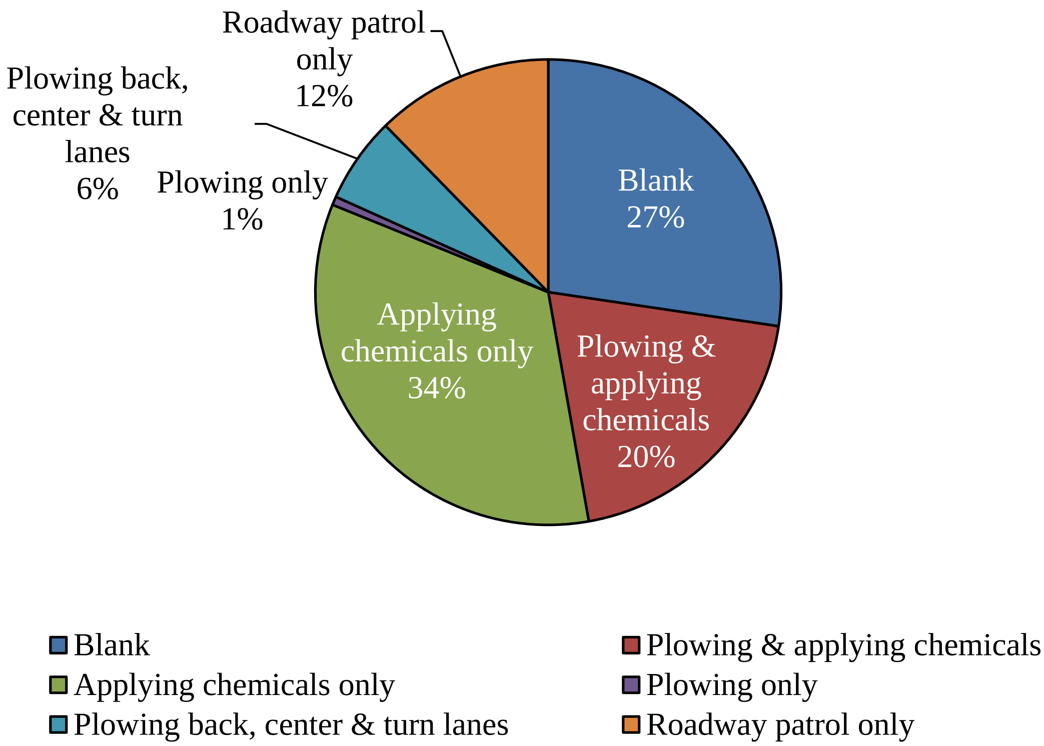


Figure 7.1: Percentage of Time Spent Performing Each Type of Road Treatment.

The amount of time spent only plowing is minimal, consisting of one percent of the time analyzed. The total amount of time plowing, including plowing while applying chemicals and plowing shoulders and additional lanes is 27%.

While the Epoke is capable of spreading material over multiple lanes, as snowfall increases it will be limited by plowing as it may only plow one lane. Accordingly, the salt reduction may still be prevalent, but the time savings will not be realized. In order to achieve the optimal use of the Epoke, it may be beneficial to exchange the Epoke with one or two standard trucks from another area when snow storms are in the forecast. By sending the Epoke to the areas at the outskirts of the storm, it will be capable of spreading material over multiple lanes while standard trucks sent to the heavier areas of the storm are able to maintain the area the Epoke is responsible for. It should be noted that plowing is not perceived as a negative impact of the Epoke, since the standard truck is only capable of plowing one lane as well, rather this suggestion is to optimize the use of the Epoke.

7.2 Route Optimization Model

To evaluate the implementation of the Epoke, the research team created a route optimization model for District 4. To describe the development of the model and the associated results, four subsections are evaluated:

- Subsection One – Development of Route Optimization Model,
- Subsection Two – Results from Initial Model,
- Subsection Three – Collection of Route Information from GPS Transponders, and
- Subsection Four – Validated Route Optimization Model.

7.2.1 Development of Route Optimization Model

The route optimization model utilized by the research team is created in ArcGIS, a computer based geographic information system (GIS) software platform produced by Esri. Within this software, there is an extension for vehicle routing amongst a plethora of other capabilities. This platform was selected based on availability, ease of use, and feasibility for implementation by winter maintenance decision makers. Complex optimization algorithms are performed in the program, and no computations or coding are required, making it more likely to be used by winter maintenance personnel.

There are several steps utilized in order to prepare the route optimization model. Initially, the map and input data layers need to be readied, which includes adding a roads dataset with extents relevant to the study area. In this case, the roads for the entire state of Ohio are used. After the roads are input, a network analyst dataset is created in order to define the edges to ensure elevation differences. For example, in two dimensions, a highway overpass appears as an intersection with the road beneath it; when the edges are used by the model, an elevation difference is applied to the two roads that allows the program to know that this is an overpass rather than an intersection. The lengths of all roads are determined, and travel times are calculated from these lengths and the speed limits of each road. Network attributes are added such as road hierarchy, one-way roads, and cost attributes. The one-way roads attribute is utilized to ensure the model does not route a vehicle in the wrong direction, while the cost attributes may add penalties for various actions such as left turns. The cost attributes are added for travel time and are minimized in order to find the most efficient route for each vehicle.

The next step of the model is to create the vehicle routing problem. The outposts and salt storage locations must be input, as each truck will be assigned to start from and return to an outpost but may refill at any salt storage location. The plowing locations must also be input, the program calls these delivery locations as the intent of the software was for delivery applications. However, by using these delivery locations the program is capable of "delivering" salt to each point, and the amount delivered corresponds to the application rate input by the researcher. This provides the capability to account for diminishing loads and may be set up to require trucks to return multiple times for multiple lane roads. Depending on the scale to which the analysis is run, routes may be defined for individual trucks or for garage outposts. Each truck or garage is input as an area in order for the program to solve the best route for each. By using the delivery locations with a specific amount to be delivered to the locations for the plows to cover, a capacity may be given to each truck so that when they have dispersed all of the salt they are required to travel to a salt storage or outpost location to refill their hopper. When inputting the truck routes, a start and finish depot must be selected for each truck.

Once the vehicle routing problem is created, it needs to be solved, and the program balances the routes based on travel times and distance traveled. There is the capability to restrict the routes to certain roads. Since ODOT maintains interstates and state routes, some restrictions were added to keep the program from routing the trucks onto lower functional class roadways. After the analysis is complete, output maps may be created within the program so that the results may be displayed for the end user.

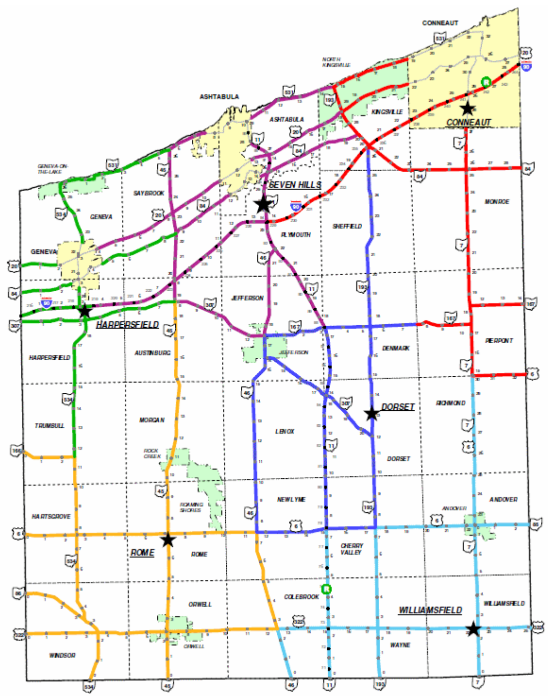
The GIS platform solves the vehicle routing problem (VRP), which consists of visits by vehicles to locations along set paths. Constraints may be applied to the locations, vehicles, and paths as described previously. The vehicle routing problem is a subset of the traveling salesman problem (TSP), which attempts to find the least costly route to visit all locations exactly once and return to the start location. The VRP requires that sets of orders be satisfied by sets of routes and vehicles, rather than by a single vehicle. The VRP must also account for the constraints created with the locations, routes, and vehicles.

7.2.2 Results from Initial Model

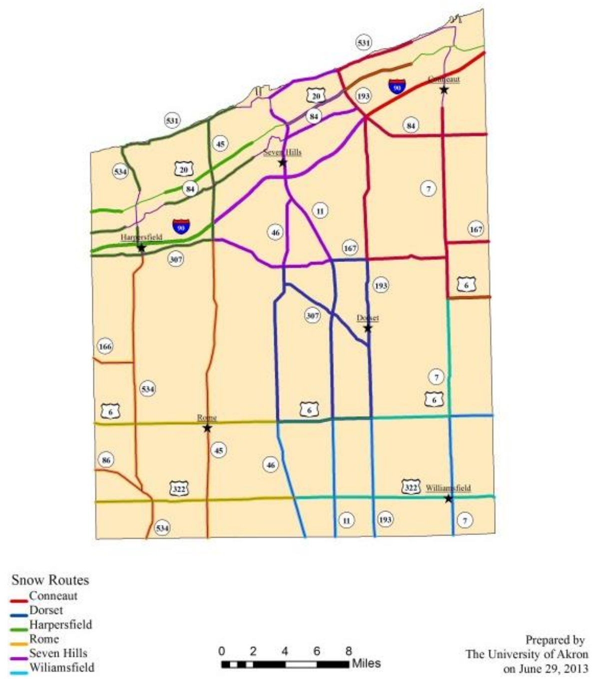
The route optimization model is run in two stages. The first stage is on a large scale, which is used to determine which routes will be maintained by which counties. The second stage is on a smaller scale, in order to optimize the routes for each individual garage. By first conducting the optimization for the entire district, the routes each county maintains are evaluated to determine if any redistribution of routes is required. When optimizing the routes for the entire district, the number of trucks currently in place for each garage is maintained. To utilize the capacity of the trucks within the model, the total capacity of all trucks for the garage is used with each route.

When running the initial model, before the winter season of 2012 – 2013, it is found that the snow plow routes for ODOT District 4 may need to be slightly altered. The initially optimized routes for each county are shown in Figure 7.2.

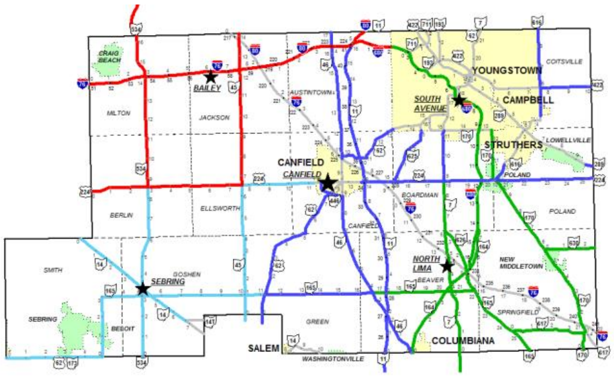
Ashtabula County Current



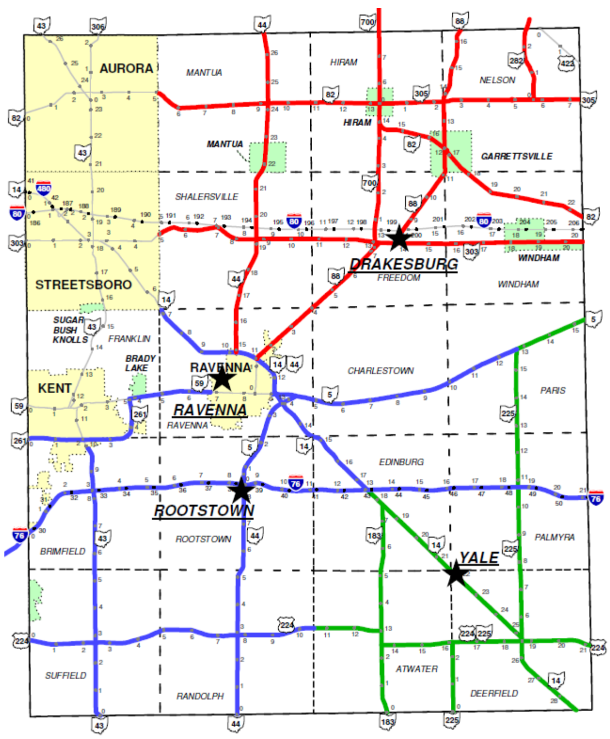
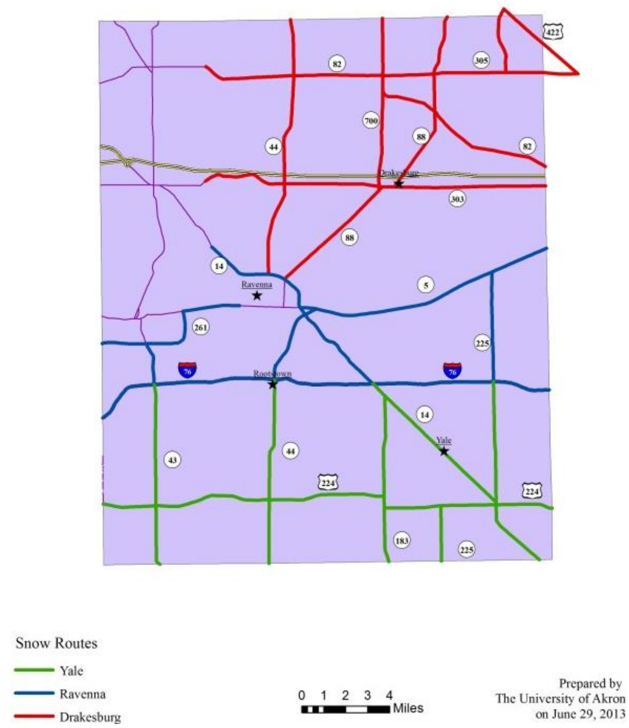
Ashtabula County Optimized



Conneaut maintains the northern portion of SR-193 and SR-167.
Harpersfield maintains the northern portion of SR-45, SR-531, and US-20.
Rome maintains SR-534.
Williamsfield maintains the southern portion of SR-46.

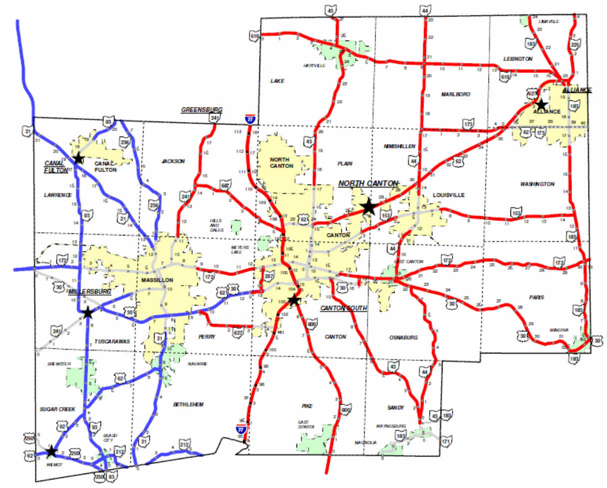
Mahoning County Current	Mahoning County Optimized
	

Bailey maintains the northern portion of SR-45.
Canfield maintains US-224 and I-80 into Trumbull County.
North Lima maintains the southern portion of SR-11.
Sebring maintains the western portion of US-224.

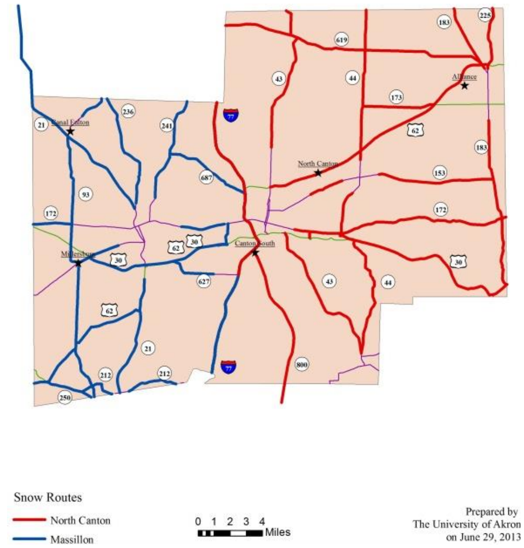
Portage County Current	Portage County Optimized
	

Drakesburg maintains US-422 and SR-305 into Trumbull County.
Ravenna maintains SR-5 and SR-225.
Yale maintains the western portion of US-224, as well as the southern portions of SR-43 and SR-44.

Stark County Current

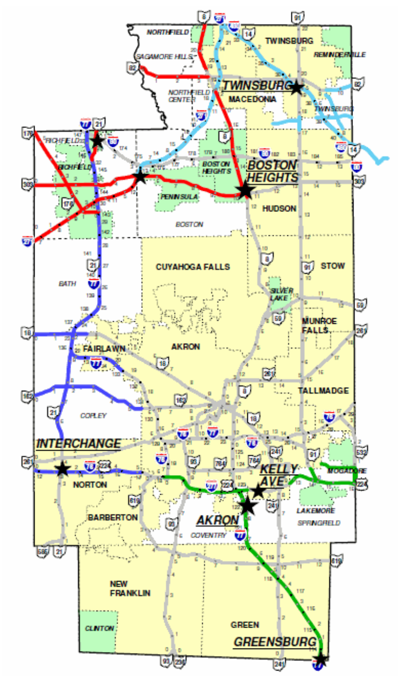


Stark County Optimized



Massillon maintains SR-172, SR-241, SR-297, SR-627, SR-687, and the southern portion of I-77.

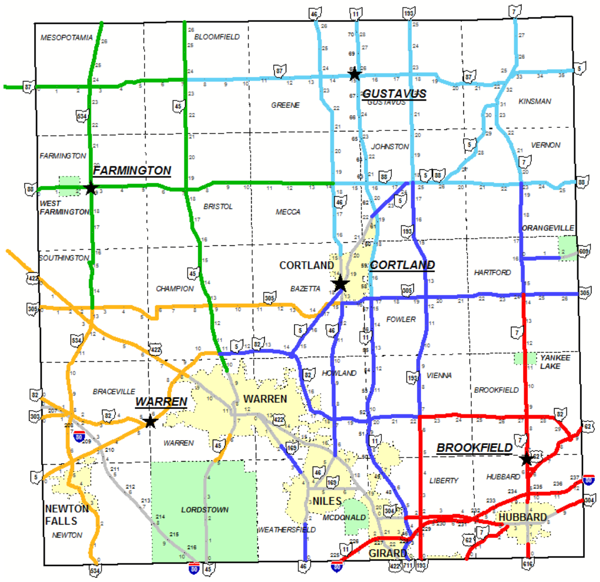
Summit County Current



Summit County Optimized

Boston Heights maintains the northern portion of I-271.

Trumbull County Current | **Trumbull County Optimized**



Brookfield maintains SR-46 and SR-169.
Cortland maintains SR-11.
Farmington maintains SR-87 and SR-305.
Gustavas maintains SR-193.
Warren maintains SR-45.

Figure 7.2: Current and Optimized Routes for Each County in District 4.

Several differences arise when comparing the current routes to the routes optimized by the model. The majority of the changes are minor and suggest that routes be redistributed amongst garages within a county. However, the model indicates that Mahoning County should maintain I-80 into Trumbull County and that Portage County should maintain US-422 and SR-82 into Trumbull County.

Along with optimizing the routes for District 4, this research team evaluated the cycle times required to maintain the routes in Summit County. The focus centered on Summit County, as this is the area where the Epoke will be utilized. Initially, the cycle times are found based on the time it takes a vehicle to traverse a section of roadway and the increased times for snow plows to turn around. The route cycle times are shown in Figure 7.3.

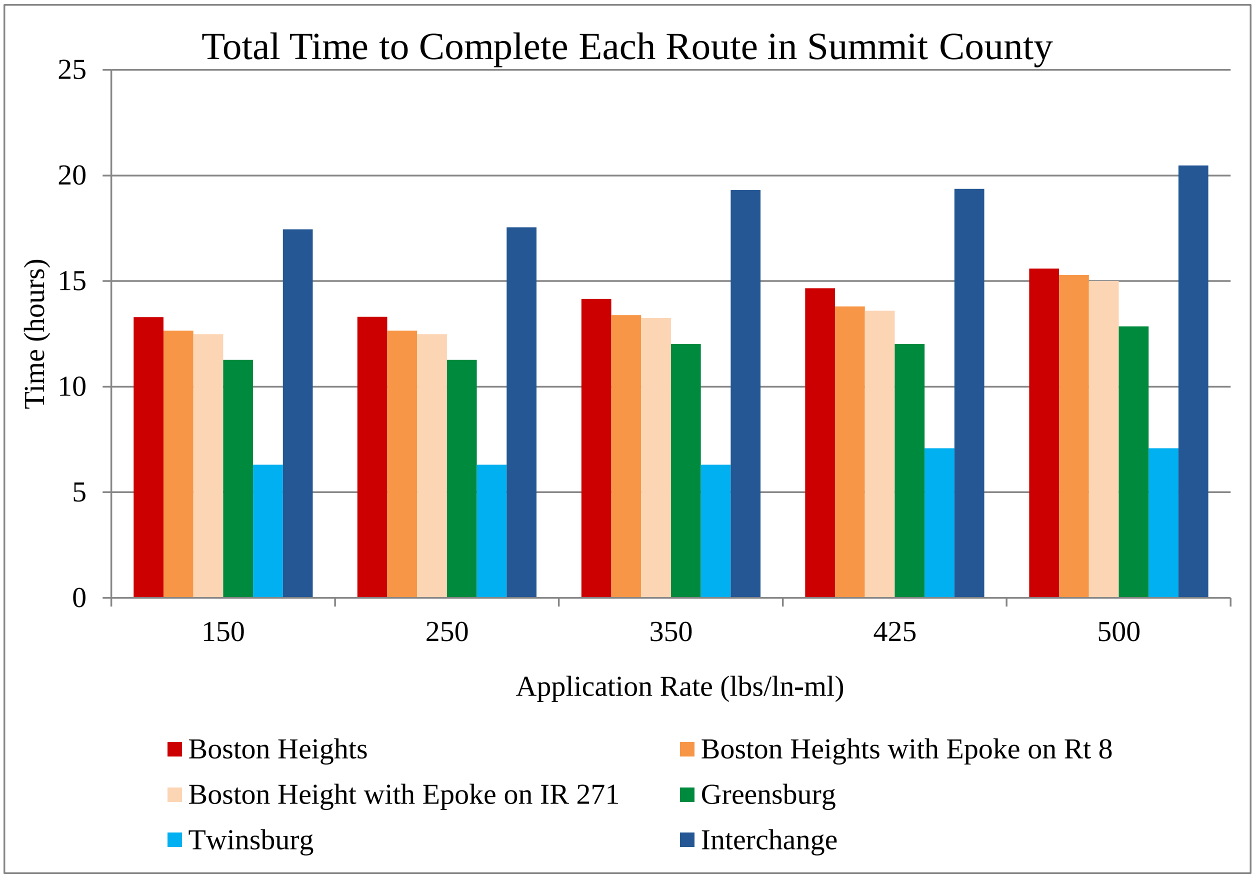


Figure 7.3: Initially Optimized Route Cycle Times.

The times shown in Figure 7.3 represent the total number of man-hours required to clear all the routes for each garage in Summit County. Simply stated, routes with a total time of 15 man-hours for a garage with five trucks would require only three hours to maintain. As the salt application rates of the trucks increase, the total time required for trucks to clear the routes is increased, which is a result of trucks needing to travel to a salt outpost to reload with additional material. One aspect of the cycle times reported from the model is that they are based on a computer model rather than on real world conditions. Accordingly, the research team validated the times by placing GPS units in plow trucks to record all the routes.

7.2.3 Collection of Route Information from GPS Transponders

After the initial model is created, several trucks are equipped with portable GPS units to track the order in which routes are maintained and the total time required to clear the routes. By tracking several trucks, the research team is able to correct any anomalies and to validate the model. GPS data are collected from four trucks in the Boston Heights ODOT outpost for the entirety of the 2012-2013 winter season. This has provided the research team with ample amounts of truck routing data encompassing 29 snow events. All routes for Summit County are also driven under normal conditions, i.e. no snow event, with the operator driving as if they were clearing the snow and ice route to conduct further comparisons.

The GPS units selected for this study are able to output the data to .kml and .csv files, which the research team uses to evaluate the data in Google Earth and ArcGIS, respectively. No data processing is required to prepare the data for Google Earth, and minimal processing consisting of adding an extra time field is required for ArcGIS. The data collected from the GPS units provides the research team with the speed and location of the plow trucks at any given time, which is used to determine the order in which routes are cleared and the times needed to clear the routes.

The researchers project the routes in ArcGIS and use the attribute table and visual location of the data points to determine the amount of time spent on each route. A matrix is created that contains each outpost and its associated routes as well as the time required to maintain each route. Since the routes are tracked for 29 events, multiple times are found for each route, and the average of these times is implemented in the route optimization model. By recording the routes of the snow plow trucks, the researchers are able to apply actual cycle times to the computer models. The results from Summit County are extrapolated and applied to the other counties based on similar characteristics amongst the areas. This provides a real world justification aspect that is utilized to ensure the accuracy of the route optimization model. When the models are validated, the results are more applicable and buyin is increased from end users.

The GPS data are analyzed in order to determine the actual amount of time required to maintain each route and the amount of time required for the trucks to turn around when making successive passes on certain routes. Since multiple times are recorded for each route, the average time is used in the model. When comparing the initial cycle times to the data from the GPS units, it is found that the model is reporting times 30% longer than the actual times on average. This indicates that the model needs to be updated and the total times need to be reduced by 30% based on the GPS data.

7.2.4 Validated Route Optimization Model

Based on the GPS data recorded from the 29 winter events, the initial model is updated and validated based on the more accurate cycle times. Once the GPS data are analyzed, the validated cycle times are utilized to update the model. All parameters of the model are held constant with the exception of the times required to complete.

One interesting discovery is that with the new time inputs, the optimized routes did not change from the initial optimization. However, the resulting cycle times for Summit County did change and are shown in Figure 7.4.

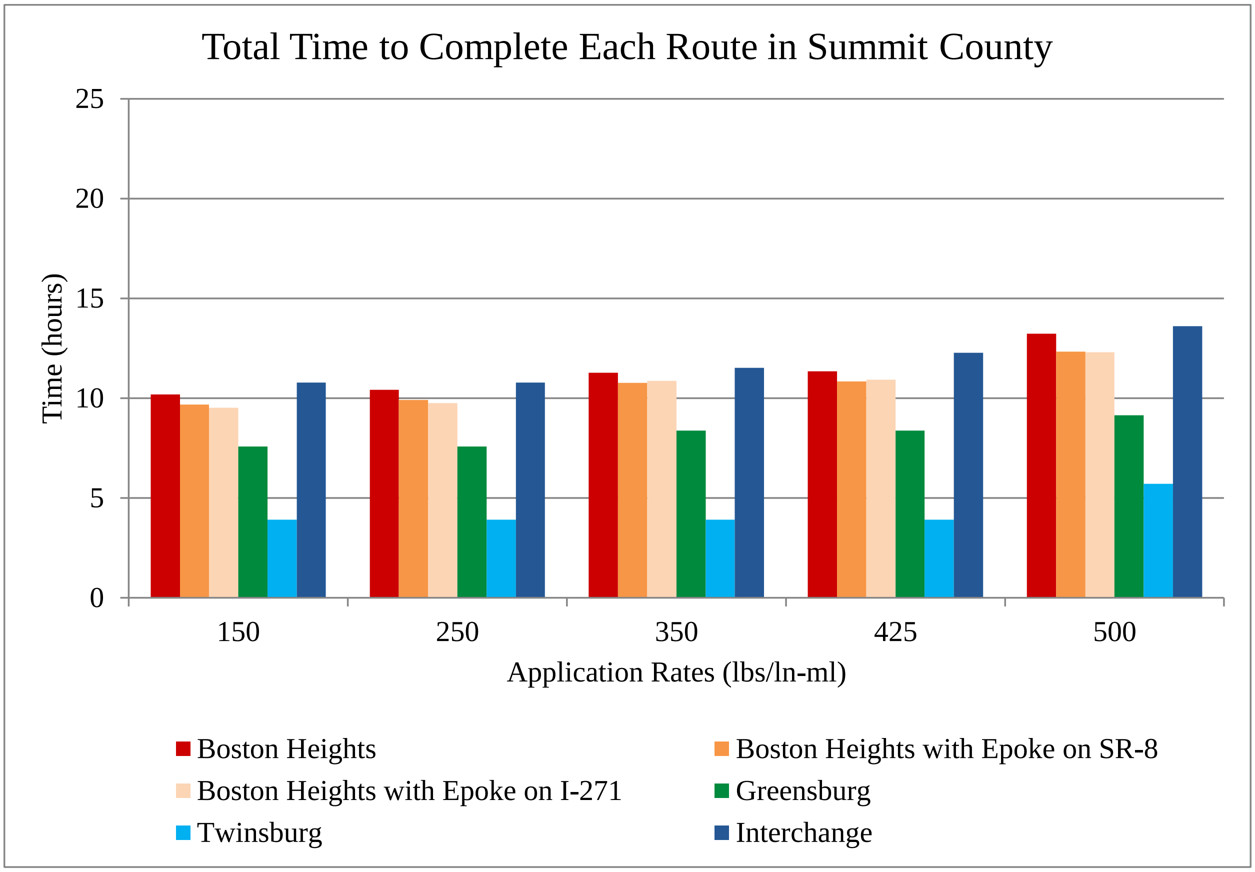


Figure 7.4: GPS Validated Routes Cycle Times for Summit County.

This figure shows that the larger time savings for the Epoke occurs when it is used for maintaining I-271; there is also a time decrease when it maintains SR-8, but it is not as large. The greatest change from the initial model is noted for the Interchange garage, which is likely due to the fact that the garage is responsible for maintaining the most lane miles in Summit County. Since all the cycle times are decreased, the largest impact is in the area maintaining the most lane miles. By validating the computer model with GPS data, the researchers are able to provide more real world analysis of the routes as well as to ensure the accuracy of the cycle times.

In addition to the cycle times, the model is utilized to provide the total salt applied at the different application rates. The total salt applied is found for both the initial model and the validated model, and since they are based on the lane miles treated, the results remained constant between the two models. The total salt applied by each garage in Summit County is shown in Figure 7.5.

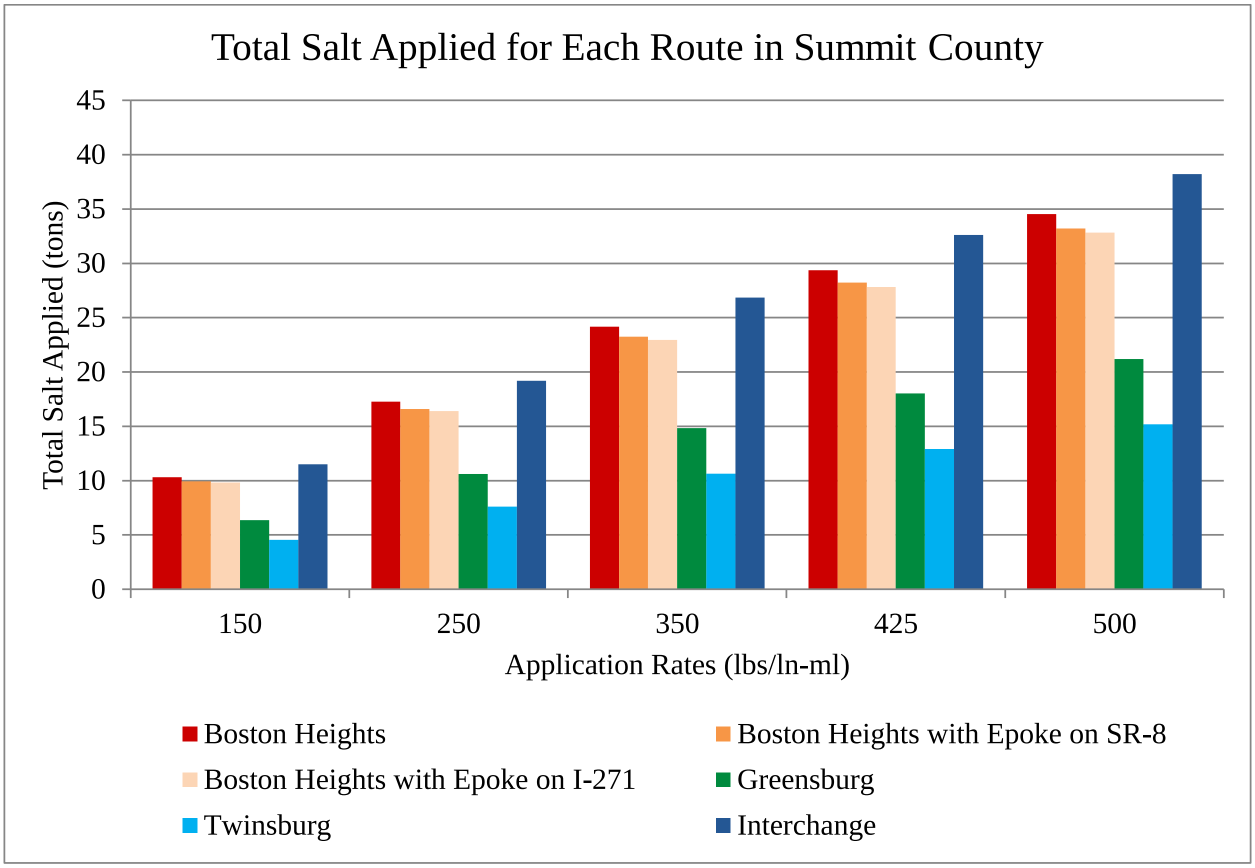


Figure 7.5: Total Salt Applied in Tons to Each Route in Summit County.

The total salt applied varies for Boston Heights depending on where the Epoke is deployed within the model. The salt reduction reflects the 12% salt savings found by the Epoke in the study. Figure 7.5 may be used as an index to determine the amount of salt utilized to maintain the routes based on the operators' application rates, which may be related to storm severity.

The model created by the researchers optimizes the snow plow routes for ODOT District 4, as well as provides the total cycle times to complete each route and the total salt applied for various application rates in Summit County. By using several application rates, the model may be applied to various storm intensities by using higher application rates for more severe storms. Since the model is based on user inputs, it must be validated in order to check the accuracy of the results, which in this case is accomplished through the analysis of GPS data collected from snow plow trucks for 29 winter events. Through the analysis of the resulting GPS data, it is found that the cycle times from the initial model are

30% higher on average than the actual routes. Accordingly, the model is updated based on the GPS data and the analysis is conducted again with the validated cycle times. By validating the model, the researchers are able to provide analysis with highly applicable results.

7.3 Operator Training on Use of Epoke

Adequate training is crucial to the successful implementation of all new equipment, including the Epoke. At the beginning of the project, initial training is provided by Epoke and Bell Equipment Company, and continuous training is provided to operators throughout the course of the study.

It is beneficial to train operators that will use the Epoke, which may include all the operators at a garage with an Epoke. It is typical for ODOT to have operators use the same truck throughout the season, but it is not uncommon for an operator to periodically be assigned to a different truck. This emphasizes the need to ensure that every operator is properly trained and aware of all the functions of the Epoke.

This section discusses operator training in detail, and it is separated into two subsections:

- <u>Subsection One</u> – Key Topics of Training and
- <u>Subsection Two</u> – Techniques for Training.

7.3.1 Key Topics of Training

There are several important topics that will need to be addressed during the training sessions, including:

- The Epoke theory,
- The basic controls of the Epoke,
- Awareness of over treating,
- Typical application rates, and
- Utilization of the Epoke when plowing.

These topics areas are summarized in Figure 7.6.

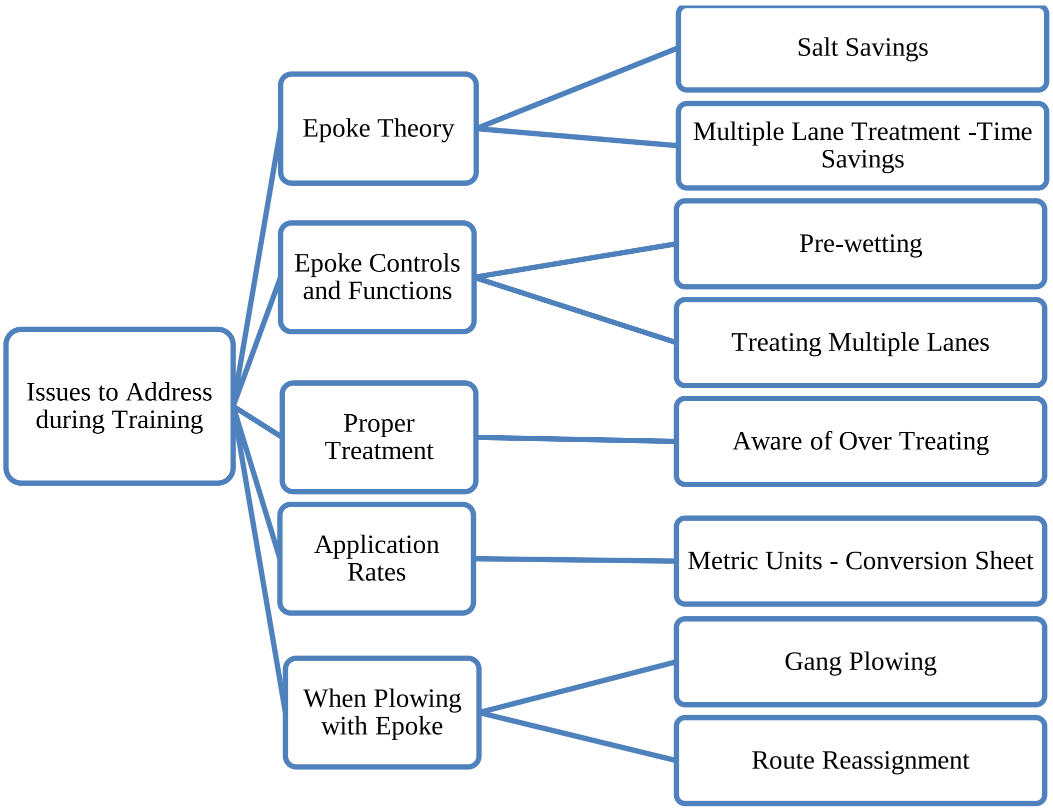


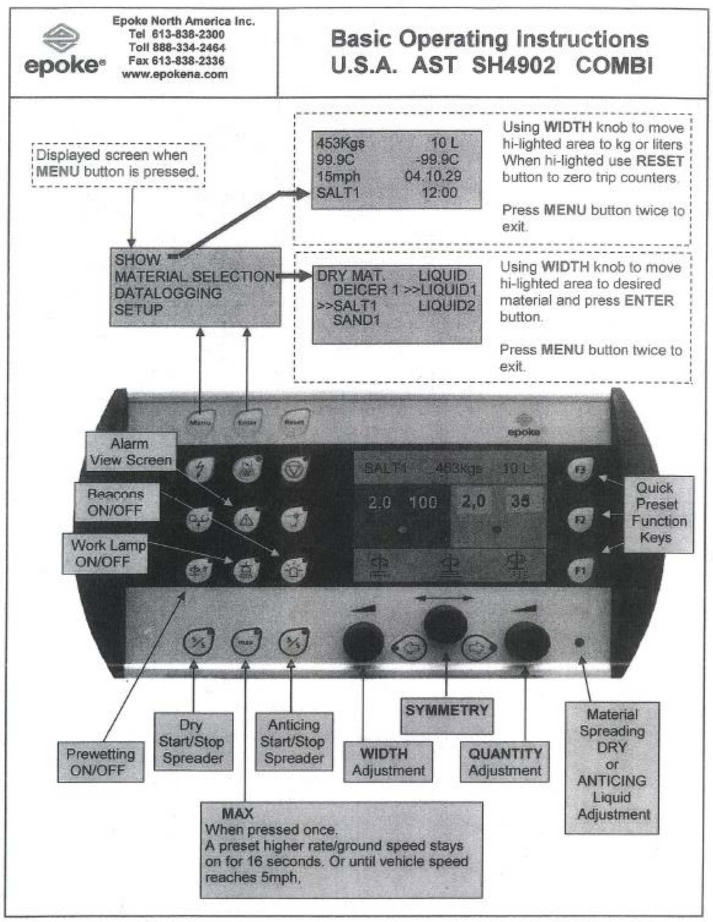
Figure 7.6: Issues to Address during Training.

It is critical to the success of the Epoke that the operators understand the theory behind the Epoke. The Epoke will only save salt and time if it is properly utilized, which requires operator buy-in regarding the Epoke theory and system capabilities. Some key concepts that operators need to be aware of include the following:

- The Epoke's ability to crush salt, allowing the salt to activate more quickly and stick to roadways,
- The Epoke's pre-wetting ratio, which will replace up to 30% of the dry salt. The operator should know how much liquid is being used for pre-wetting in order to estimate the amount of additional liquid required to properly treat the roadway,
- The liquid application rate, which is additional liquid being spread on top of the already pre-wetted salt, and
- The proper procedure for treating multiple lanes while operating through traffic. The general public should be notified of the new equipment being implemented to help decrease any confusion that may occur during operations.

The EpoSat system may help new drivers adjust to the Epoke more quickly. The EpoSat is capable of guiding operators on the recorded routes with the standard applications rates being automatically applied.

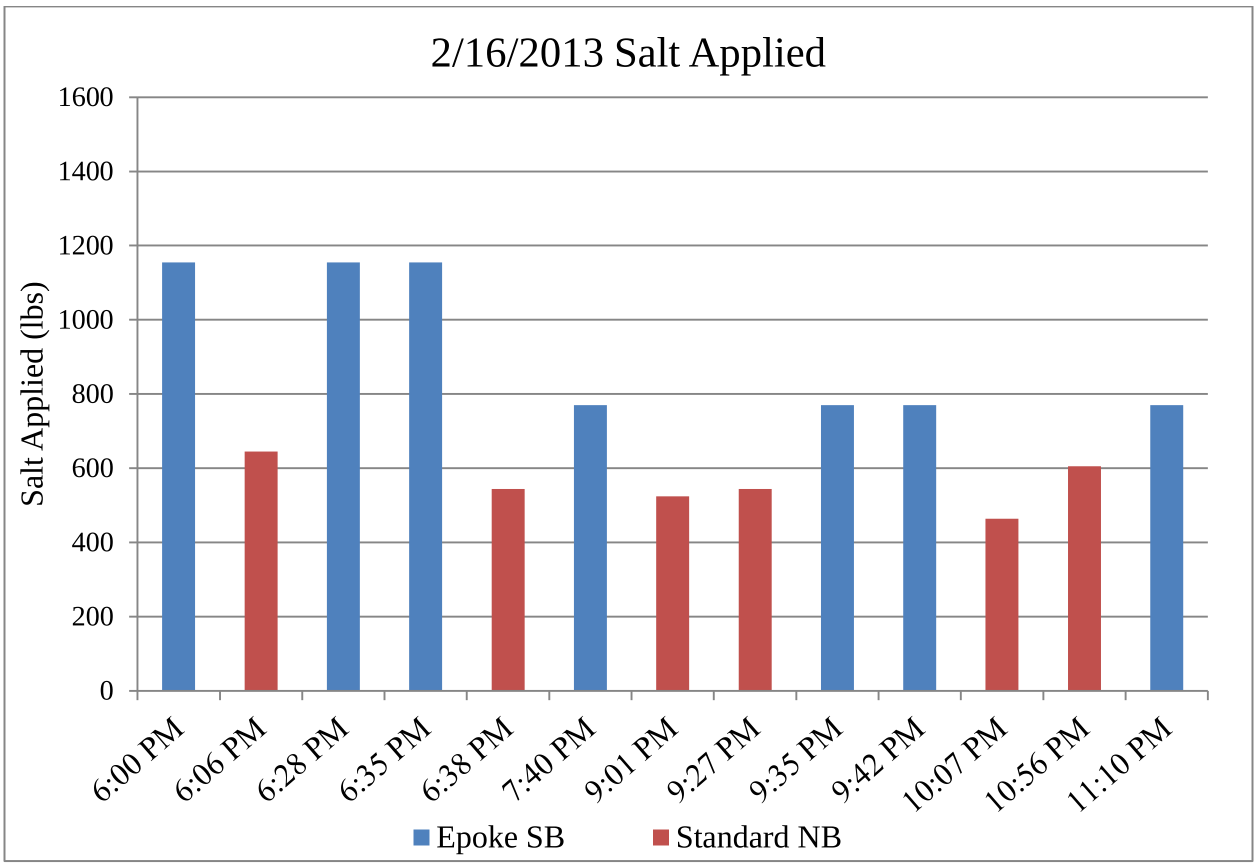
All operators that will use the Epoke need to be trained on the controls and unique functions of the system. The controls, which differ from a standard truck, include separate application rate settings for the dry material and the liquid material. The Epoke has the ability to replace up to 30% of the salt by weight with liquid through the use of the pre-wet button; at ODOT this liquid is usually brine. The operator should be aware of the value for the pre-wetting ratio, as it may be adjusted between 5% and 30%. The desired ratio should be discussed with the garage manager. Throughout this study, the pre-wetting ratio was set at the maximum of 70:30, allowing for increased liquid usage. When using "combi" spreading which is salt, pre-wetted or dry, with liquid applied as well, the operators need to manually decrease the dry application rates to account for the additional liquid being used. The Epoke controller with labels is shown in Figure 7.7.



Note: Figure Provided by Epoke. ODOT keeps copy in Epoke for reference.
Figure 7.7: Epoke Controller with Controls Labeled.

The operators at the Boston Heights garage placed labels above the screen to indicate which rate corresponds to dry and liquid material. The Epoke will record the total amount of material used at the top of the screen and the application rates will appear in the middle of the screen. The material may be spread over one, two, or three lanes, and the direction of the spraying may be varied between left, right, or directly behind the truck. The bottom of the screen will display the number of lanes and the direction of treatment, which may be changed by using the controls below the screen. The plow is controlled by a separate control panel which is located beneath the Epoke control panel.

One issue that arose during the study is overuse of the Epoke when compared to the standard truck. The most severe occurrence was on February 16, 2013, which is otherwise a good comparison day in that the Epoke and standard trucks treated opposite directions of the study zone. The amount of salt applied by the Epoke and the standard truck in the study zone is shown in Figure 7.8.



Note: Times corresponded to when the study zone was treated.

Figure 7.8: Total Salt Applied by the Epoke and Standard Truck on February 16, 2013.

To summarize Figure 7.8, Table 7.1 shows the total amount of salt applied by each truck.

Table 7.1: Total Salt Applied by Each Truck on February 16, 2013.

	Epoke Salt Used in Study Zone (lbs)	Standard Truck Salt Used in Study Zone (lbs)
NB	0	3,326
SB	6,544	0

The Epoke treated seven times in the study zone, while the standard truck treated six times. Based on the similar number of treatments, it is expected that the total salt applied will be similar. However, the Epoke applies twice as much salt as the standard truck due to the fact that it is capable of treating multiple lanes. If the Epoke is spreading over multiple lanes, it should require fewer passes than the standard truck to treat. However, when plowing of the roadways is necessary, the Epoke should spread over one lane to avoid plowing off the material spread on the previous pass.

This day highlights the importance for training, since the Epoke is capable of over-applying salt. The vehicle speeds from this day are shown in Figure 7.9.

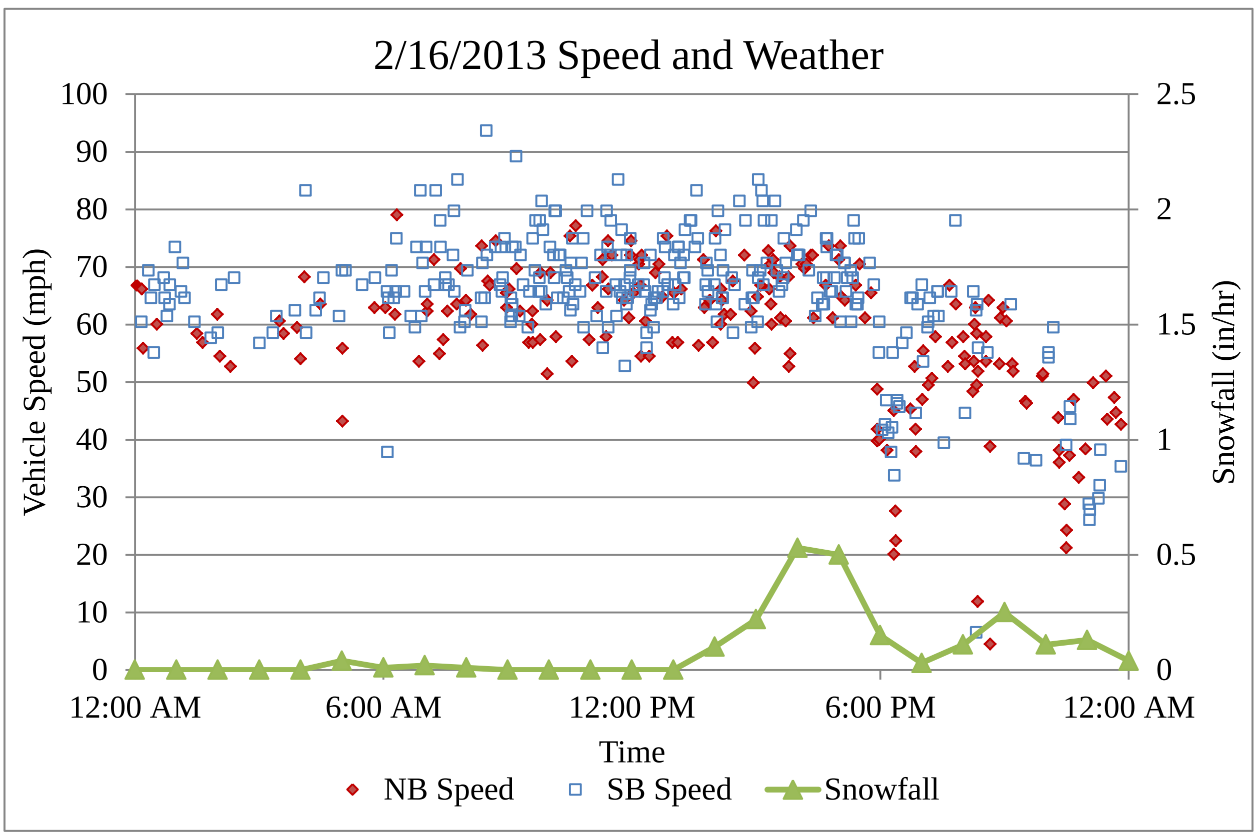


Figure 7.9: Vehicle Speeds on February 16, 2013.

Figure 7.9 shows that the vehicle speeds are similar in both the northbound and southbound directions, with the average speeds during the snow events of 63 mph and 64 mph in the northbound and southbound directions, respectively. This shows despite applying twice as much salt as the standard truck, there is no significant improvement in vehicle speeds in the direction maintained by the Epoke.

The units on the Epoke are metric, which differ from the imperial units on the standard ODOT trucks, so it is important for the drivers to understand how much material is being applied to the roads. Table 7.2 shows several conversions for dry and liquid material application rates.

Table 7.2: Epoke Unit Conversion Table.

Dry Material		**Liquid Material**	
g/m^2	**lbs/ln-ml**	**ml/m^2**	**gal/ln-ml**
1	10.6	1	1.3
9.4	100	3.9	5
14.1	150	7.7	10
18.8	200	11.6	15
23.5	250	15.4	20
28.2	300	19.3	25
32.9	350	23.2	30
37.6	400	27.0	35
42.3	450	30.9	40
47.0	500	34.7	45

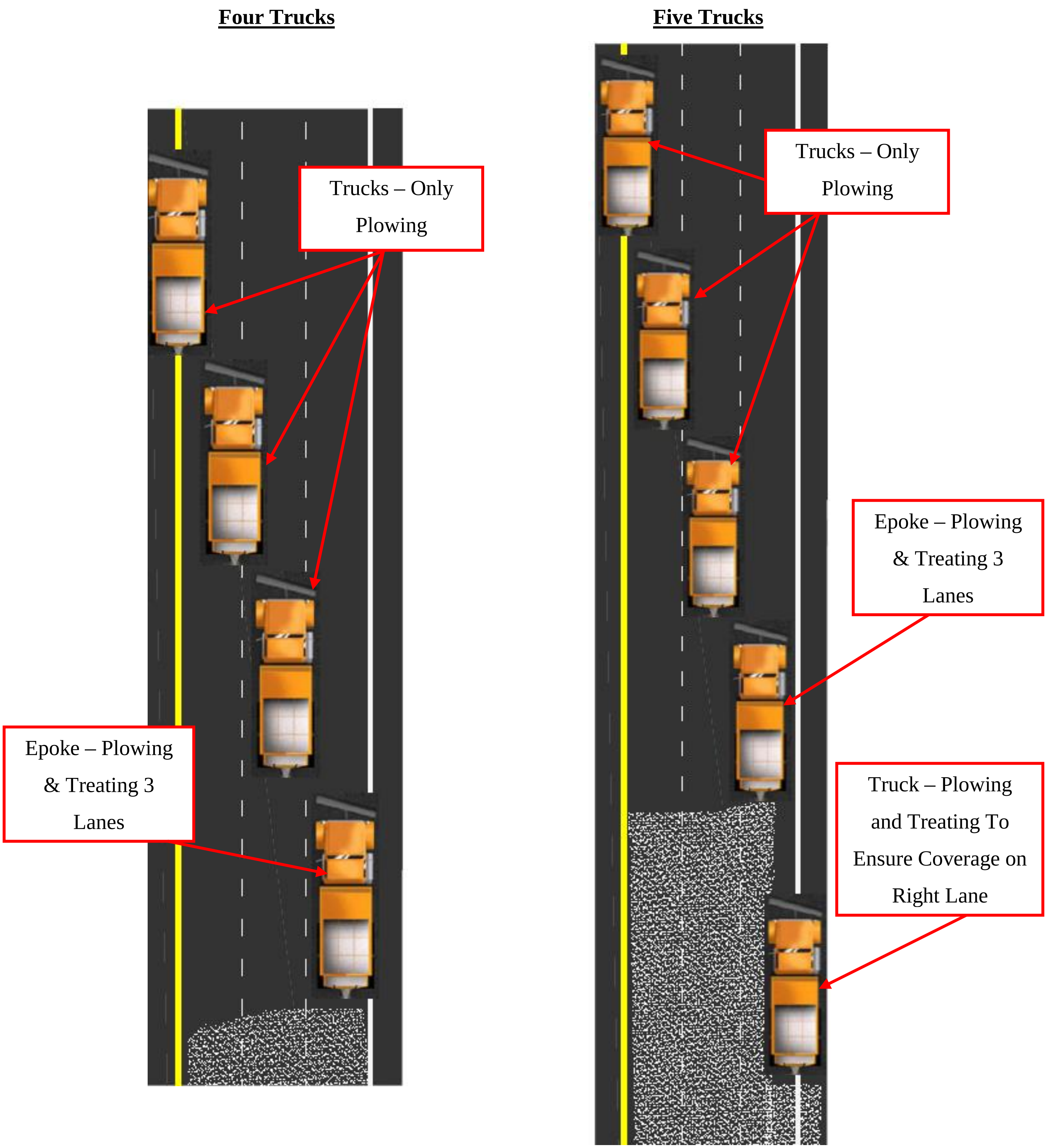
A standard conversion sheet should be placed in the Epoke, similar to the Table 7.2 above. Table 7.3 shows different application rates used over the 2012-2013 winter season at the Boston Heights garage.

Table 7.3: Sample Application Rates of Epoke and Standard Truck.

	Epoke		Standard	Snowfall		
Date	Dry (g/m^2)	Wet (mL/m^2)	Pre-wet (lbs/ln-ml)	Average (in/hr)	Total (in)	Classification
12/26/2012	23	27	300	0.82	10.72	Heavy
1/21/2013	23	24	300	0.03	0.48	Light
1/25/2013	23	24	250	0.27	2.57	Moderate
2/16/2013	23	25	275	0.20	2.17	Moderate
2/17/2013	18	20	250	0.04	0.58	Light
2/22/2013	18	20	230	0.12	0.36	Light
3/13/2013	9	16	150	0.05	0.32	Light

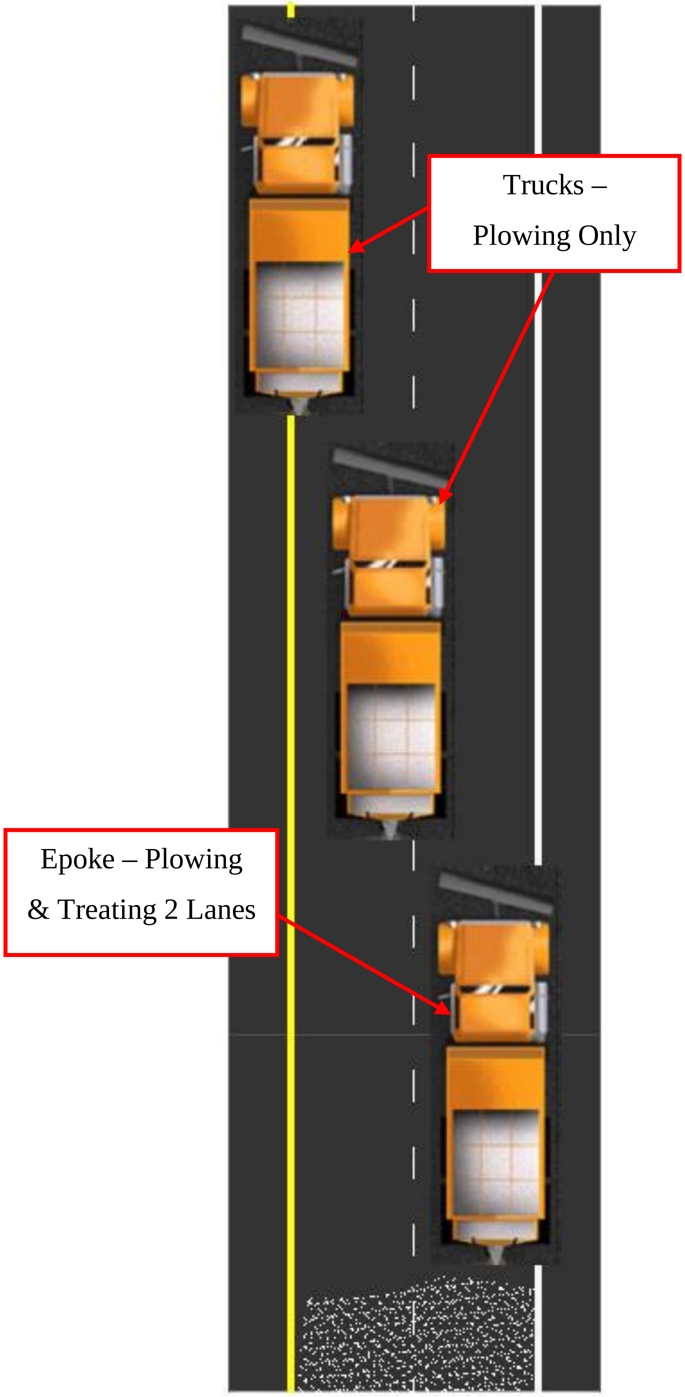
As previously stated, it is very easy to over treat with the Epoke, undermining the benefits. Table 7.3 may help operators realize the equivalence of the two trucks application rates and should be used along with proper routing. It is ODOT’s policy to allow their operators to apply the amount of material they feel is needed to provide safe travel conditions to the public; however, the operators that are not accustom to using an Epoke may need some guidance in appropriate application rates until they become more familiar with the system.

Though the Epoke may treat multiple lanes in a single pass, it may only plow one lane at a time. When plowing, the salt savings would still be realized, but the time savings would be minimized. One possible implementation of the Epoke during plowing is to gang plow with the Epoke as the last vehicle treating multiple lanes. Gang plowing consists of aligning multiple trucks on a segment of highway to plow all lanes at the same time. When the Epoke is stationed in the back of the alignment it may treat up to three lanes at once without the risk of any material being plowed off by another truck. Figures 7.10 show the optimal alignment for gang plowing with the Epoke on three lanes with four or five trucks in the alignment. Figure 7.10 shows gang plowing with four trucks includes the Epoke in the back of the right lane while three other trucks are ahead of the Epoke in the middle, left, and left shoulder lanes. Figure 7.10 shows gang plowing with five trucks includes the Epoke plowing the right lane while treating three lanes. The last truck in the alignment is treating and plowing part of the right lane and the right shoulder, which will ensure that the right lane is properly treated despite any of the Epoke’s material being plowed off while plowing the right shoulder.



Note: This image was accessed from www.epokena.com and modified.
Figure 7.10: Gang Plowing with the Epoke on a Three Lane Roadway.

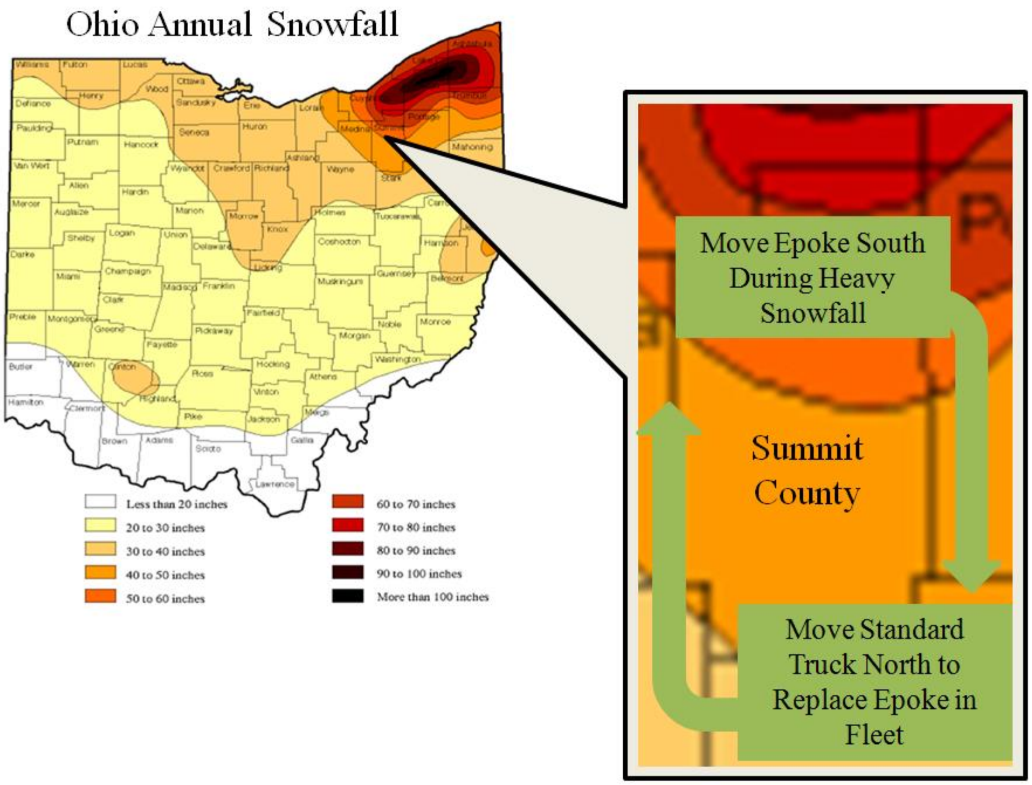
Figure 7.11 shows the optimal alignment with the Epoke on a two lane roadway when gang plowing.



Note: This image was accessed from www.epokena.com and modified.
Figure 7.11: Gang Plowing with the Epoke on a Two Lane Roadway Using Three Trucks.

As shown in Figures 7.10 and 7.11, the Epoke is able to treat the lanes in one pass and the material is not being plowed off by other trucks. With the Epoke as the only vehicle treating in most of the scenarios, it will likely run out of material more quickly than the other trucks. While the Epoke is refilling, the other vehicles may continue to maintain other areas or ramps.

The Epoke may be reassigned to different locations and routes depending on the weather. Since the Epoke is limited by its ability to plow a single lane, moving the Epoke to an area that may be receiving lower amounts of snowfall will help to optimize the savings of the Epoke. Coordination between nearby garages will be necessary to determine where the Epoke should be reassigned and to ensure that a standard truck is taking the Epoke's place in its usual fleet. Figure 7.12 shows the reassigning of the Epoke.



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

Figure 7.12: Reassigning the Epoke during Heavy Plowing Storms.

To reduce deadheading, or the amount of time spent traveling without plowing or treating, the Epoke should move to a garage within 20 or 30 miles. As shown in Figure 7.12, northern Summit County receives higher annual snowfall while areas to the south receive much less snow. During these events, reassigning the Epoke to the areas with less snow will help the time savings that the Epoke offers while treating. ODOT has indicated that reassigning the Epoke is beneficial in a county with only one Epoke, and that gang plowing is more realistic if there is an Epoke at each garage or outpost.

7.3.2 Techniques for Training

There are many options that may be employed to train the operators in the proper use of the Epoke, including both classroom and field training. Classroom training would be best for informing the operators of the Epoke theory, ways to prevent over treating, gang plowing with the Epoke, and common application rates. PowerPoint presentations and posters are excellent ways to visually train operators in a classroom setting. Posters may be displayed in the garage area after the presentation as a reminder to the operators. Figure 7.13 shows an example of a poster created during this study to train the operators.

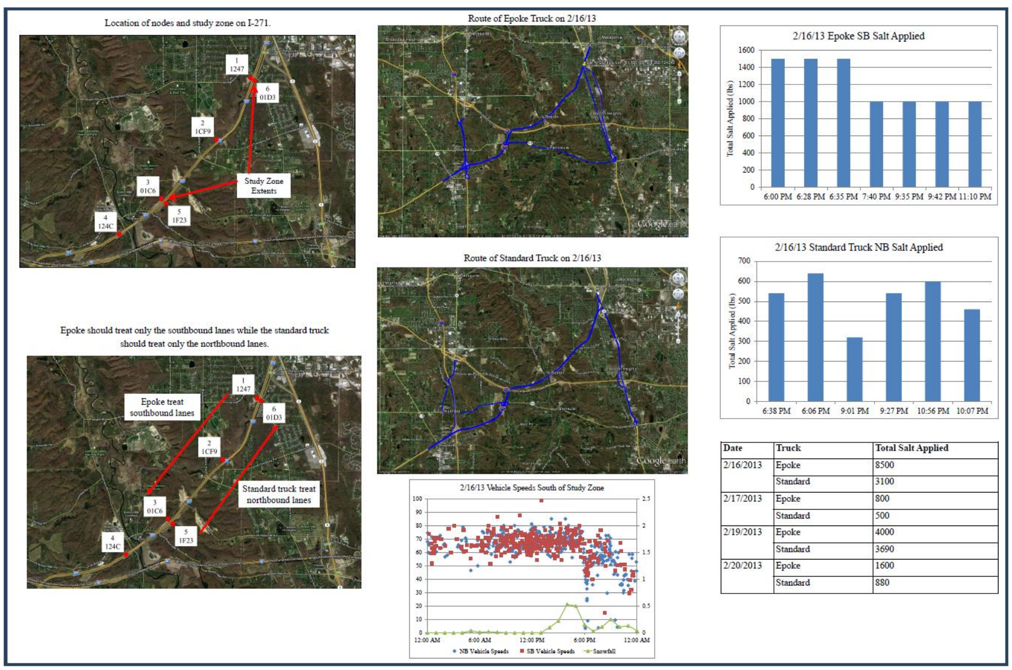


Figure 7.13: Sample Poster used for Training during Evaluation.

Figure 7.13 shows a poster that was created to address some of the key issues that surfaced during this evaluation. This poster visually shows the event in which over treating occurred and the proper route that the Epoke needs to be treating. With any visual aid, there needs to be a meeting held to discuss the context of the poster and allow the operators to ask questions and voice any concerns. Some key factors to consider when creating a visual aid are:

- Include large, clear pictures and figures,

- Clearly represent any objectives,
- Limit the content – the majority of the content should be discussed when the visual aid is presented rather than being included on the visual aid itself, and
- Choose a few topics to present at a time – don't overload information on one visual aid.

When training the operators on the controls of the Epoke, classroom and field training may be utilized. Introduction to the basic controls may be shown in the classroom; however the operators will need time in the truck to become familiar with the operations of the system. The operators will need experience driving and using the multiple lane treating functions of the Epoke. Water may be placed in the tanks on the Epoke so that the operators may practice using the multiple lane spray bar prior to the start of the winter season. Training should be done before the winter season to ensure any issues are resolved while there is time to address them, and continuous communication should be maintained during the season.

With proper training, the salt and time savings from the Epoke may be maximized. Coordination between the garage managers and the operators is important for the successful implementation of the Epoke. The M&R 661 forms should be checked frequently throughout the season to verify the amount of material being used is appropriate. If any issues arise, more training may be necessary and should be done immediately. This stresses the need for communication between operators and managers. Constant communication should take place that includes discussion of routing and application rates.

7.4 Survey of Epoke Implementation and Training

A survey was conducted to determine how other Epoke users implement their Epoke(s) within their fleet and how they train their operators. Phone calls were made to various transportation departments that have used or are currently using Epoke within their fleets. All the departments contacted use one of the bulk spreader models. The survey questions and responses are presented in Table 7.4.

Table 7.4: Survey to Other Epoke Users on Implementation and Training.

Survey Questions	Epoke Users		
	Saskatchewan DOT	PENN DOT	City of Cuyahoga Falls, Ohio
How many Epokes do you have in fleet? How large is fleet?	Four Epokes throughout province, and about 300 plow trucks in fleet.	One Epoke for two years. 43 trucks in fleet. Tailgate spreaders is primary truck type in rest of fleet.	16 Epoke, entire fleet is Epokes.
Which type of Epokes do you currently use?	Two are a 4700 model and two are 4900 model.	Bulk Spreader: 4900 AST COMBI.	Models 3500, 4400 and have ordered a 4902.
How long have Epokes been incorporated into your fleet?	First one purchased about five years ago. Two more added two years ago and one currently being installed for next season.	2-year pilot study from 2010 to 2012.	Started implementing Epokes in 2005. Over the years has made entire fleet Epokes.
What types of roadway is Epoke responsible for maintaining?	All in different locations. Two used for TransCanada highway, one in east and one in middle. One on major 4 lane highway, and new one will be implemented on a 4 lane highway also.	Was assigned to an 4 lane highway with one other truck.	All types, with State Route 8 (6 lanes, divided) being one of the major roadway segments.
Do all your operators know how to operator the Epoke?	At the garages in which the Epokes are located, most of the operators are trained.	No just the two operators that used Epoke.	Since entire fleet is Epoke, all operators are trained.
Do you require a certain training procedure for operators prior to using the Epoke?	Epoke distributor is available to train, however, mostly rely on operators that are currently trained to train new operators.	Epoke came out and trained two operators and managers, technical support was in area to help.	Annual refresher training is performed. Cleans systems frequently after season, and runs through "end of the season" checklist provided by Epoke. Calibration done in house at the beginning of season. Epoke has provided an mechanics training session for the City's mechanics to be familiar with systems.
Have there been any problems with operator buy-in to Epoke?	Has not seen any problems with operator buy-in.	Highly received by two operators that used it, and other operators like to see more in fleet. Epoke had no down time during study.	Various issue in beginning, not all due to Epoke, but all operators buy-in now.
Is there a weather conditions that you feel the Epoke is ideal for?	No, works great in all weather conditions.	During non-plowing events the Epoke was sent out on route alone, allowing a truck and operator to be eliminated during these events.	Great for anti-icing, if you have a model with large liquid tanks. Two inches or less snow accumulation is optimal for Epoke because you can use more liquid than dry salt.
Do you implement the Epoke differently during different weather conditions? (i.e. heavy snowfall, freezing rain)	No.	No, stayed on its assigned route during study, however, if it was a non-plowing event, only Epoke would be deployed on its route.	Whole fleet is Epoke. When still had a mix fleet, the Epoke mostly stayed on assigned routes.
Do you use the Epoke in gang plowing? Is there a specific placement in the gang plowing for the Epoke?	No, they don't implement gang plowing.	Gang plowing was used if there was heavy snow; however, only used on assigned route with one other truck during plowing events. No special alignment incorporating the Epoke during gang plowing.	Yes with the last truck treating only. When still had a mix fleet of Epokes and standard systems, the Epoke would be placed as the last truck in alignment to treat.
Do you use the Epoke for anti-icing? If yes, how often?	Used often for freezing rain and direct application. Had many events over the last few years.	Yes, if needed. Beneficial larger tanks on Epoke for anti-icing. Not many events with Epoke during study; area usually receive more lake effect snow.	Yes. Would anti-ice as needed, as long as there isn't a chance for a rain event.
Do you use the Epoke for anything other than snow and ice? i.e. dust control	No, not right now, only for winter maintenance.	No, primarily used for winter maintenance during study.	No, just snow and ice. Doesn't have a need for clean-up with sand or dust control but aware that the Epoke may be used in other ways.

7.5 Implementation Plan

The implementation plan developed from this evaluation is divided into eight subsections:

- Subsection One – Recommendations for Implementation,
- Subsection Two – Steps Needed to Implement Findings,
- Subsection Three – Suggested Time Frame for Implementation,
- Subsection Four – Expected Benefits from Implementation,
- Subsection Five – Potential Risks and Obstacles to Implementation,
- Subsection Six – Strategies to Overcome Potential Risks and Obstacles,
- Subsection Seven – Potential Users and other Organizations that may be Affected, and
- Subsection Eight – Estimated Cost of Implementation.

7.5.1 Recommendations for Implementation

The Epoke, EpoSat, and Epoke tanker are currently implemented at the Boston Heights Garage. ODOT management may discuss placing the Epoke on a route where its benefits may be maximized, such as roadways with multiple lanes. During snowfall, it is recommended that the Epoke is placed as the last truck in a gang plow alignment or reassigning the Epoke to a nearby area when possible, as discussed in section 7.3. Since the Epoke may complete a route more quickly than a standard truck, it is recommended that the Epoke help maintain other routes when its route is complete, which may increase the labor savings of the Epoke.

7.5.2 Steps Needed to Implement Findings

As previously stated, ODOT management should discuss the best route(s) to assign the Epoke based on the results and suggestions presented herein. The Epoke is ideal on multilane roadways and the maximum labor savings will be seen in areas where plowing is less frequent. If ODOT chooses to resign the Epoke during certain weather events, planning and coordination should be done prior to the beginning of the winter season. Operator training is a very important step that is crucial to the successful implementation the Epoke, as discussed in section 7.3.

7.5.3 Suggested Time Frame for Implementation

The Epoke is being used for snow and ice maintenance as well as herbicide spraying at the Boston Heights Garage, which allows it to be used year around. Discussions and coordination between ODOT management may be in order if reassigning the Epoke during certain winter, as discussed in section 7.3. The current Epoke should be implemented immediately in the manner described herein.

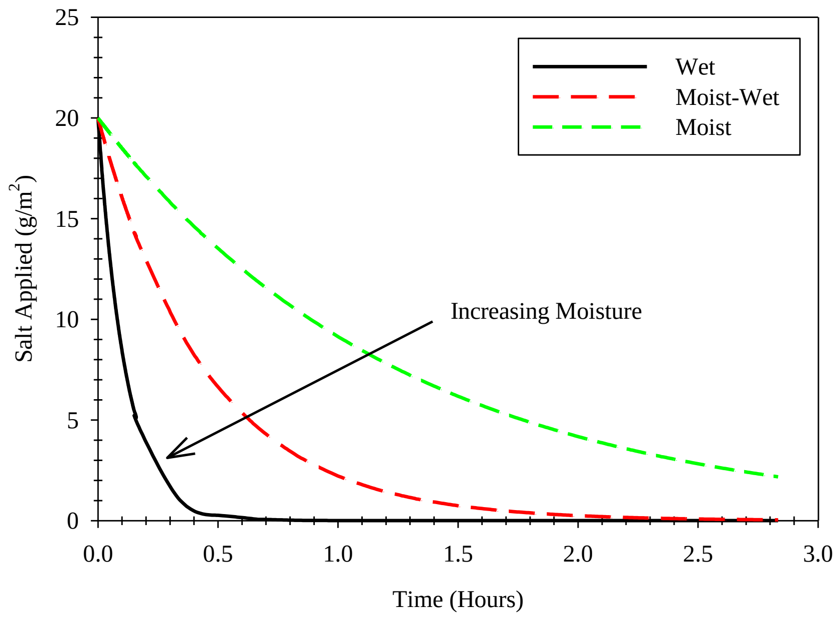
7.5.4 Expected Benefits from Implementation

The benefits from the Epoke are seen in the form of salt and labor savings. Through this evaluation, the Epoke was found to have a 12% salts savings at the Boston Heights Garage, as discussed in section 5.4.2. The Epoke is found to have a payback period on investment in year 8 for a garage that uses 20,000 tons of salt per year at the currently price of salt, more details are provided in section 6.4.2. The labor savings will be dependent on the amount, type and size of the roadways being treated; at the Boston Heights Garage there is an Epoke to Standard truck ratio of 1:1.6 as discussed in section 6.2. Labor savings may decrease overtime hours and/or reduce the need for seasonal employees.

7.5.5 Potential Risks and Obstacles to Implementation

As seen on the salt application data from February 16, 2013, in section 7.3, it is easy to over treat with the Epoke, which would reduce the salt savings from using the Epoke. Since the Epoke may treat multiple lanes in one pass, there is a potential for the general public to become upset if their vehicles get hit by the material while passing the Epoke.

There is very little published data regarding anti-icing operation with fine-grade salt like that used by the Epoke. The most complete data set found was from Martinelli and Blackburn (2001) conducted in Kansas and Wisconsin. One of their key findings was that while the finer grade salt produced the desired reaction faster on the pavement, the salt residual decreased faster than coarse-grade salt. Therefore, one potential risk of implementation of the Epoke is that more frequent application rates would be required. Using the models and coefficients reported by Blomqvist et al. (2011), and applying the appropriate traffic pattern and volume for the I-271 section, we performed preliminary calculations to estimate the potential impact. Figure 7.14 summarizes this analysis and shows that under “wet” surface condition, the salt can lose its effectiveness in as little as 30-35 minutes or remains for almost 2 hours under moist-wet conditions.



Note: Figure modified from Blomqvist, Göran, et al., 2011 and represents similar traffic volumes to study area.
Figure 7.14: Salt Residual Versus Time Modeled for Traffic Volume and Variable Surface Moisture Conditions.

This analysis is consistent with the recommendation by Martinelli and Blackburn (2001) that the cycle reapplication time should be shortened to less than 60 minutes and could be a potential risk-obstacle to Epoke implementation.

7.5.6 Strategies to Overcome Potential Risks and Obstacles

Properly training the operators that may be using the Epoke should eliminate any problems with over treating. ODOT should be reviewing the performance of the operators using the Epoke throughout the winter season, in case more training is needed. Notifying the general public about the new equipment and its abilities may reduce any issues involving the Epoke and the general public interacting with the Epoke when it is spreading material over multiple lanes. It should be noted that there have not been any issues involving the Epoke and the public during this evaluation.

To overcome the potential risk-obstacle of the shorter cycle reapplication rate duration for the Epoke discussed in the previous section, one strategy would be to model the impact of limiting the application duration on the current routes accounting for different traffic volumes and weather conditions.

Another strategy could be to also record the salt residual at given time intervals and accumulated traffic for several isolated winter events and compare to model predictions.

7.5.7 Potential Users and other Organizations that may be affected

Any organizations or agencies that perform winter maintenance may be interested in the data and results found during this evaluation. Other ODOT garages and transportation departments may use this evaluation to decide if an Epoke would be beneficial in their fleet. Potential users may calculate their own cost analysis based on the methods used in this project.

7.5.8 Estimated Cost of Implementation

There will not be any additional cost to implement the Epoke and the Epoke tanker. The final cost for implementation is heavily based on the cost of the equipment purchased; the equipment from this evaluation is already purchased and in operation. If other ODOT garages decide to purchase any of the equipment evaluated during this project, there will be the cost of the equipment and the cost to train the operators.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The eighth chapter within this research report contains the conclusions and recommendations gathered from the project and is divided into two sections:

- Section One – Epoke, and
- Section Two – Epoke Tanker.

These sections provide a synopsis of the results associated with savings as well as a cost analysis of the two Epoke systems.

8.1 Epoke

The Epoke Sirius S4902 AST Combi Bulk Spreader was evaluated as a method to reduce expenditures in ODOT's winter maintenance budget. To summarize the findings of this study, this section is divided into four subsections:

- Subsection One – Salt Savings,
- Subsection Two – Labor Savings,
- Subsection Three – Net Present Value and Payback Period, and
- Subsection Four – Implementation.

8.1.1 Salt Savings

During this evaluation, there were eight winter events in which the Epoke and standard truck were treating only their assigned directions of the study zone. The assigned directions of the study zone are shown in Figure 4.9. Comparing the amount of salt applied by the Epoke and the standard truck on these good comparison days, it was determined that the Epoke used 12% less salt than the standard truck while treating the same segment of roadway. The salt calculations used to determine the salt savings are discussed in section 5.4.1. The data from the good comparison days are presented in section 5.4.2. The Epoke was evaluated for two winter season; however the first winter season, 2011 to 2012, was mild and only had three winter events. The second winter season, 2012 to 2013, resulted in a total of 44 winter events. A summary of all the winter events are shown in section 5.3, including an observational breakdown of the event's associated severity.

8.1.2 Labor Savings

The Epoke is capable of treating up to three lanes in a single pass; therefore the research team examined the potential for a labor savings. Using the data collected on the good comparison days, the Epoke was able to provide a similar LOS compared to the standard truck while making fewer passes, as described in section 6.2.1. The LOS on both routes is found to be similar from analysis of the Bluetooth speed data acquired in the study zone. The study zone is treated 17 times in the southbound direction by the Epoke and 26 times in the northbound direction by the standard truck. When comparing the number of passes each truck made to keep the road clear it is determined that one Epoke is equal to 1.6 standard trucks, and this time savings ratio is used in calculating the labor savings of the Epoke. The labor savings calculation is shown in section 6.2.4.

8.1.3 Net Present Value and Payback Period

The NPV is determined given a time series of cash flows, both incoming and outgoing. The variables that are used to calculate the NPV of the Epoke are: initial cost, which in this case is the difference in cost between the standard ODOT truck and the Epoke, the salt savings, and the labor savings; the equation is shown in section 6.4.1. The initial cost is an outgoing cost and therefore will be subtracted from the incoming cost, which will be the salt and the labor savings per year. Figure 6.3 is a summary of the assumptions used in the cost analysis of the Epoke, which includes labor rate, number of events per year, length of events, equipment breakdown, salt usage, and salt savings. Figure 6.4 in section 6.4.1 indicates that ODOT will see a NPV of $51,500 to $81,043 after eight years, for an annual salt usage of 20,000 tons and a NPV of $8,825 to $26,644 for an annual salt usage of 10,000 tons, depending on the inflation rate. A summary of the NPV of the Epoke after eight, ten, and twelve years is shown in Table 6.5 in section 6.4.1.

The payback period on an investment is the ratio of money gained or lost on an investment compared to the amount of money invested. The investment in this case is $77,000 dollars, which is the difference in cost between the Epoke and the standard truck that ODOT currently uses, and the yearly maintenance cost difference of $580. The savings from the Epoke are based on the 12% annual salt savings and the annual labor savings found from the 1.6:1 time savings ratio as seen in this evaluation. As shown in Figure 6.7 in section 6.4.2, the payback period may be seen during year eight, if salt prices are $40/ton and the annual salt used in 20,000 tons. If only using 10,000 tons per year the payback period will be in year 14 with salt prices of $40/ton. Higher salt prices and labor costs will result in faster a payback period.

8.1.4 Implementation

To optimize the potential savings of the Epoke, the research team has provided ODOT with an implementation plan, located in chapter 7. Through the use of ArcGIS modeling, one part of the implementation plan includes the evaluation of the cycle time required to maintain the routes in Summit County using one Epoke. The results of the model determined that the Epoke will have the shortest cycle time when maintaining I-271. The Epoke maintaining SR-8 shows a similar but slightly higher cycle time compared to I-271. The Epoke may obtain the greatest labor savings on longer roadways segments with a high number of lanes. Section 7.2 discusses the route optimization model conducted for the Epoke.

Adequate training is crucial to the successful implementation of all new equipment, including the Epoke. At the beginning of the project, initial training is provided by Epoke and Bell Equipment Company, and continuous training is provided throughout the course of the study. Figure 7.6 in section 7.3.1 presents some key topics to address during training. Some of these topics include: Epoke theory, the controls and functions of the Epoke, proper treatment, and implementing the Epoke during plowing.

The Epoke is limited by its ability to plow. One possible implementation of the Epoke during plowing is to gang plow with the Epoke as the last vehicle treating multiple lanes. Gang plowing consists of aligning multiple trucks on a segment of highway to plow all lanes at the same time. Figures 7.10 and 7.11 display a few different ways to align the Epoke during plowing, depending on the number of trucks available to gang plow and the number of lanes which need to be plowed. Another implementation plan for the Epoke when plowing is necessary is to move the Epoke to an area that may not be getting as much snowfall, which will help optimize the savings of the Epoke, as discussed in section 7.3.1.

8.2 Epoke Tanker

Along with the spreader for the snow plow truck, ODOT purchased an additional Epoke Virtus Spreader (Epoke tanker) to mount on the back of a 5000 gallon tanker trailer. The tanker truck is used to spread liquid, which for ODOT is typically a brine solution, for anti-icing of routes prior to snow events. ODOT typically deploys this tanker, which had previously been able to treat only one lane at a time, along with three other standard trucks with liquid tanks to completely anti-ice Summit County roadways. This previous operation would require the four trucks a total of 12 to 14 hours to complete. The Epoke tanker was employed in the second winter season. During this time, there were 27 events where the Epoke tanker is performing anti-icing as shown in Table 5.11 in section 5.3. Of the 27 anti-icing events, 17 required only anti-icing activities. The 10 additional anti-icing events required additional material to be spread during the winter events. Using this information and the GPS data from anti-icing events, it is found that it requires the Epoke tanker six to eight hours to anti-ice all of Summit County. A summary of all the anti-icing events is provided in section 5.6.3.

When the Epoke tanker is deployed to anti-ice roadways in Summit County, rather than the four standard trucks, it results in a savings of $258. The Epoke tanker saves six hours of labor costs and $152 in fuel savings. This cost analysis is discussed in further detail in section 6.4.3. Based on the number of anti-icing events last season as well as the operator's pay rate and current fuel costs, the payback period on the Epoke tanker will not be seen. However, the Boston Heights garage expressed other benefits to having the Epoke tanker in the fleet, and these benefits are presented in Figure 6.9 in section 6.4.3.

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APPENDIX A

SAMPLE CALCULATIONS

Total Material Applied Example

	Standard Truck	Epoke
Salt Application Rate (lbs/ln-ml)	250	250
Brine Application Rate (gal/ln-ml)	-	25
Length of Application (miles)	5	5
Number of Lanes Treated	1	2

Total Material Applied

$$Total\ Material\ Applied\ (lbs) = Application\ Rate\ \left(\frac{lbs}{ln-ml}\right) x\ Number\ of\ Lanes\ Treated\ x\ Length\ of\ Application\ (miles)$$

$$Standard\ Truck\ Total\ Material\ Applied = \left(250\frac{lbs}{ln-ml}\right) x\ (1\ lane) x\ (5\ miles) = 1{,}250\ lbs$$

$$Epoke\ Total\ Material\ Applied = \left(250\frac{lbs}{ln-ml}\right) x\ (2\ lanes) x\ (5\ miles) \qquad = 2{,}500\ lbs$$

Standard Truck Total Salt Used

$$Converstion\ for\ lbs\ of\ salt\ used = \left(\frac{7\ gal\ of\ brine}{2000\ lbs\ of\ salt}\right) \times \left(\frac{2.28\ lbs\ of\ salt}{1\ gal\ of\ brine}\right) = 0.008$$

$$Total\ Salt\ Used = (Total\ Material\ Applied) + (Total\ Material\ Applied \times 0.008)$$

$$Standard\ Truck\ Total\ Salt\ Used = (1{,}250\ lbs) + (1{,}250\ x\ 0.008) = 1{,}260\ lbs$$

Epoke Total Salt Used

$$\begin{aligned} Total\ Salt\ Used \\ &= (Total\ Pre\text{-}wetted\ Material\ Applied \times 0.7) \\ &+ (Total\ Pre\text{-}wetted\ Material\ Applied \times 0.3 \times 0.233) \\ &+ (\text{Total Liquid Applied } \times 0.233) \end{aligned}$$

$$\begin{aligned} Epoke\ Total\ Salt\ Used &= (2{,}500\ lbs\ x\ 0.7) + (2{,}500\ lbs\ x\ 0.3\ x\ 0.233) + (25\ x\ 2\ x\ 5\ x\ 0.233) \\ &= 1{,}983\ lbs \end{aligned}$$

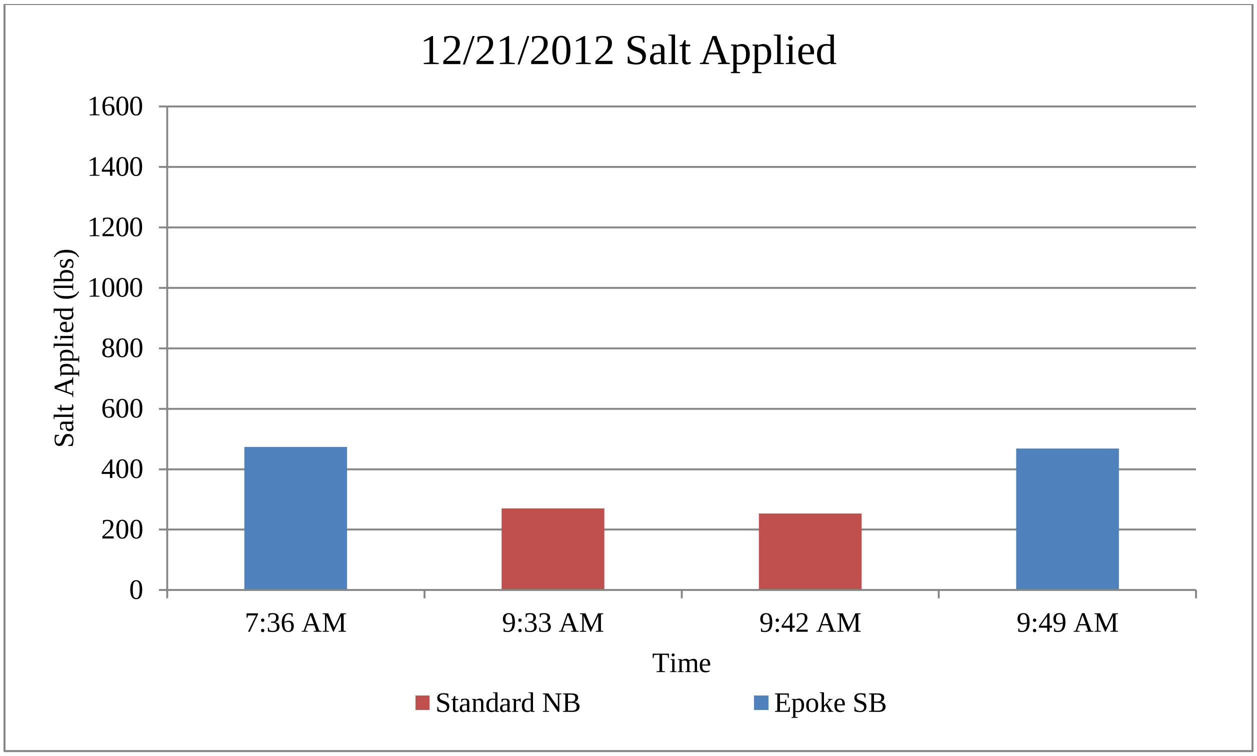
In this example, the Standard Truck treated one lane using 1,251.02 pounds of salt while the Epoke treated two lanes using 1,983 pounds of salt. These values include the dry material applied as well as the salt fraction from the application of brine.

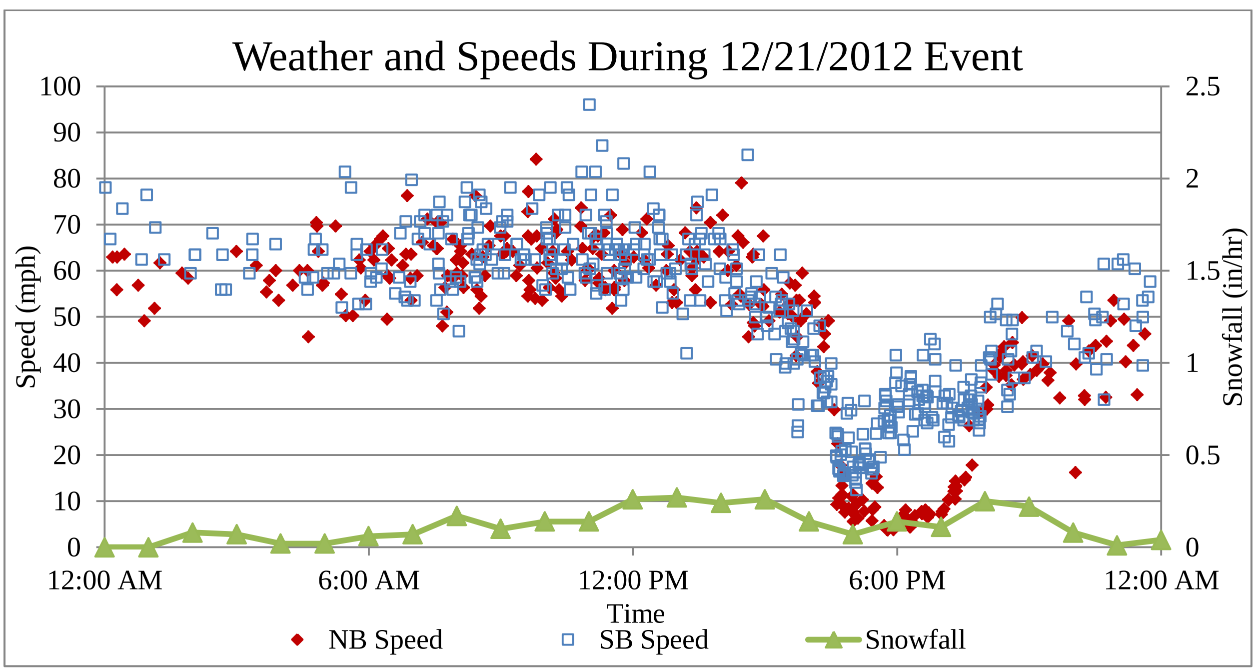
APPENDIX B

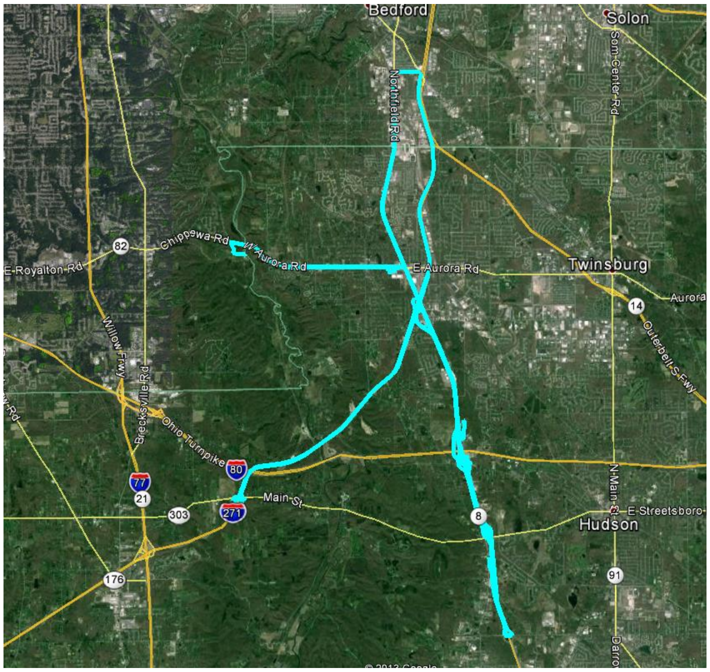
SUMMARY OF EVENTS

2012 – 2013 Winter Events Summary

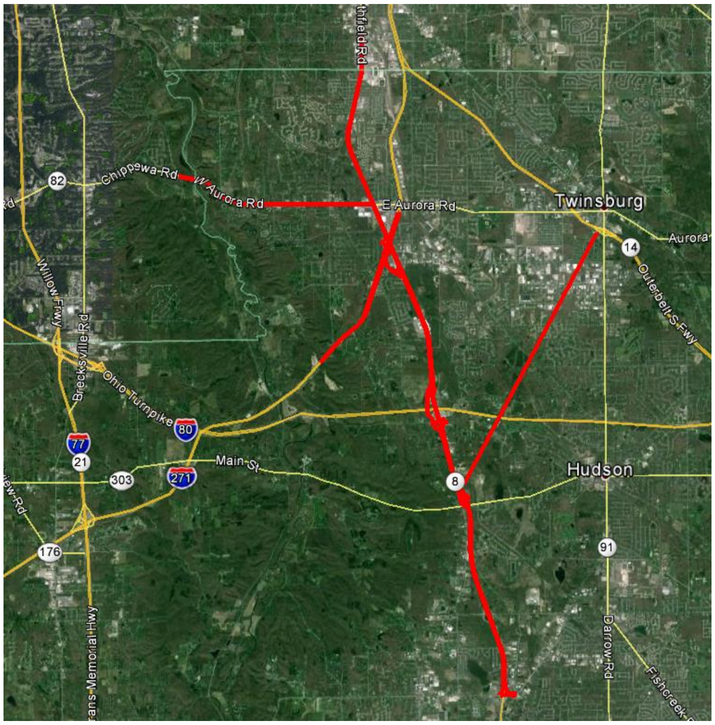
December 21, 2012





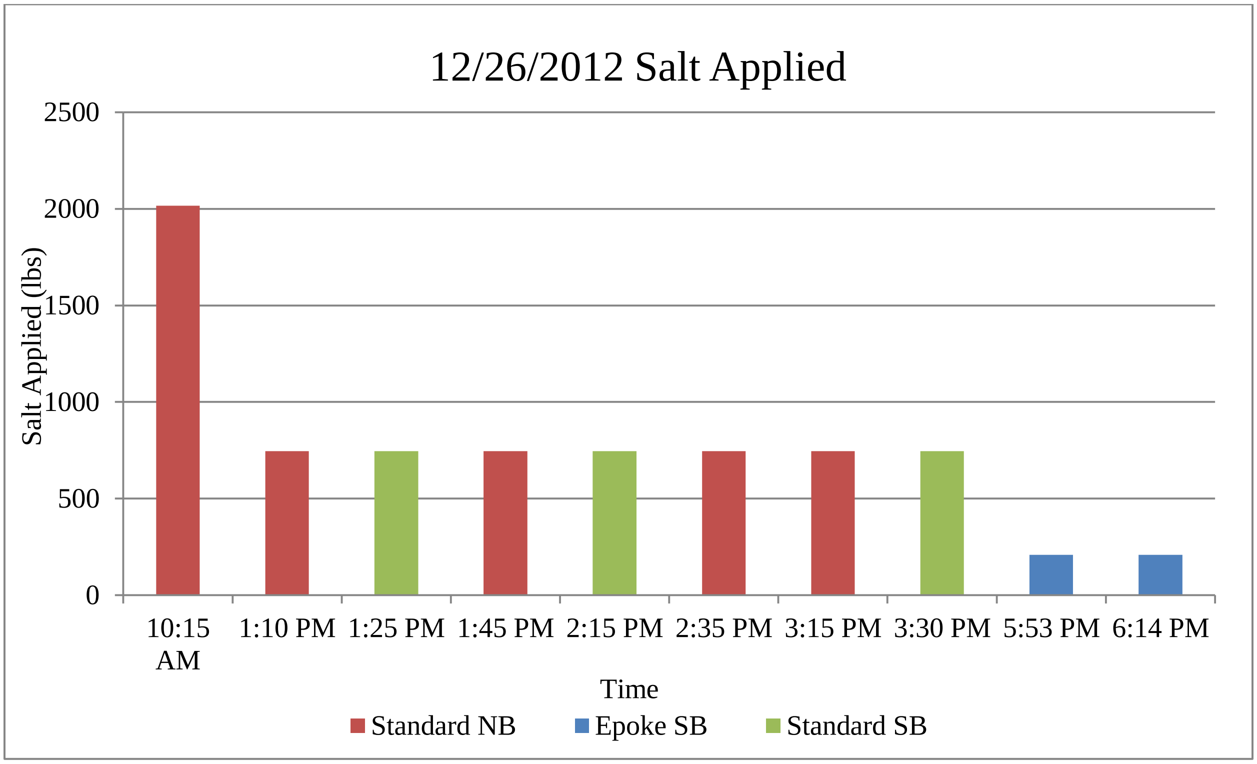


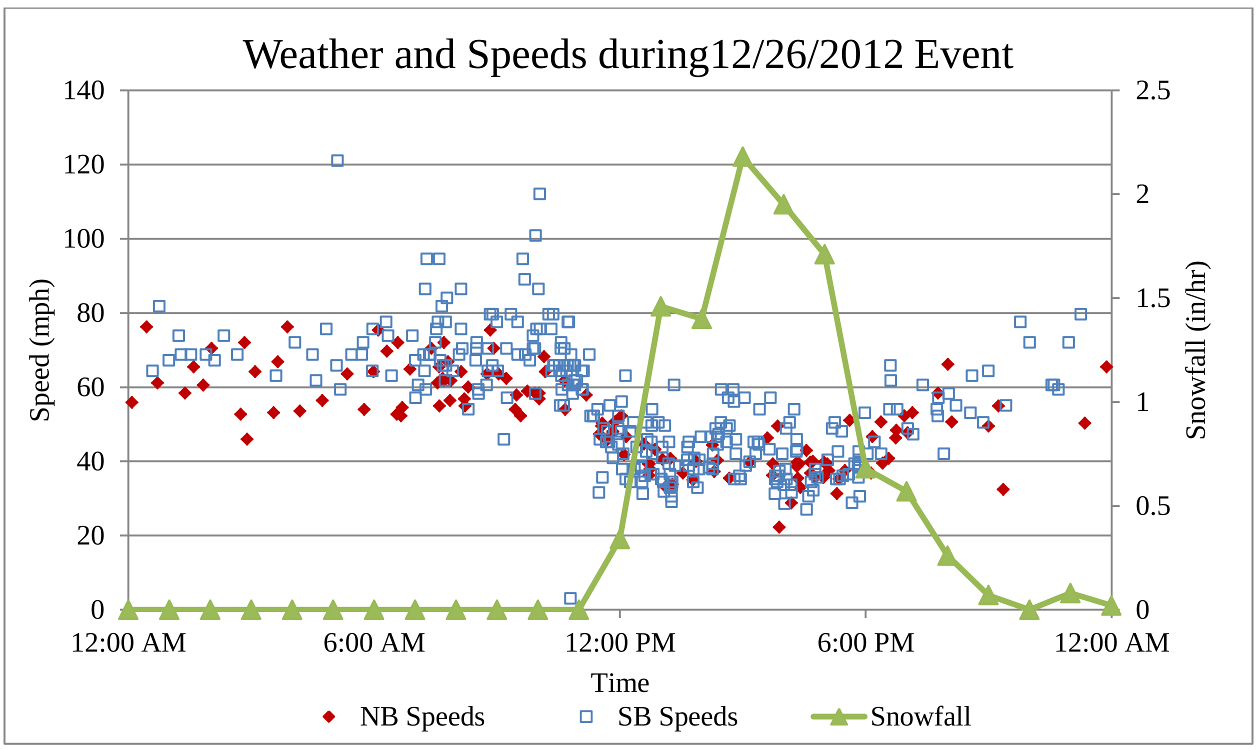
Epoke's Route - Aerial provided by Google Earth

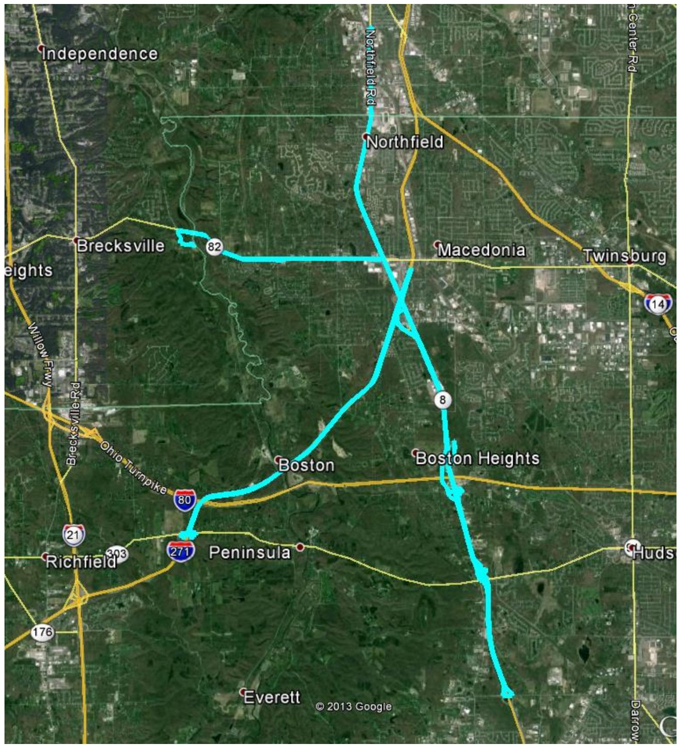


Standard Truck's Route - Aerial provided by Google Earth

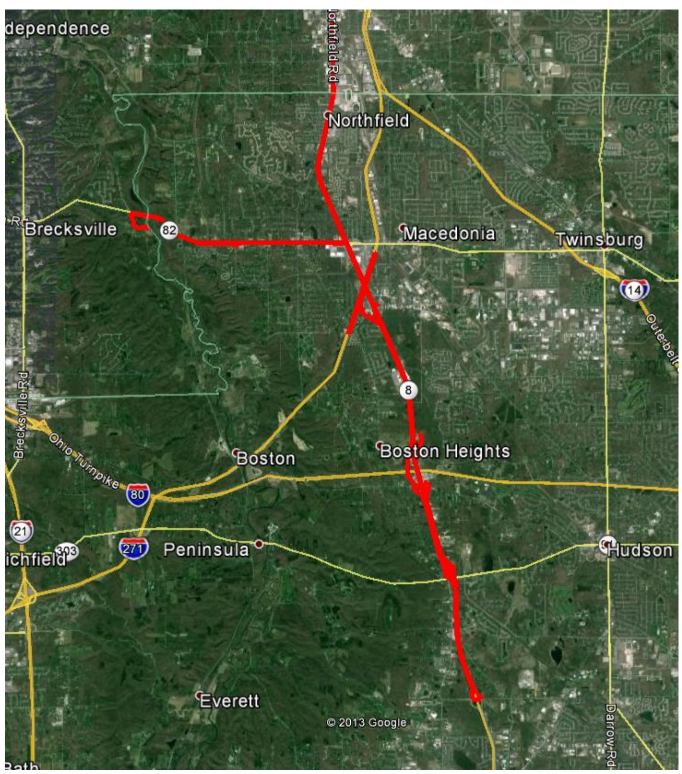
December 26, 2012





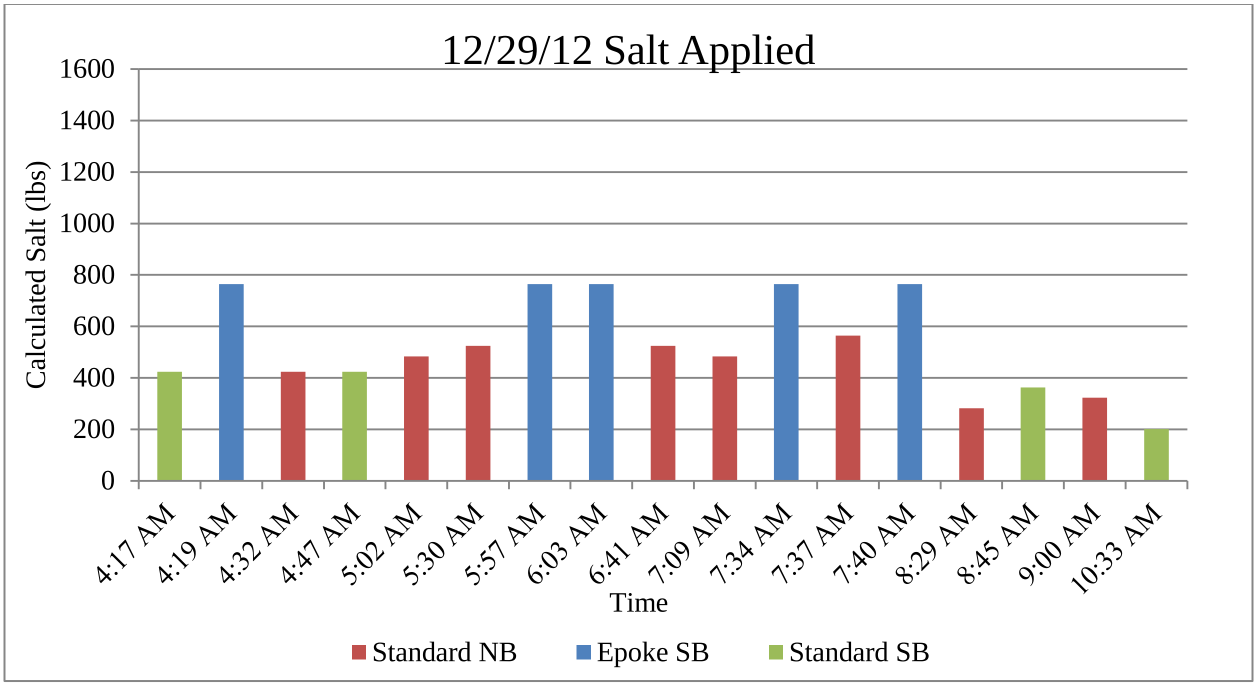


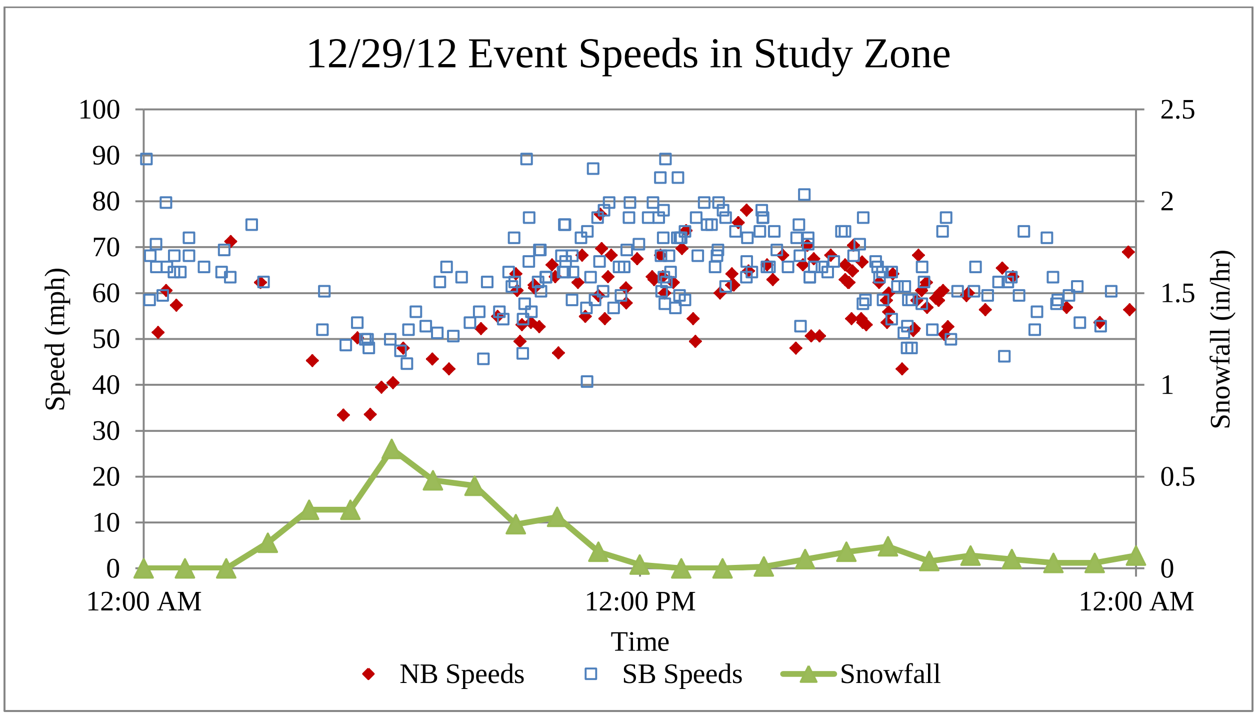
Epoke’s Route - Aerial provided by Google Earth

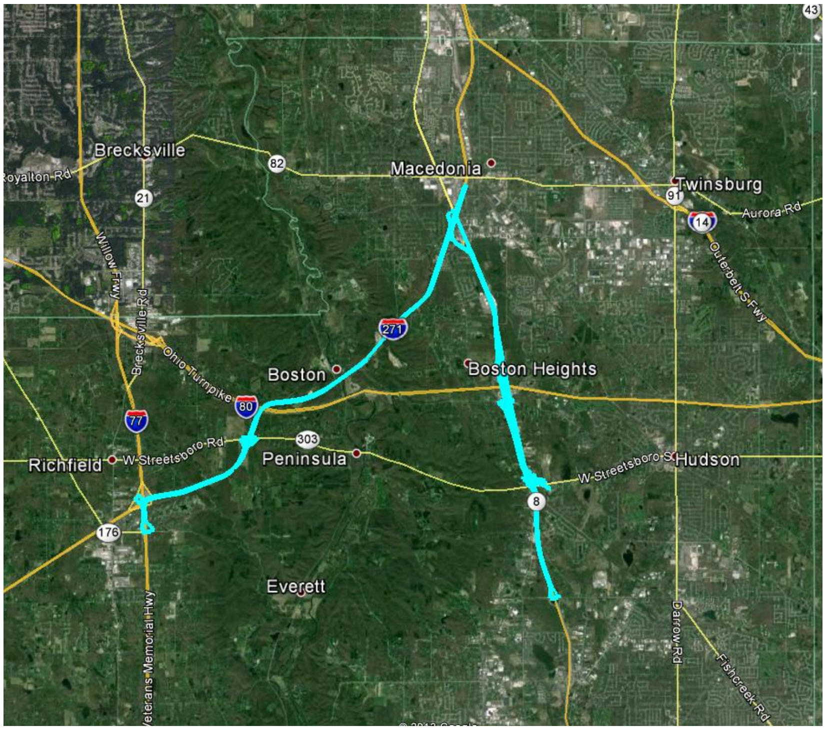


Standard Truck’s Route - Aerial provided by Google Earth

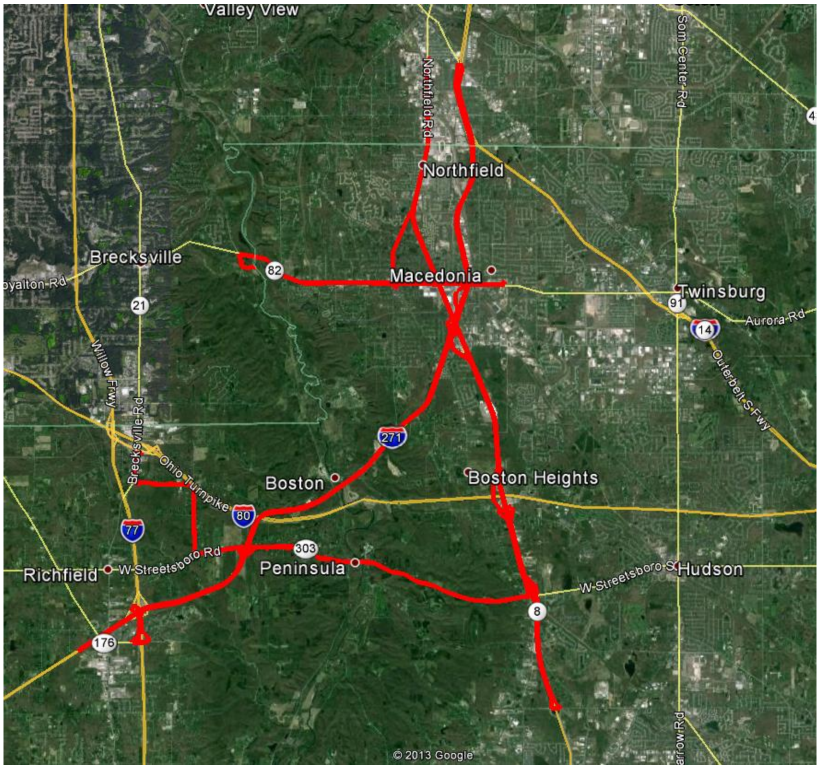
December 29, 2012





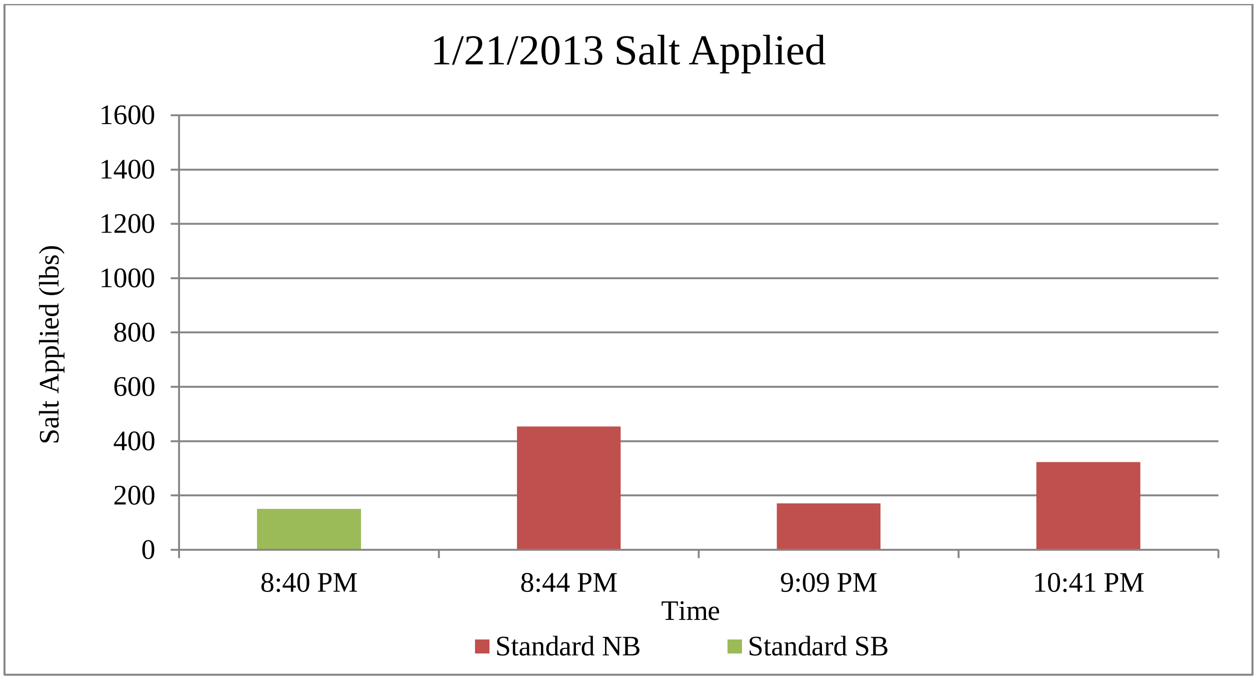


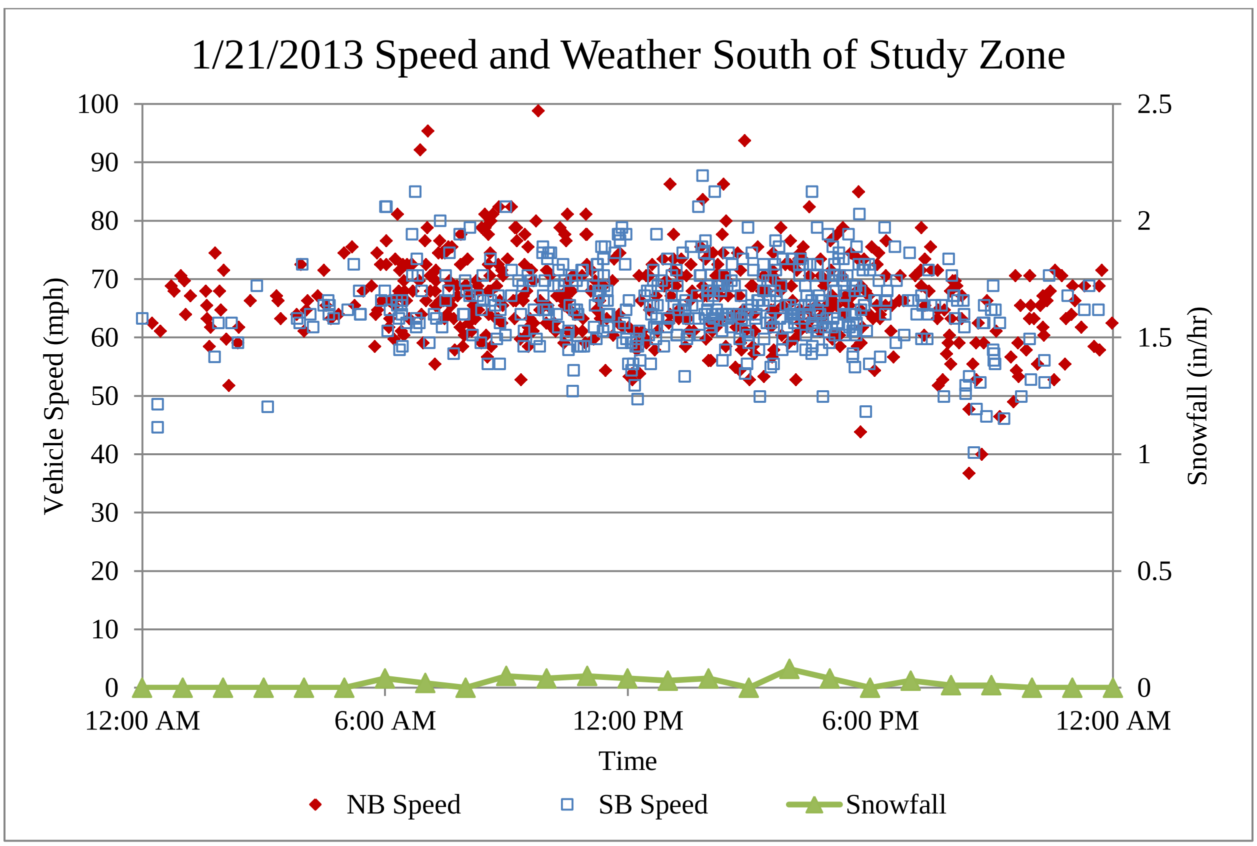
Epoke’s Route - Aerial provided by Google Earth

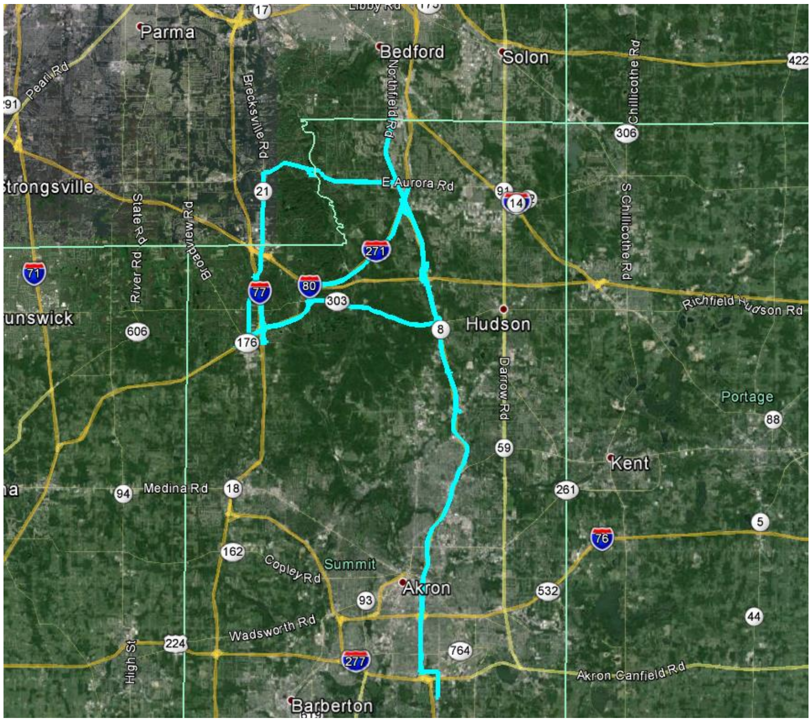


Standard Truck’s Route - Aerial provided by Google Earth

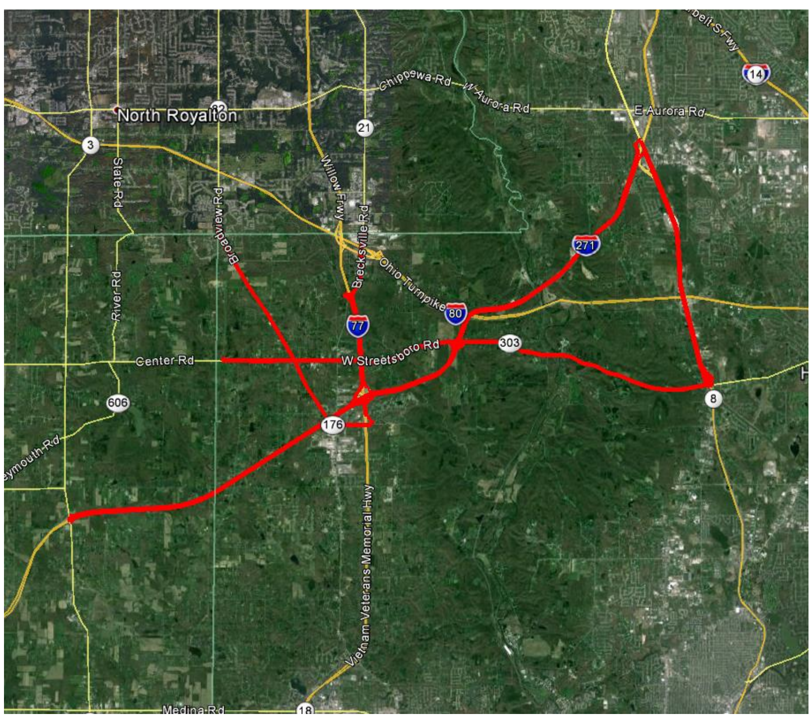
January 21, 2013





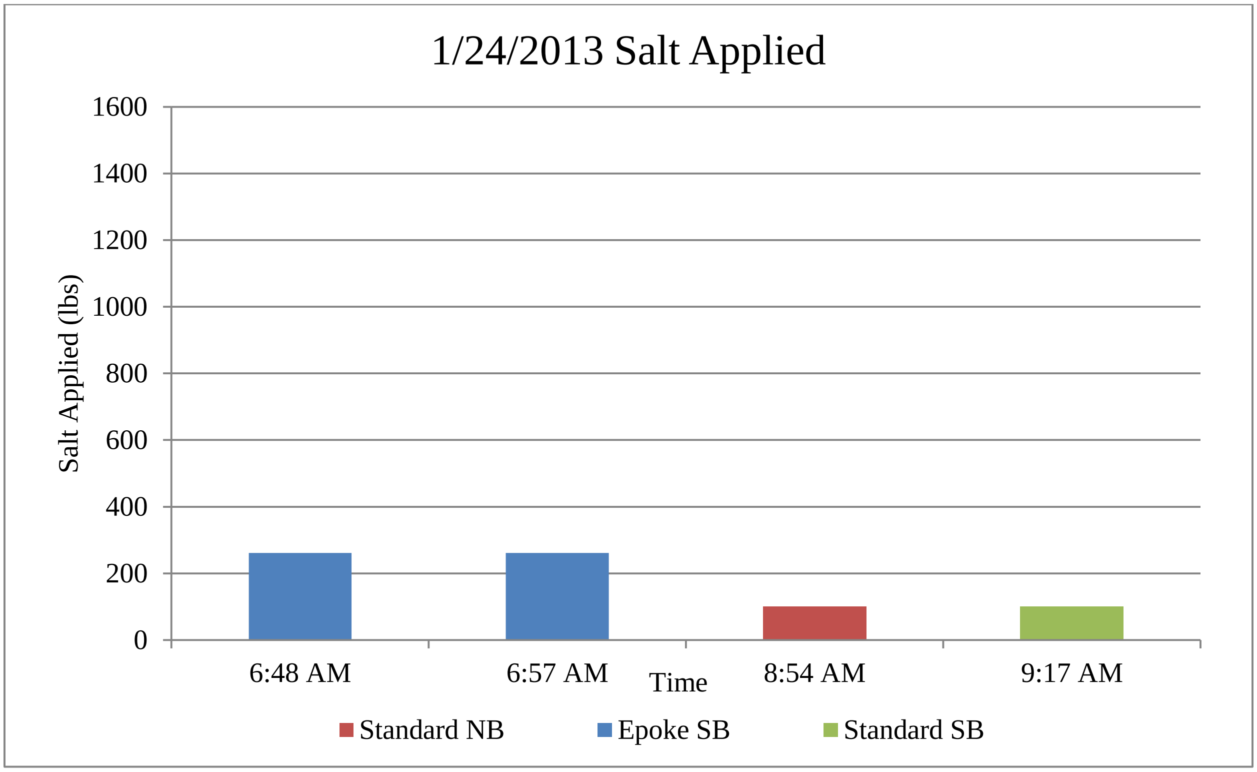


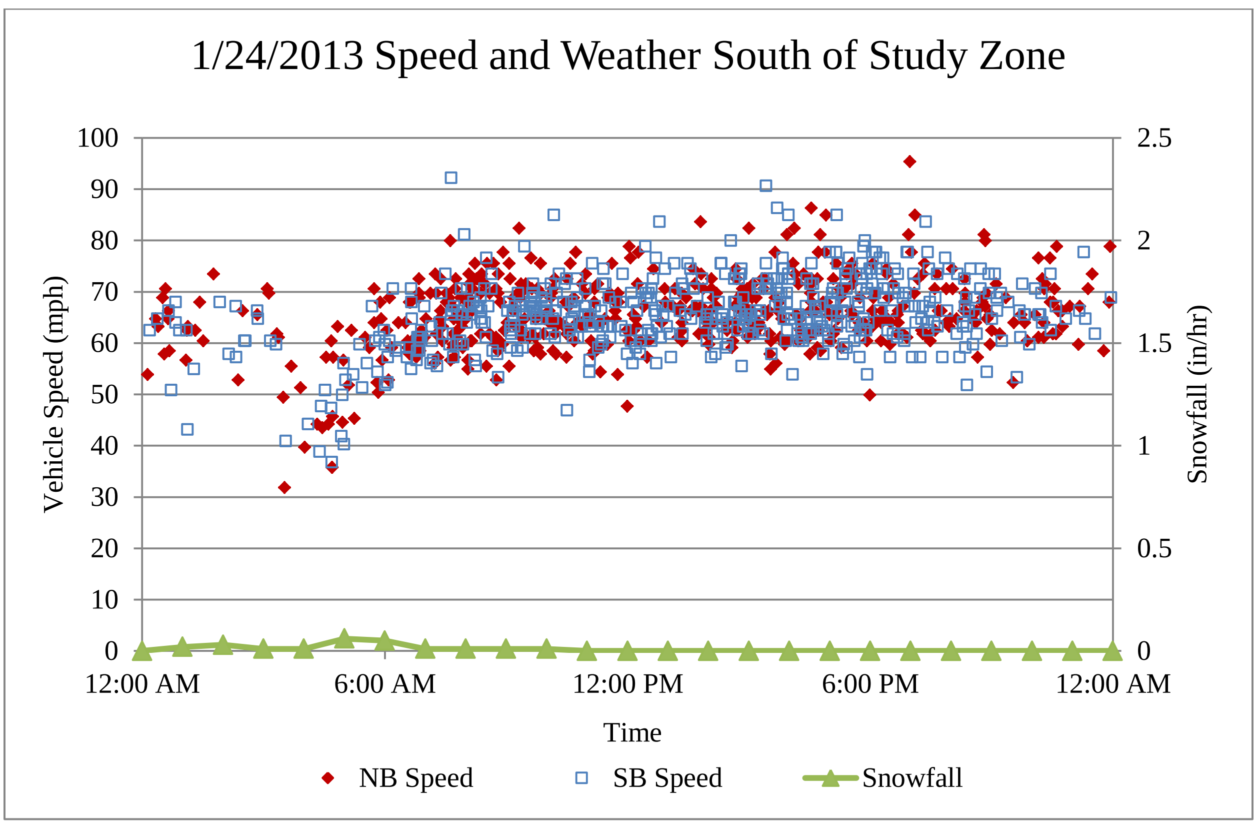
Epoke’s Route - Aerial provided by Google Earth

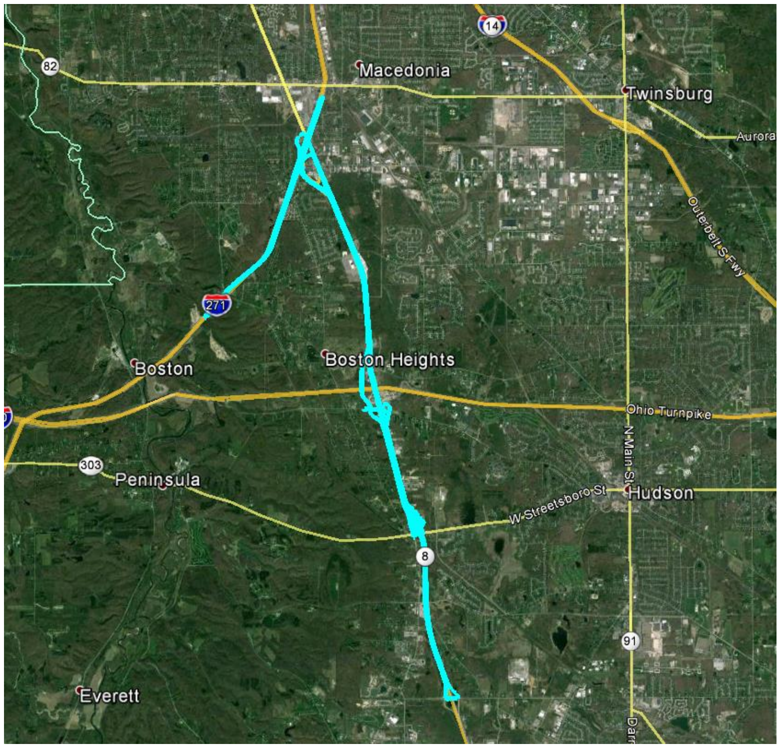


Standard Truck’s Route - Aerial provided by Google Earth

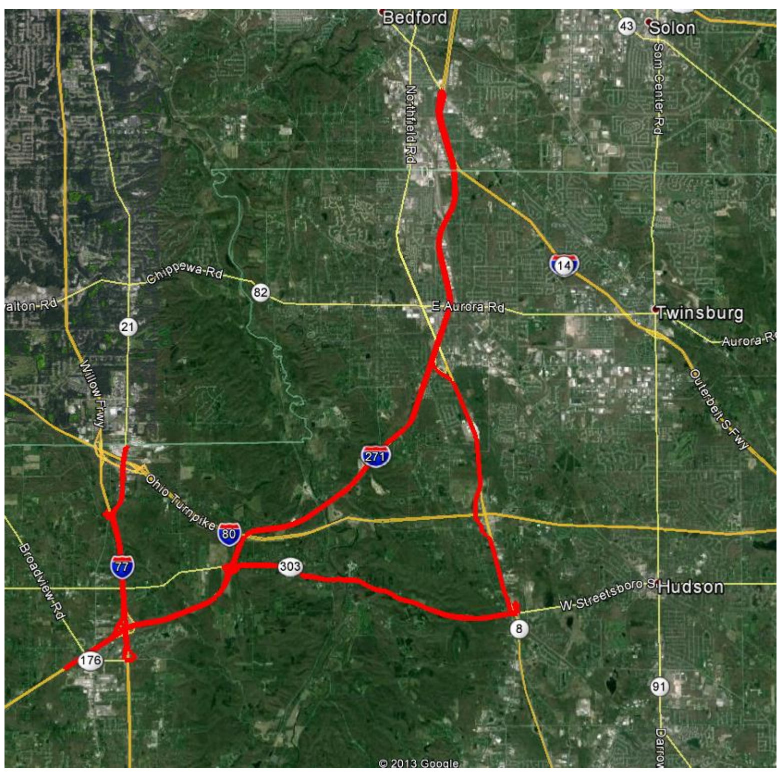
January 24, 2013



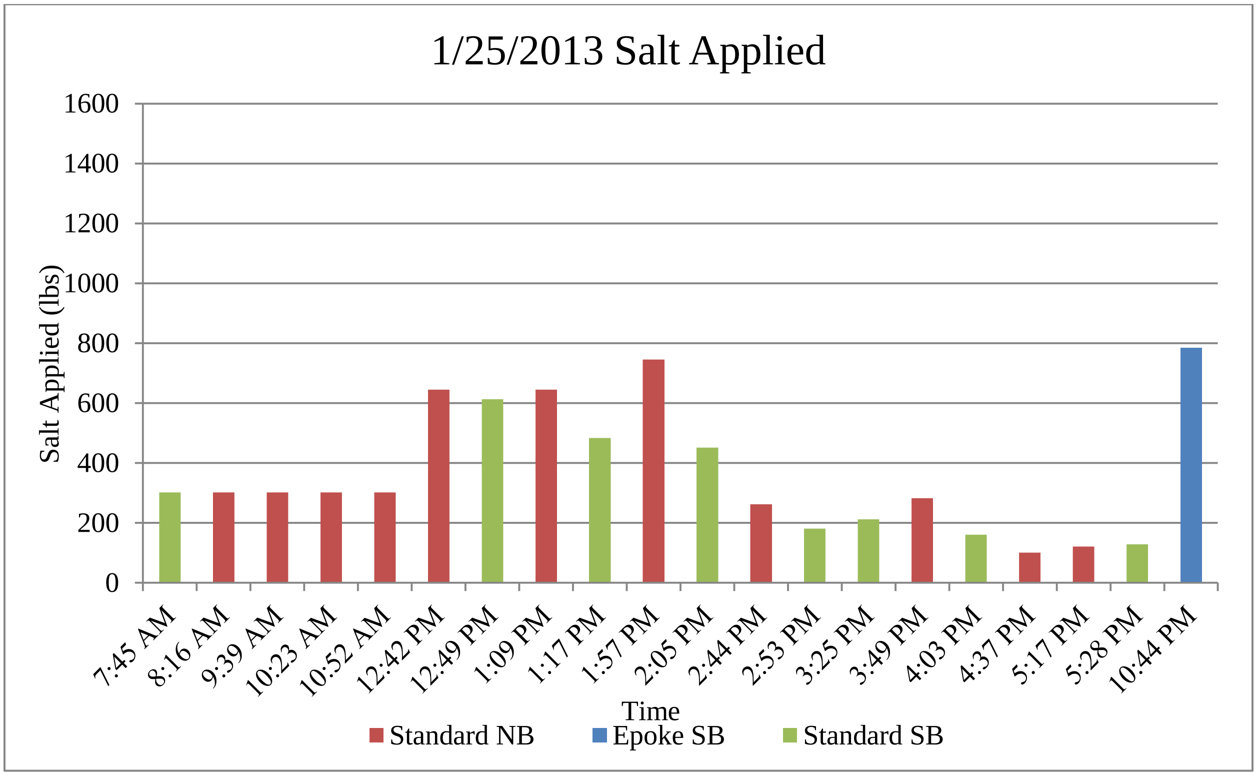


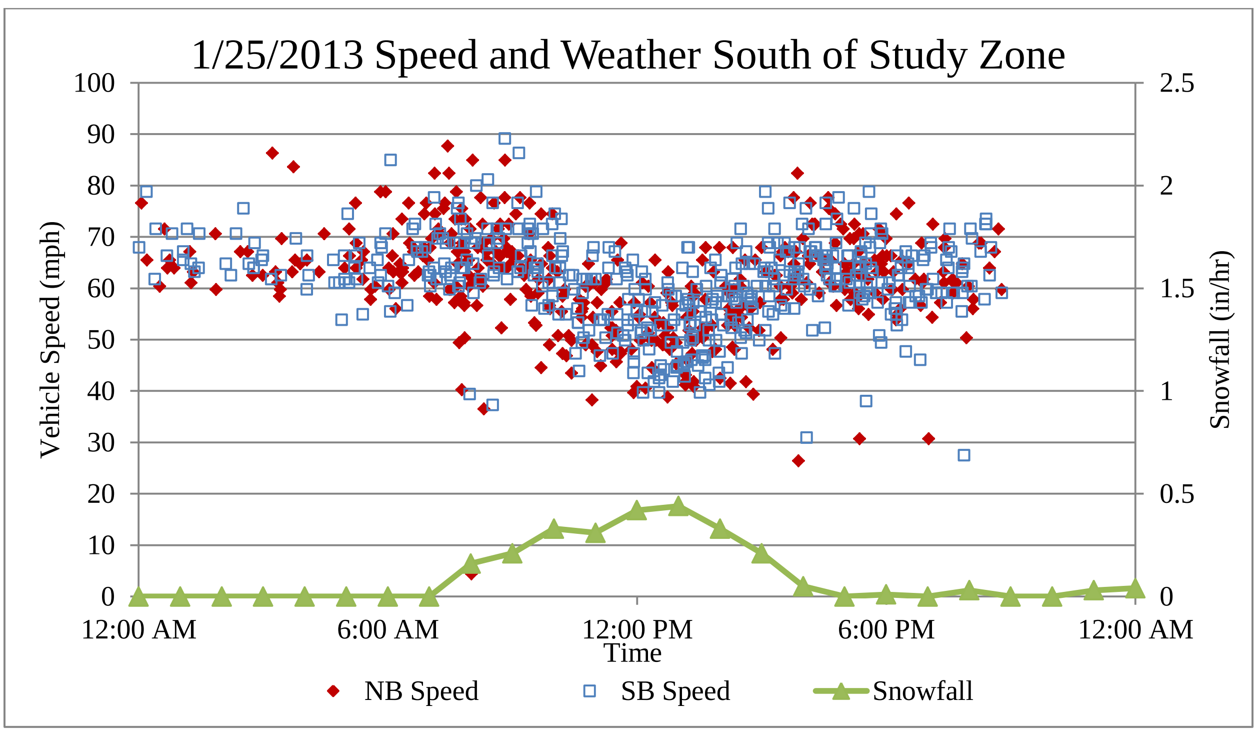


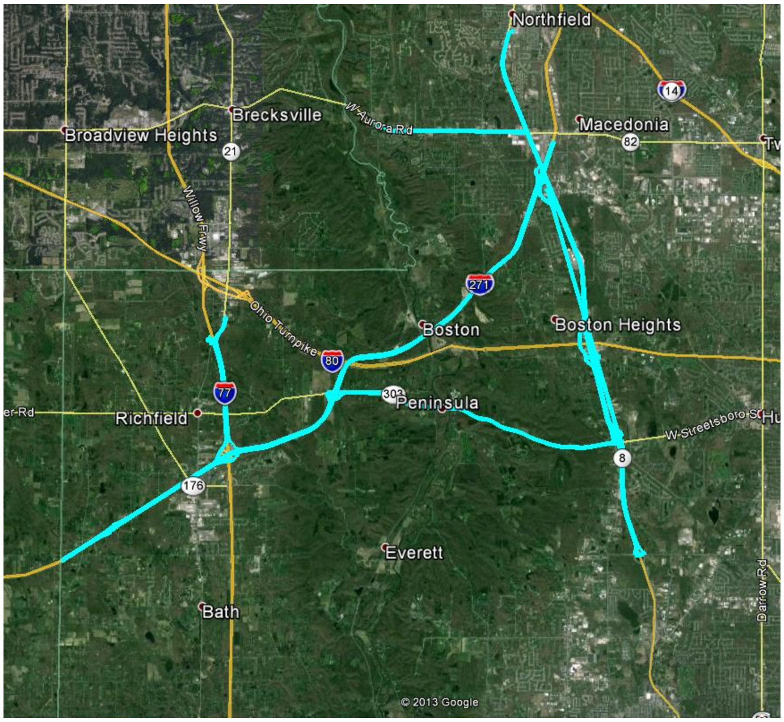
Epoke’s Route - Aerial provided by Google Earth



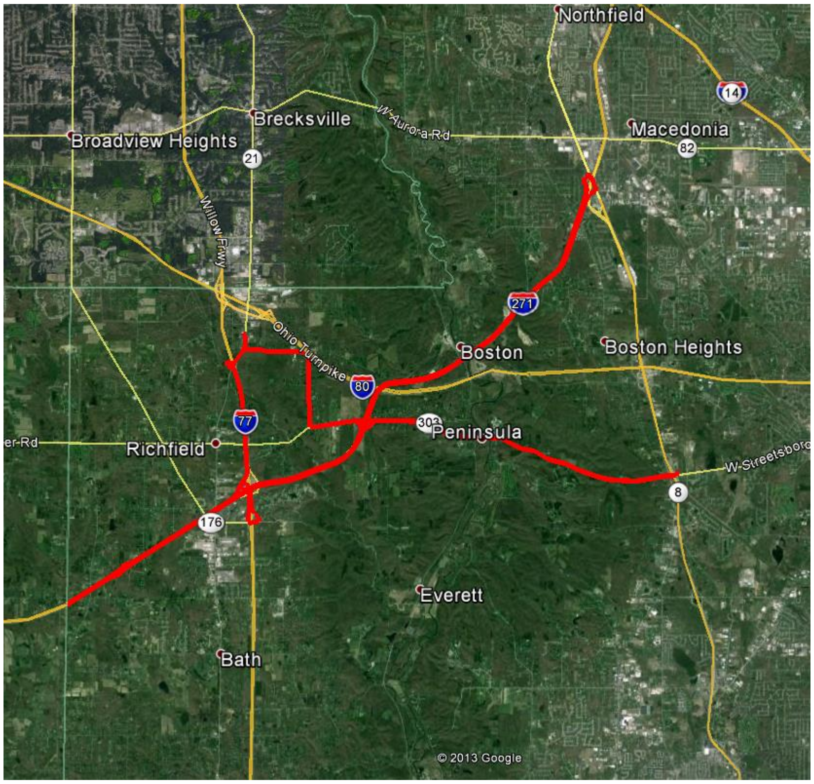
Standard Truck’s Route - Aerial provided by Google Earth


1/25/2013 Salt Applied
Salt Applied (lbs)
1600
1400
1200
1000
800
600
400
200
0
7:45 AM
8:16 AM
9:39 AM
10:23 AM
10:52 AM
12:42 PM
12:49 PM
1:09 PM
1:17 PM
1:57 PM
2:05 PM
2:44 PM
2:53 PM
3:25 PM
3:49 PM
4:03 PM
4:37 PM
5:17 PM
5:28 PM
10:44 PM
Time
Standard NB
Epoke SB
Standard SB


1/25/2013 Speed and Weather South of Study Zone
Vehicle Speed (mph)
100
90
80
70
60
50
40
30
20
10
0
Snowfall (in/hr)
2.5
2
1.5
1
0.5
0
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Time
NB Speed
SB Speed
Snowfall

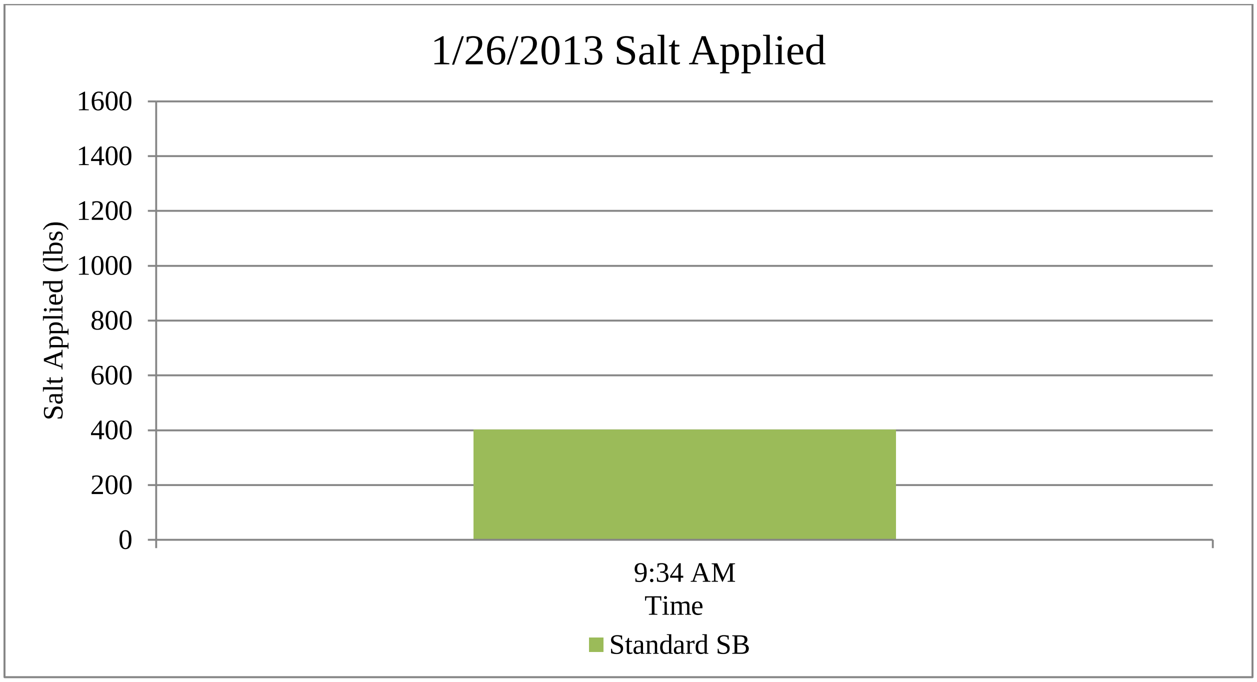


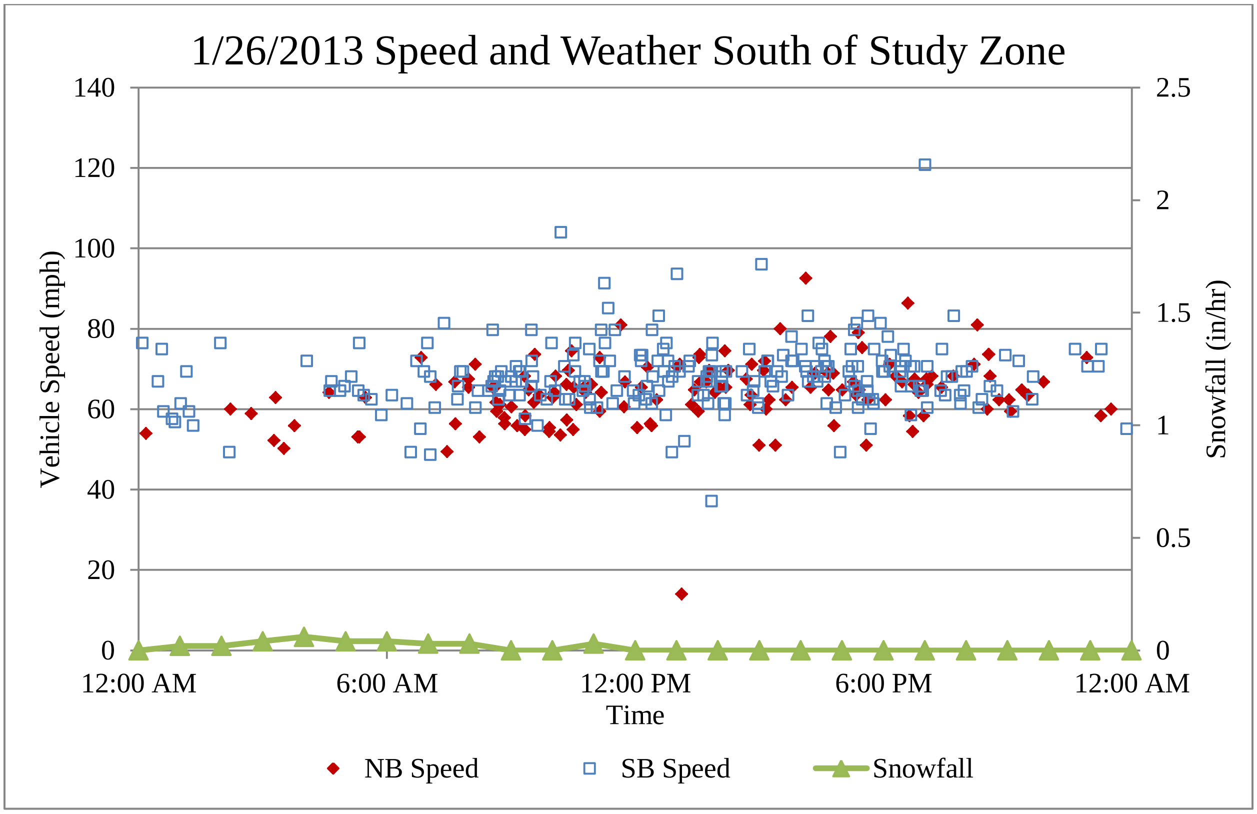
Epoke’s Route - Aerial provided by Google Earth

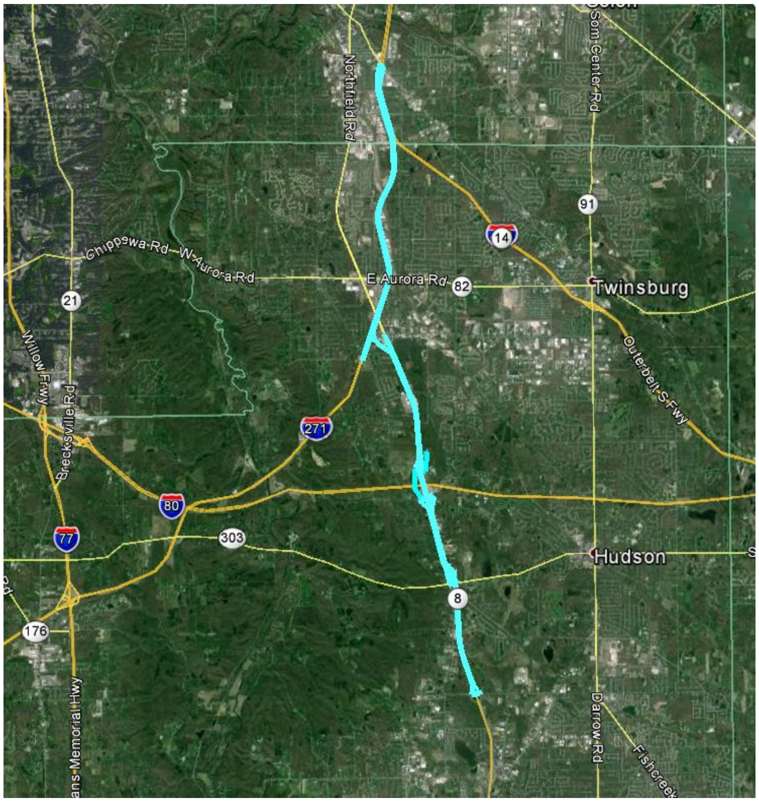


Standard Truck’s Route - Aerial provided by Google Earth

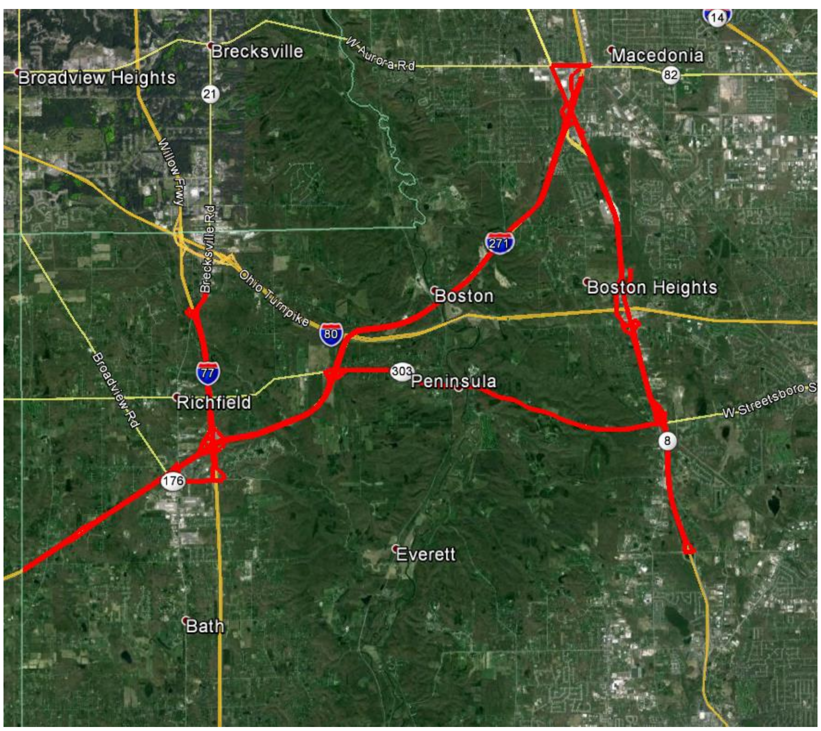
January 26, 2013





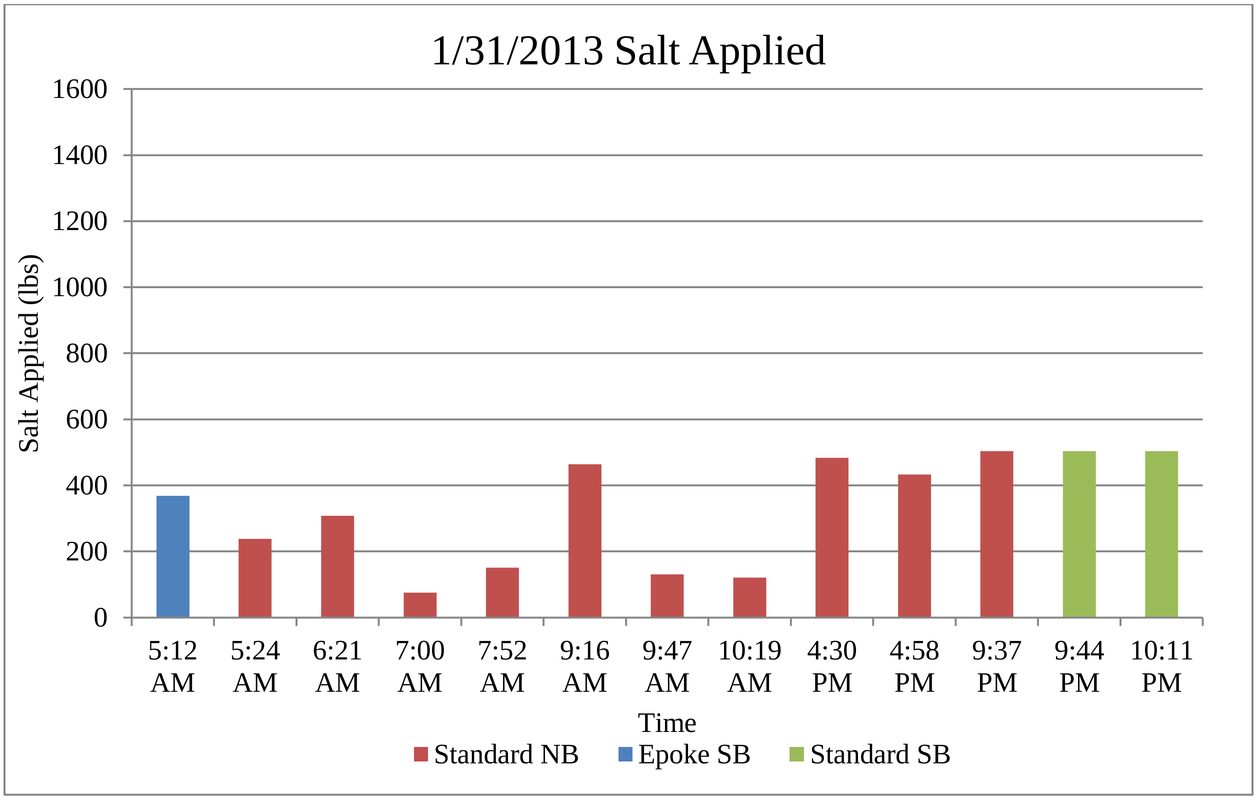


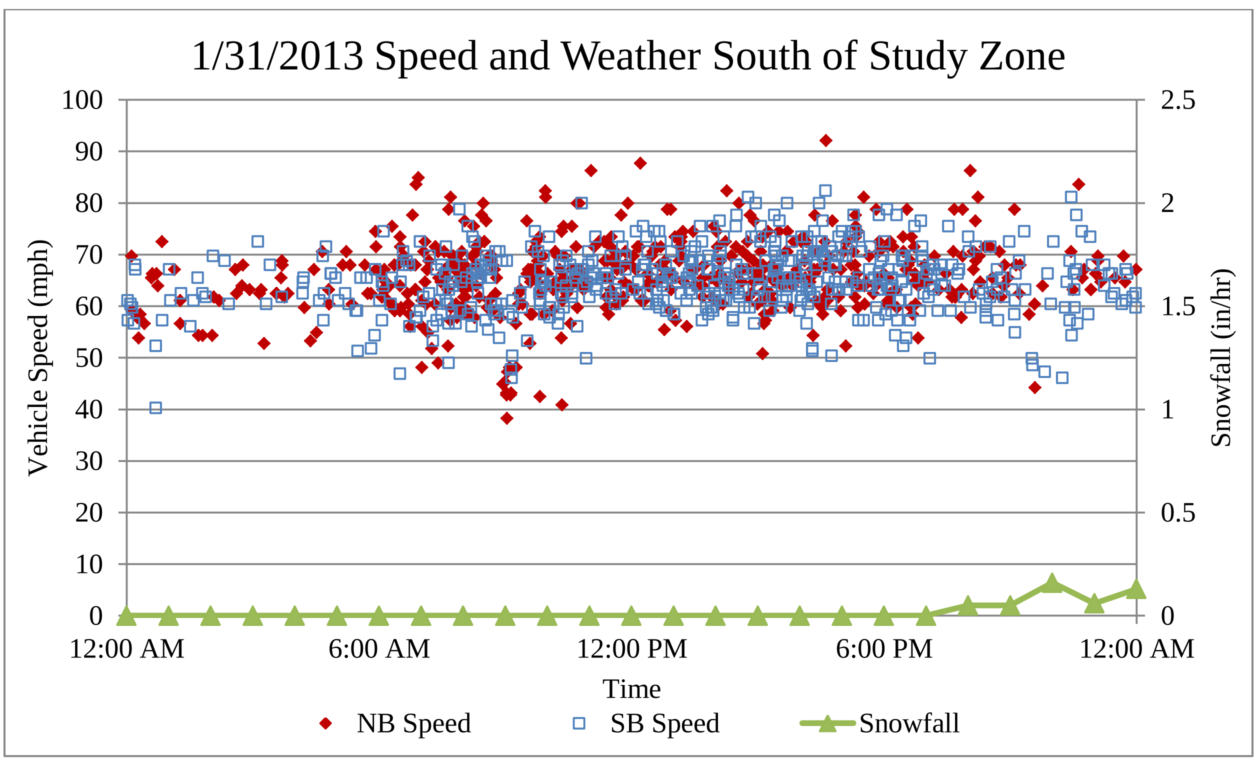
Epoke's Route - Aerial provided by Google Earth

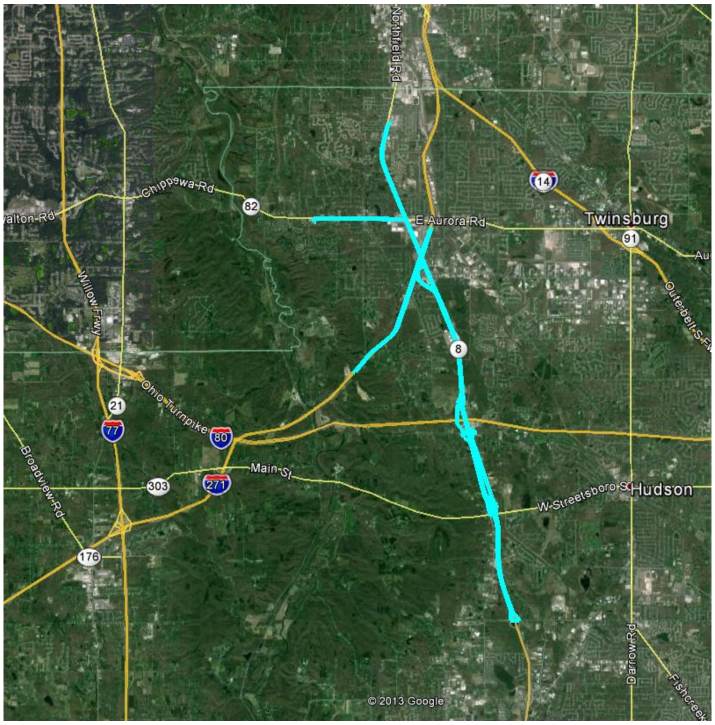


Standard Truck's Route - Aerial provided by Google Earth

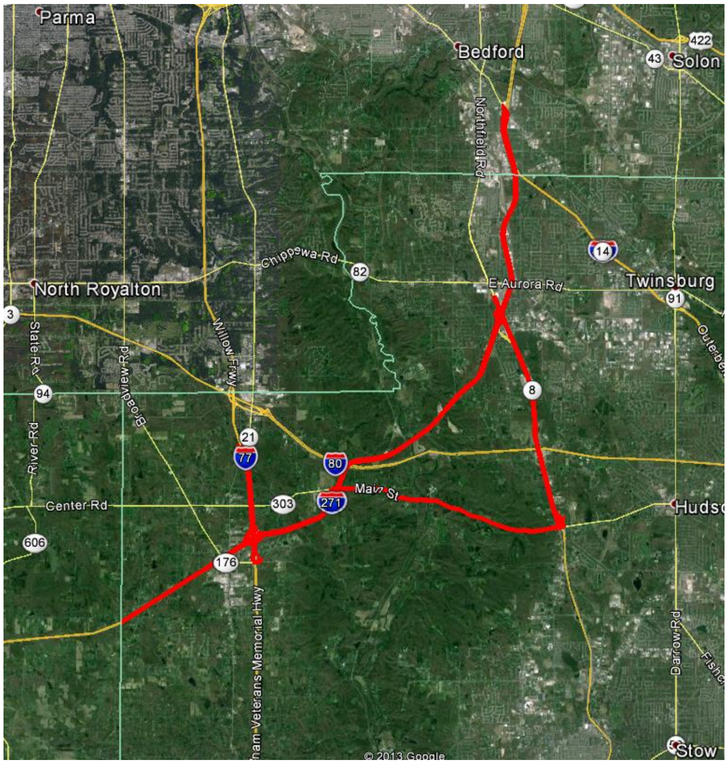
January 31, 2013





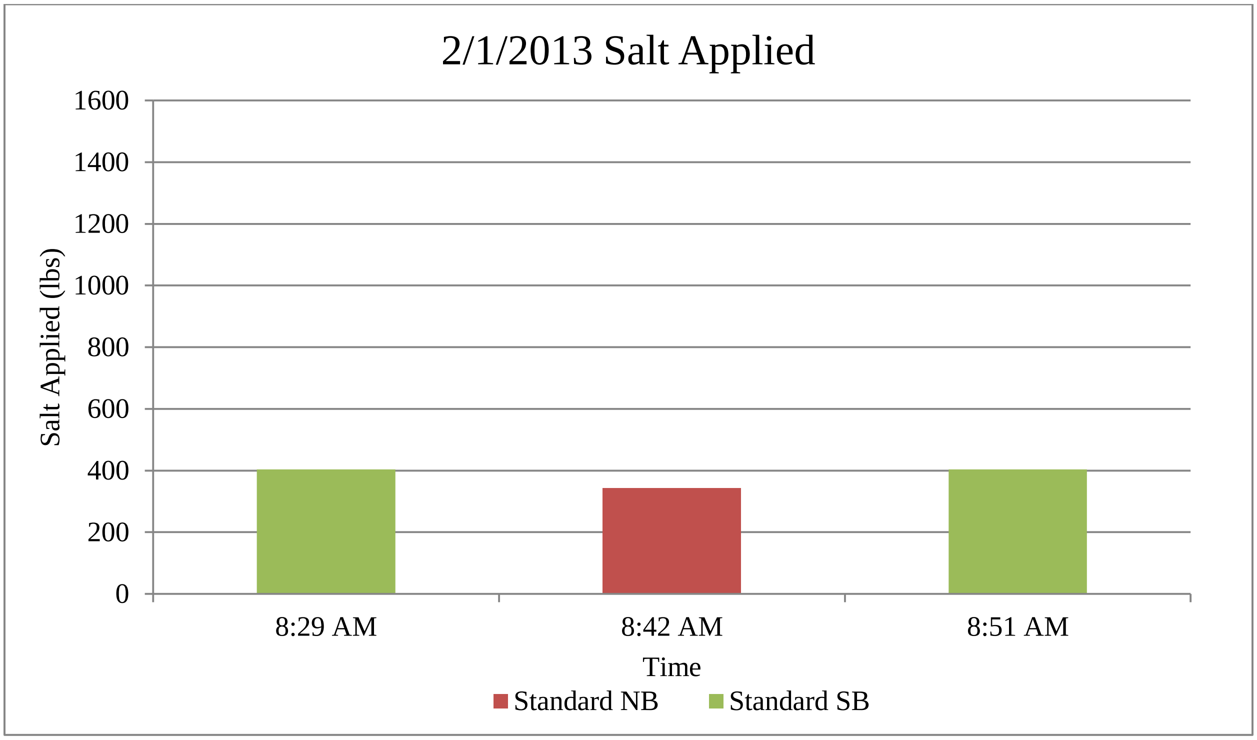


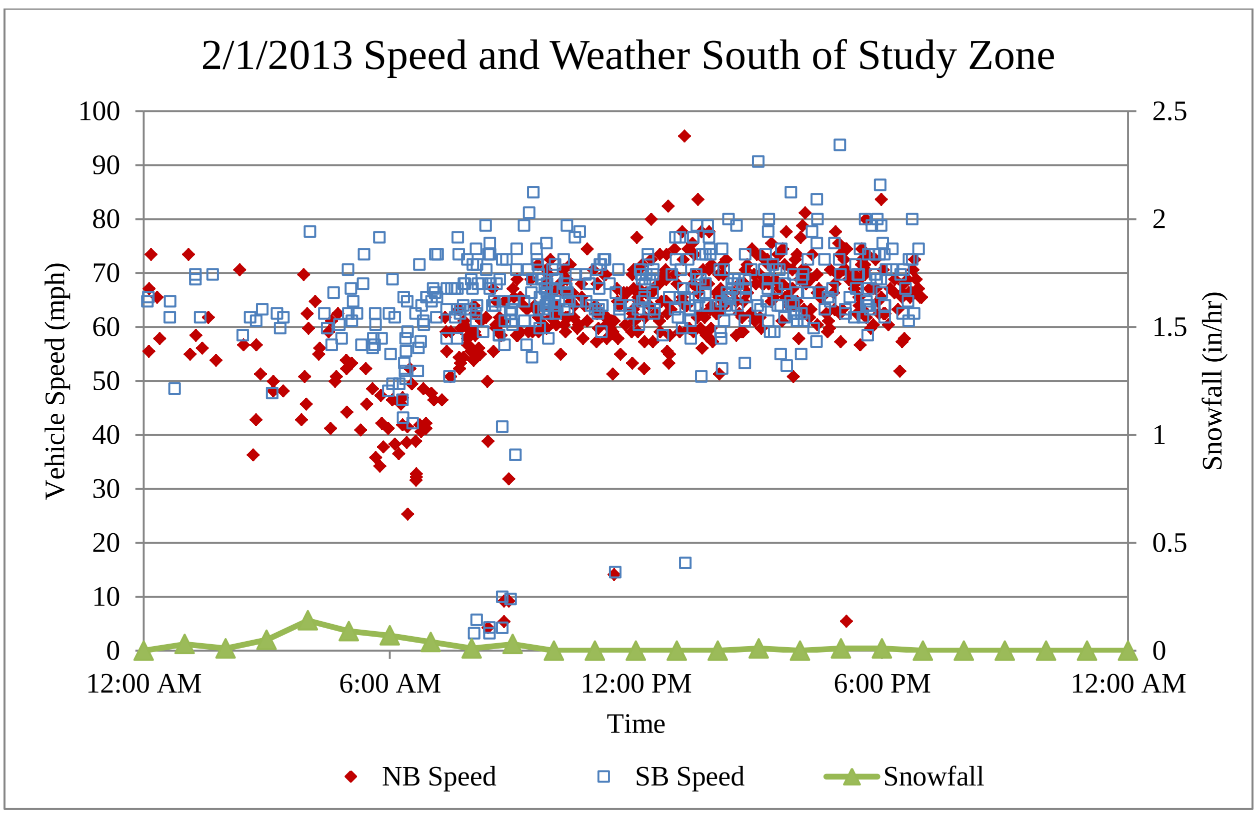
Epoke's Route - Aerial provided by Google Earth

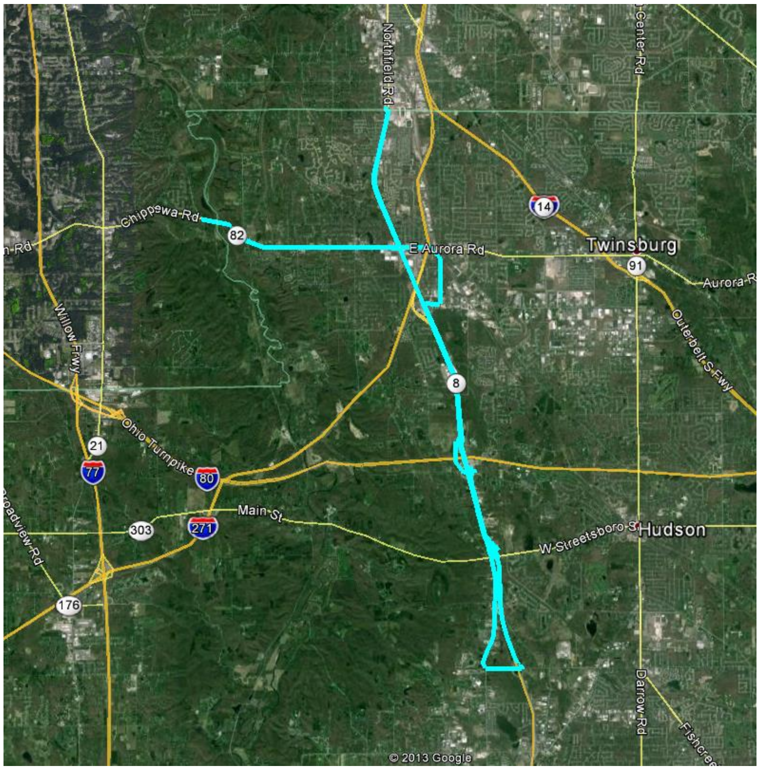


Standard Truck's Route - Aerial provided by Google Earth

February 1, 2013

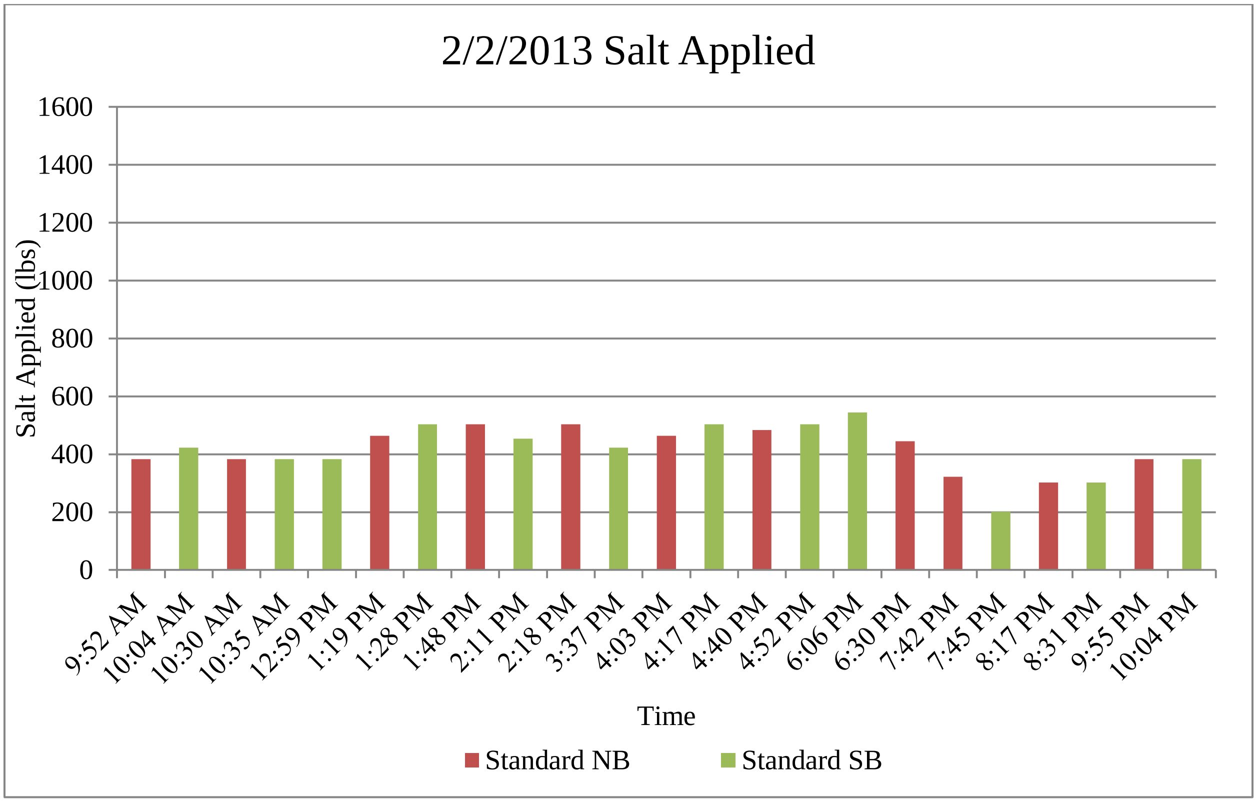


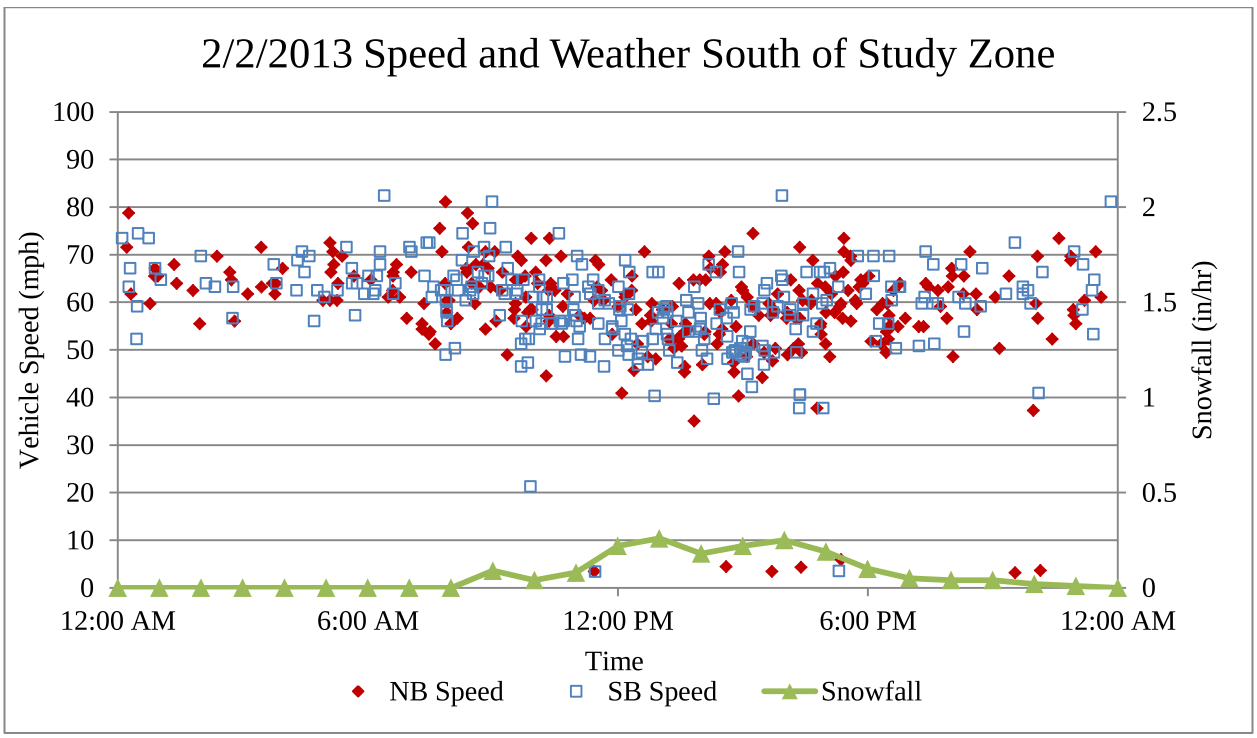


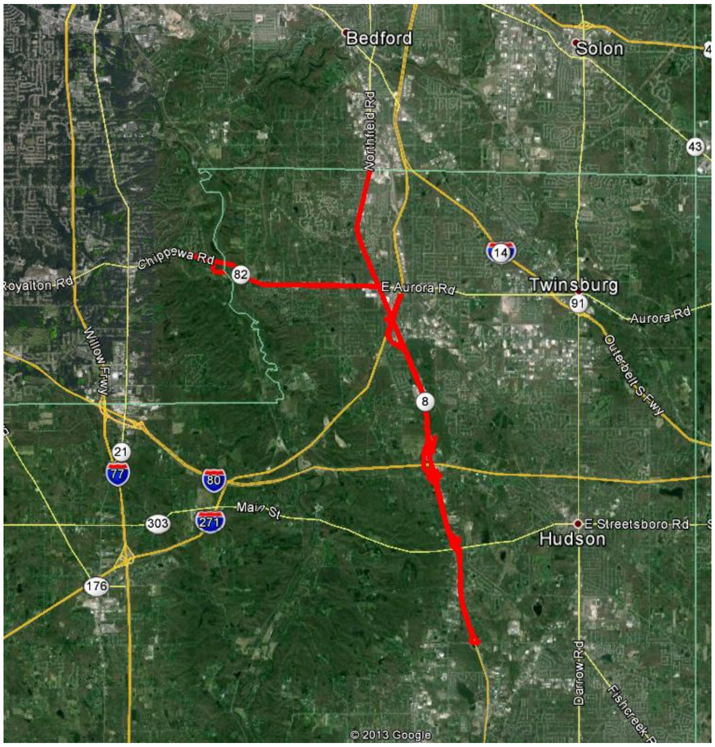


Epoke’s Route - Aerial provided by Google Earth

February 2, 2013

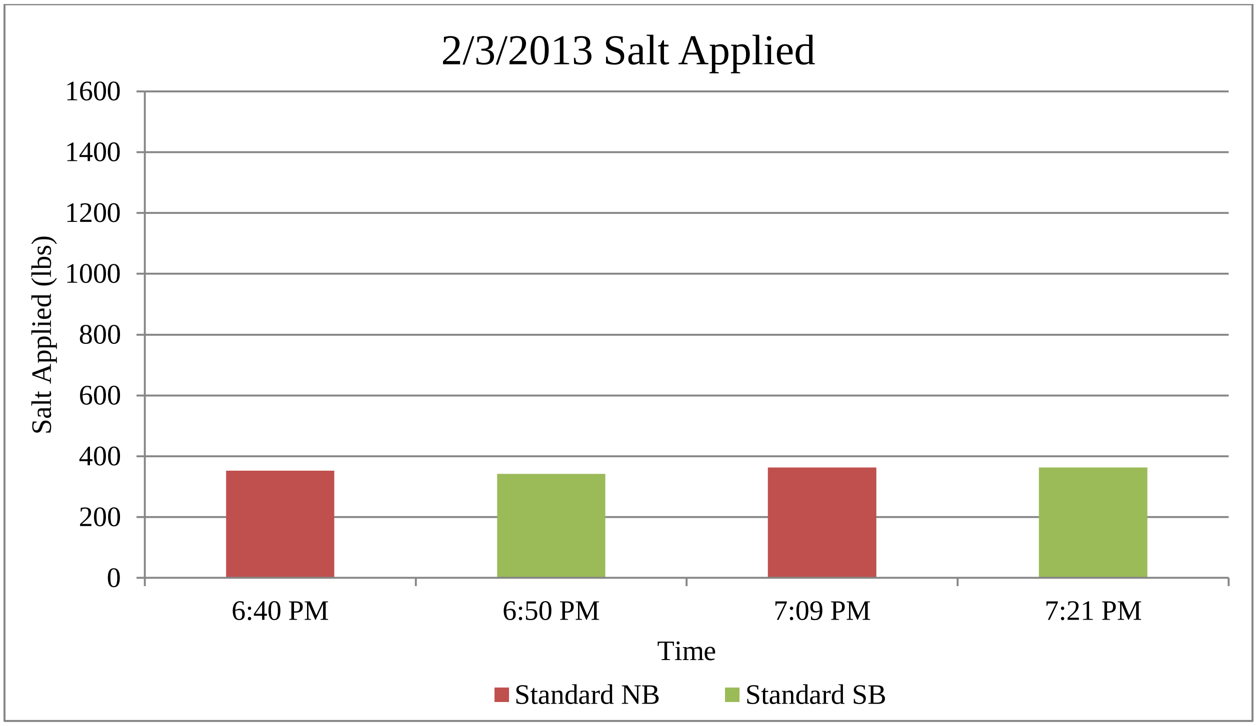


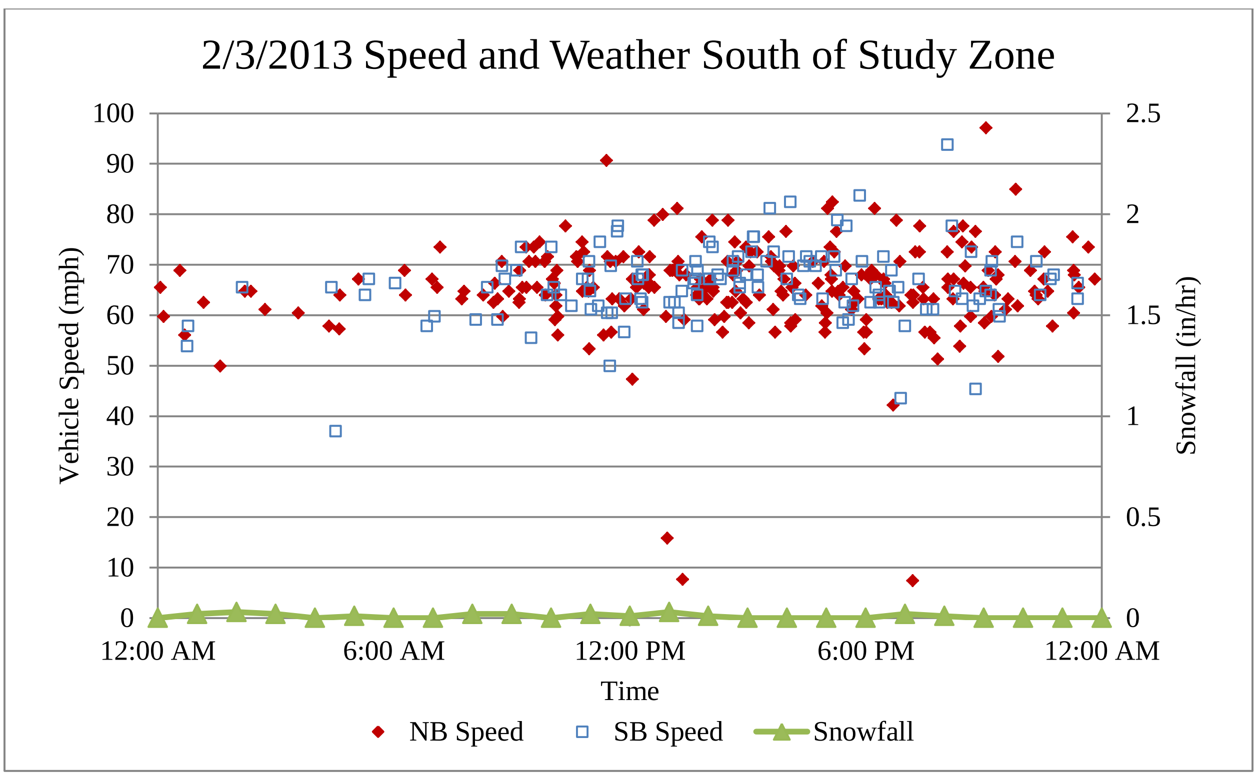


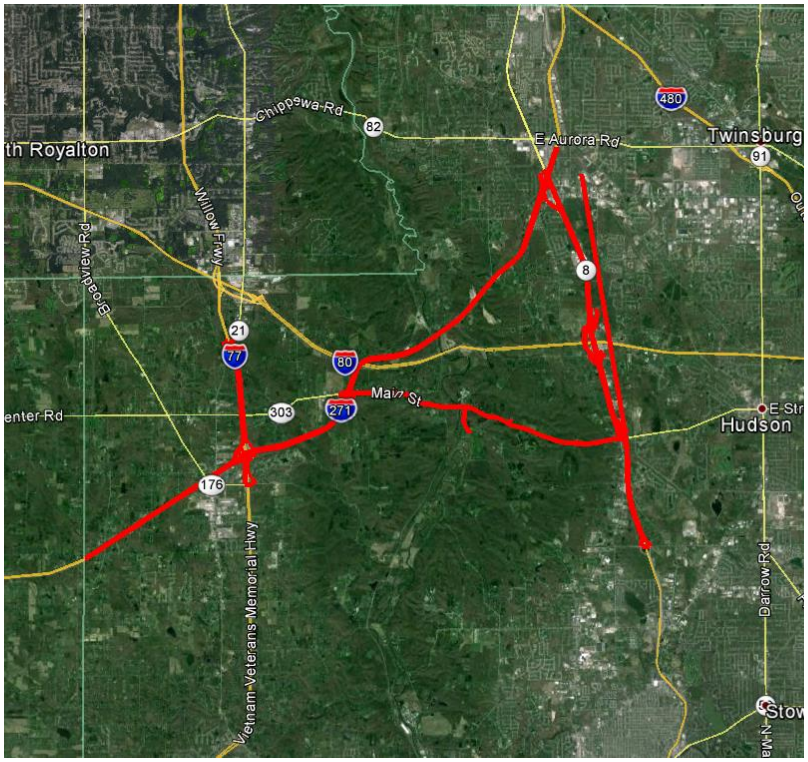


Standard Truck's Route - Aerial provided by Google Earth

February 3, 2013

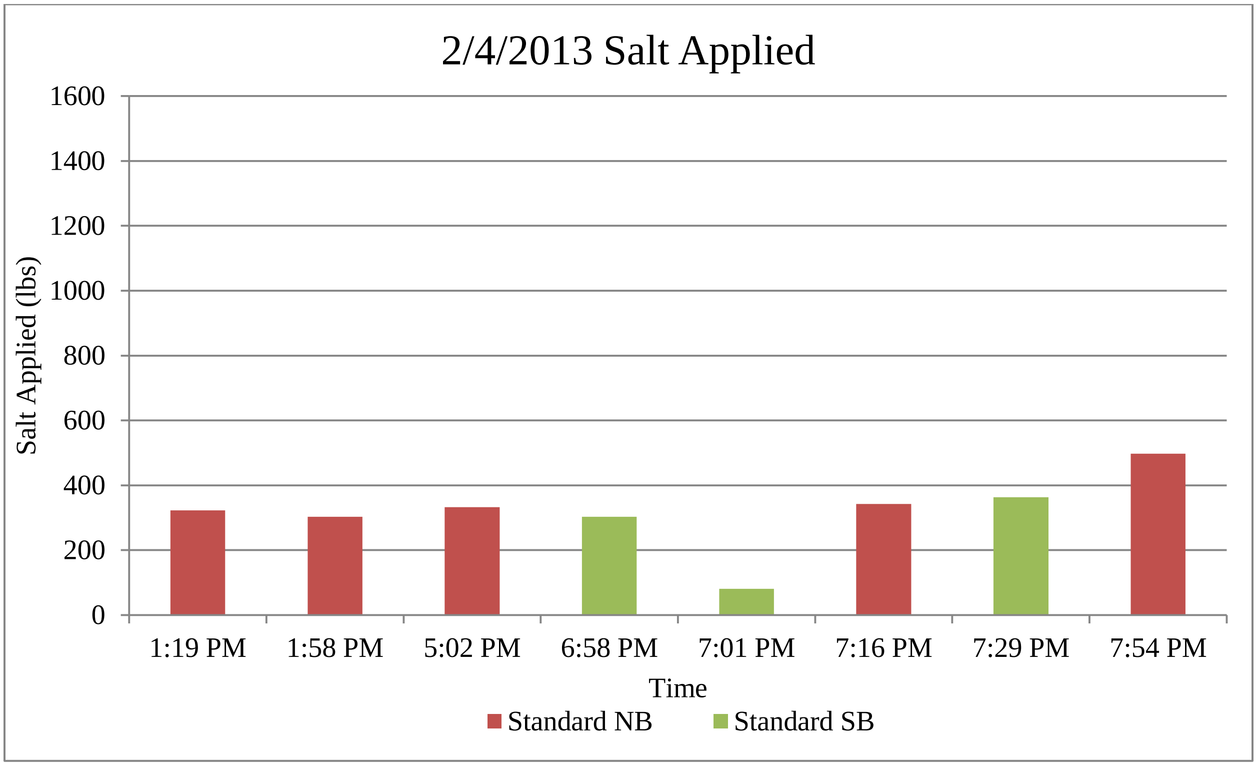


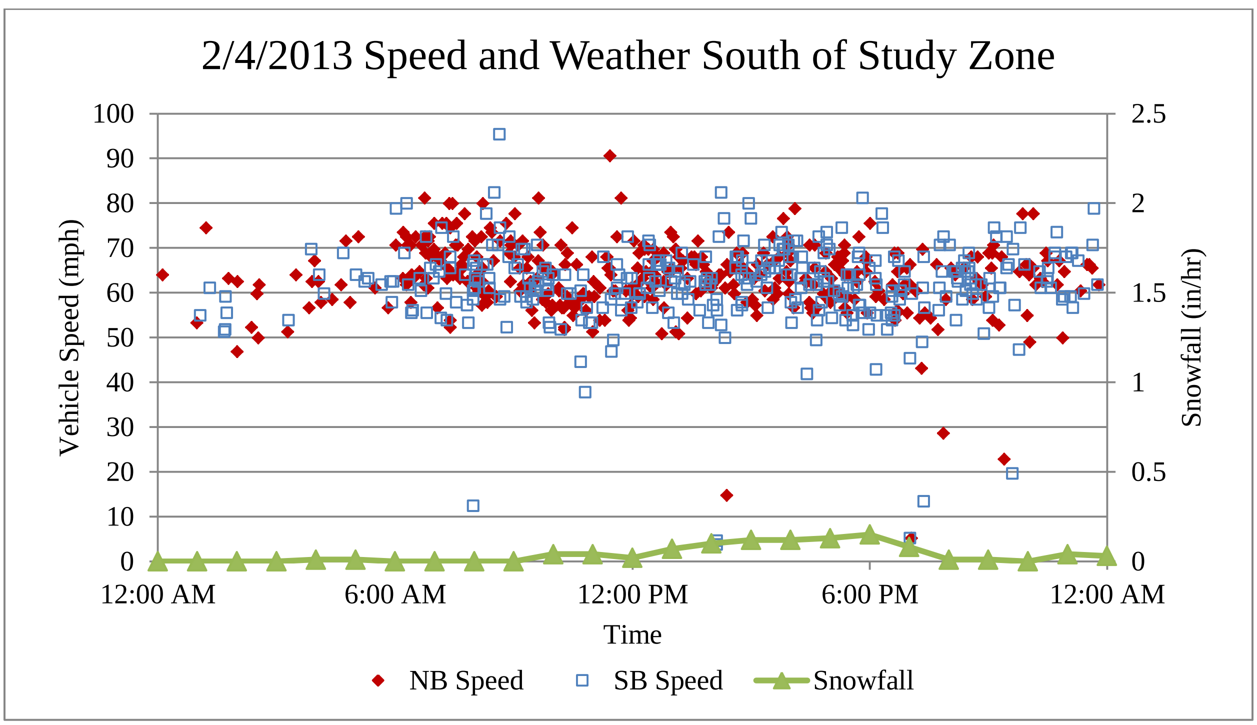


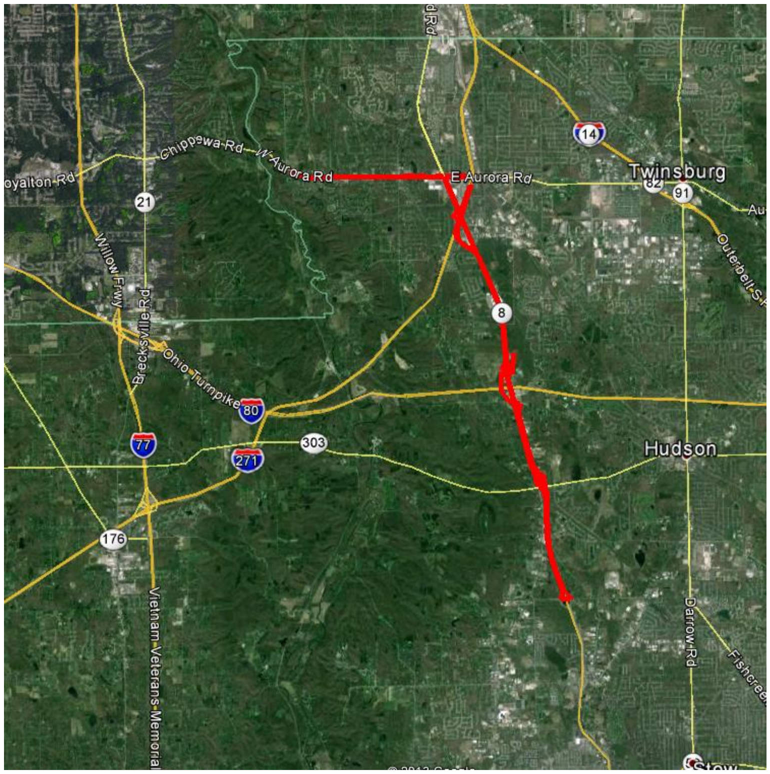


Standard Truck's Route - Aerial provided by Google Earth

February 4, 2013

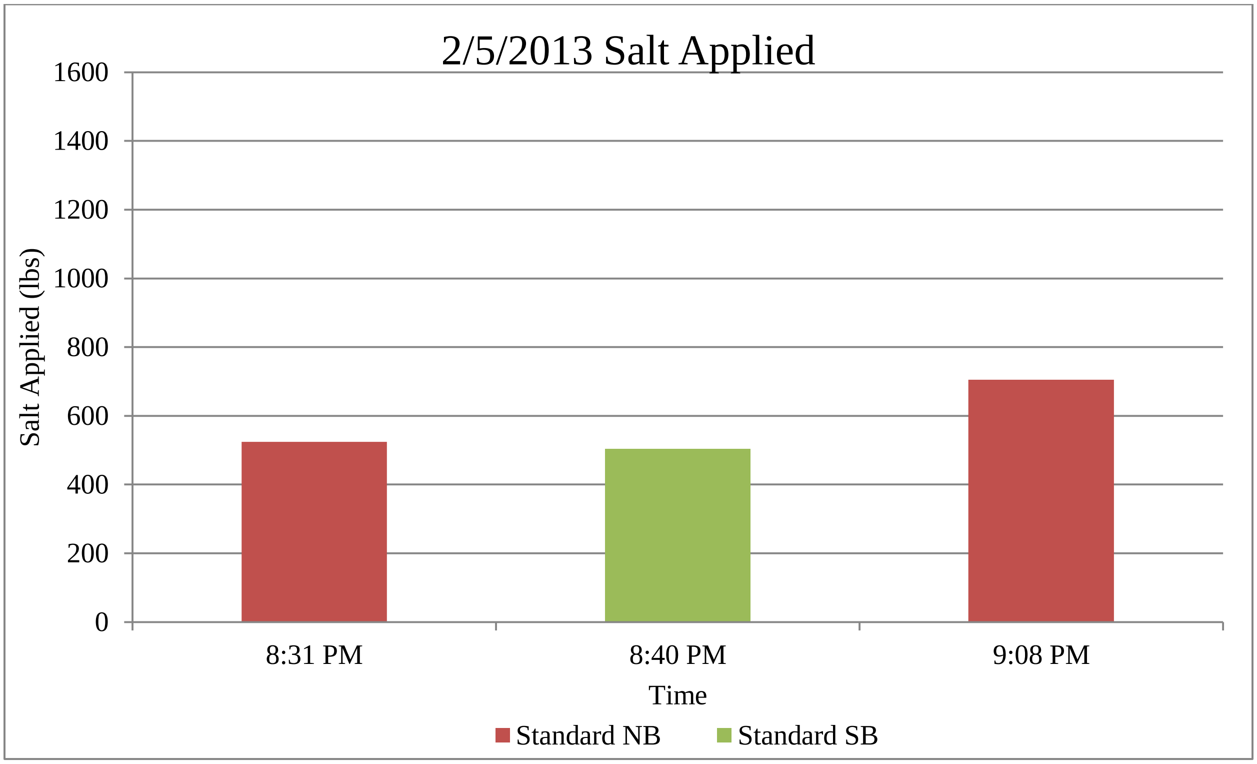


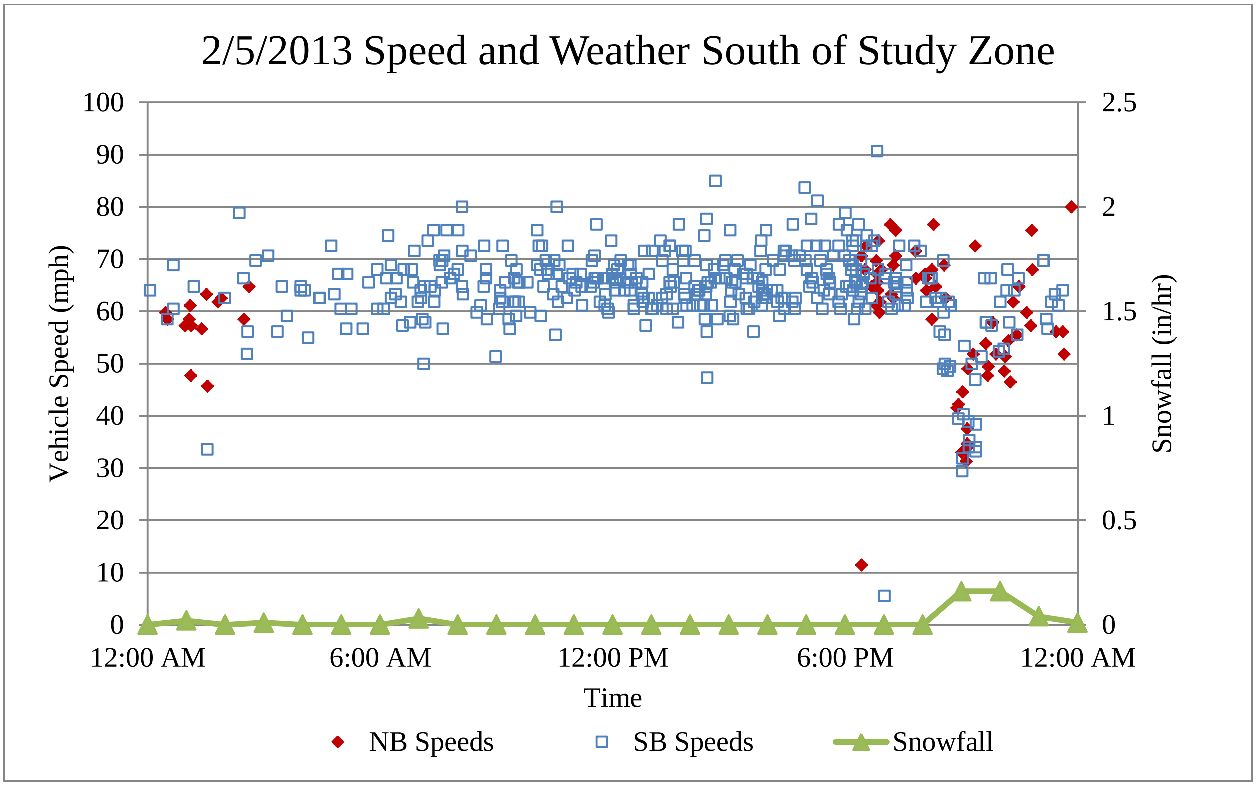


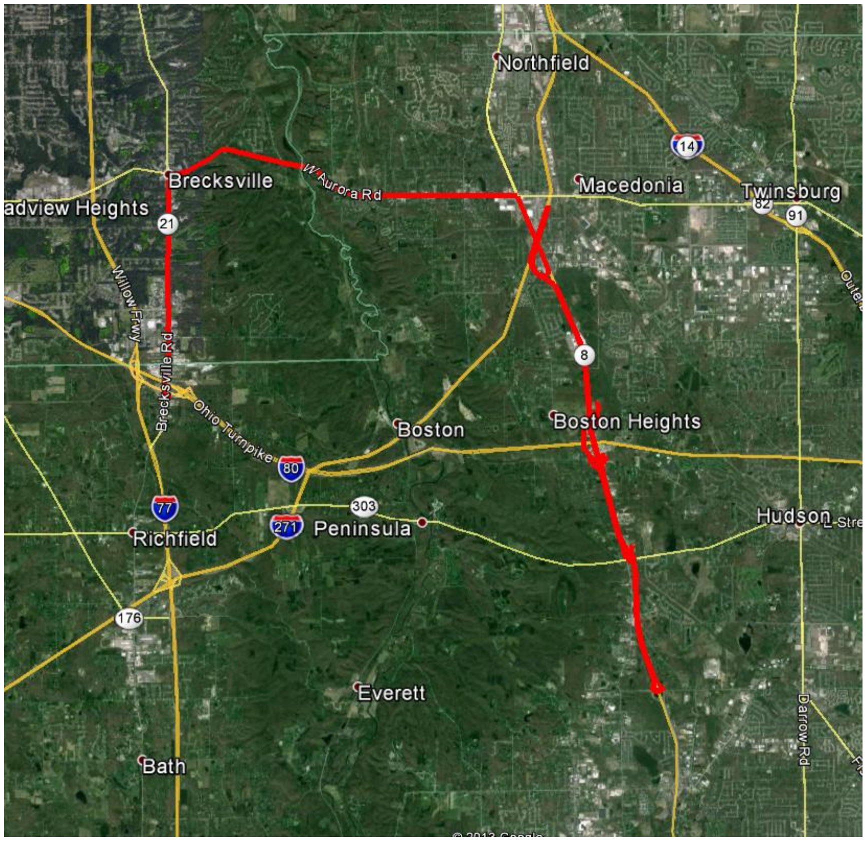


Standard Truck's Route - Aerial provided by Google Earth

February 5, 2013

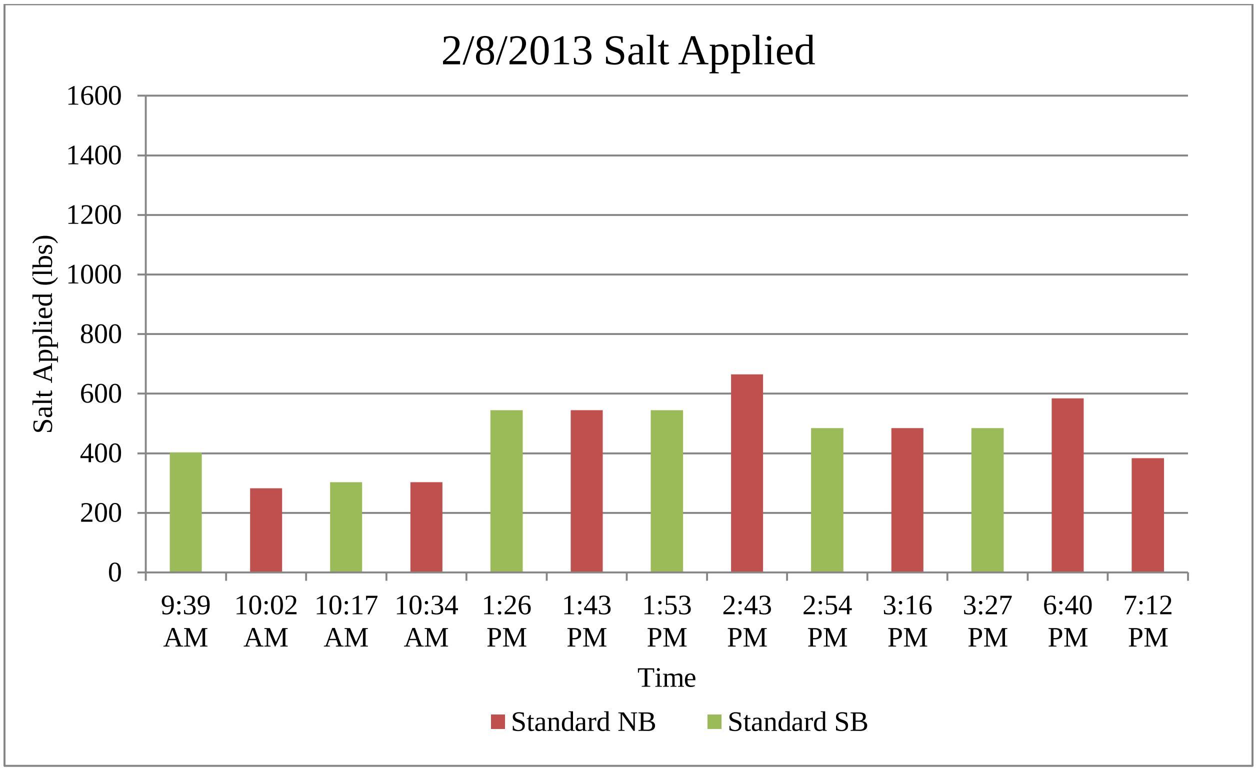


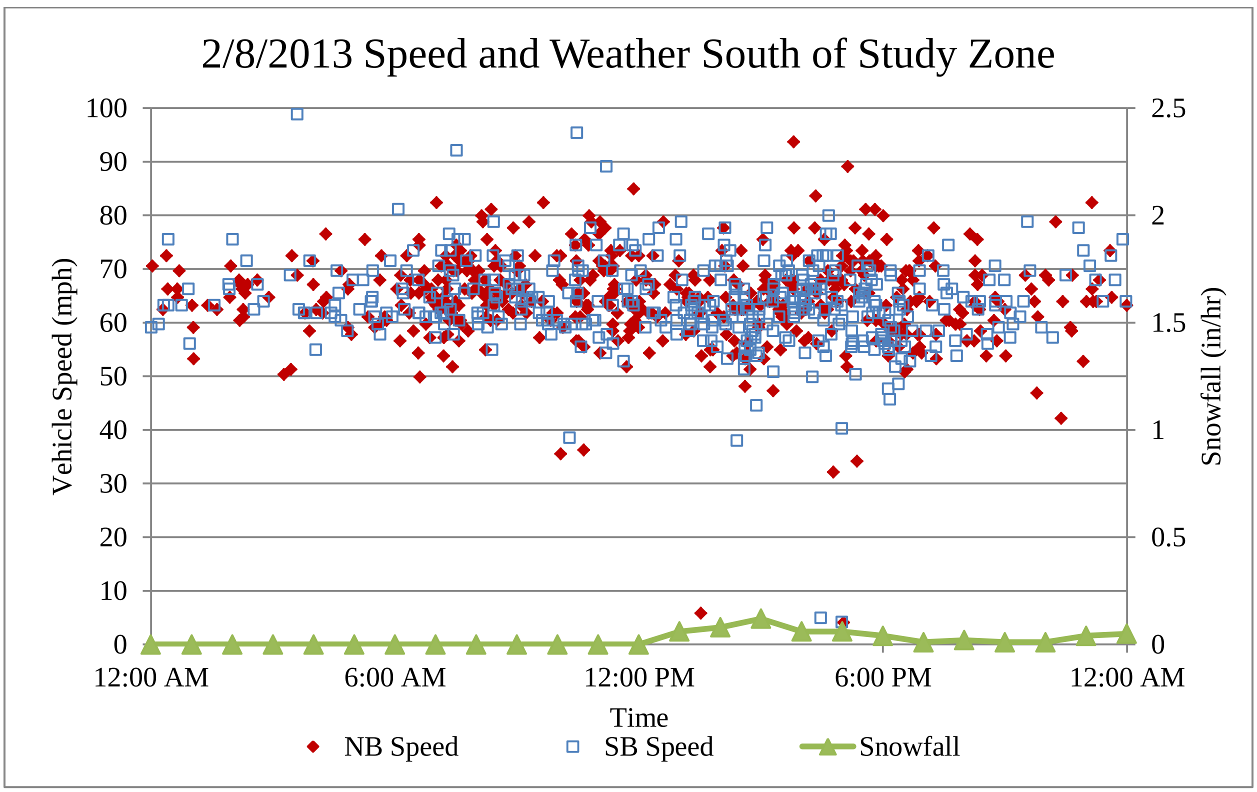


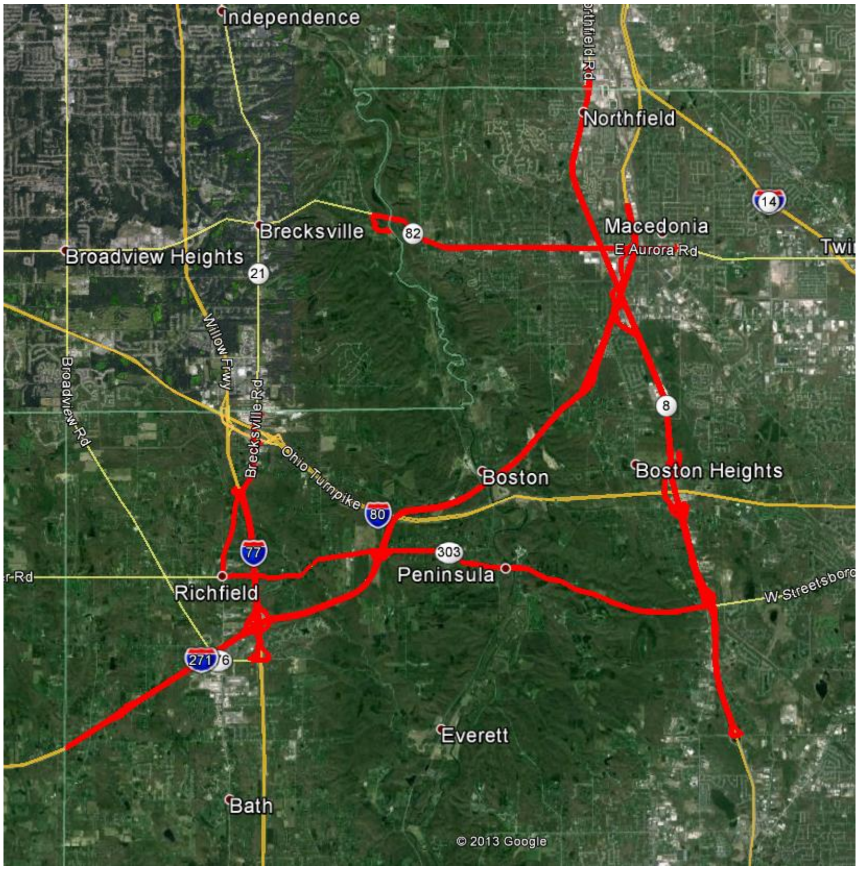


Standard Truck’s Route - Aerial provided by Google Earth

February 8, 2013

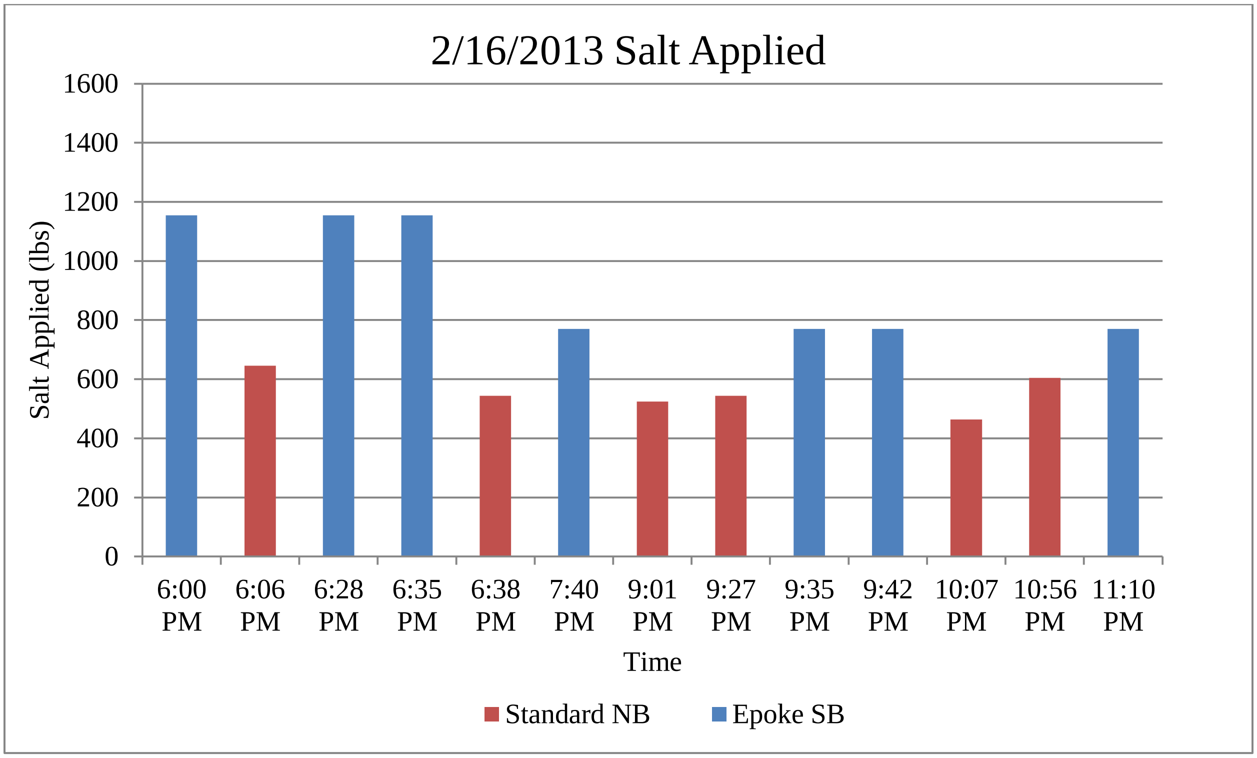


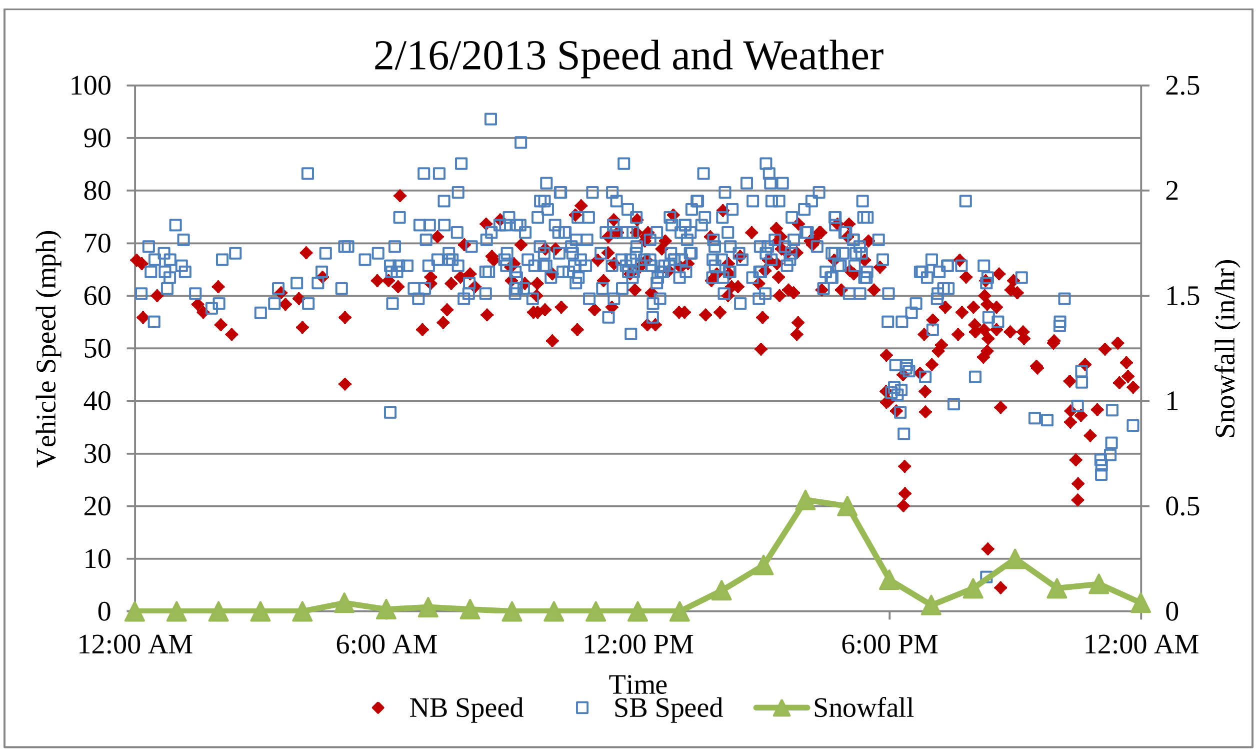


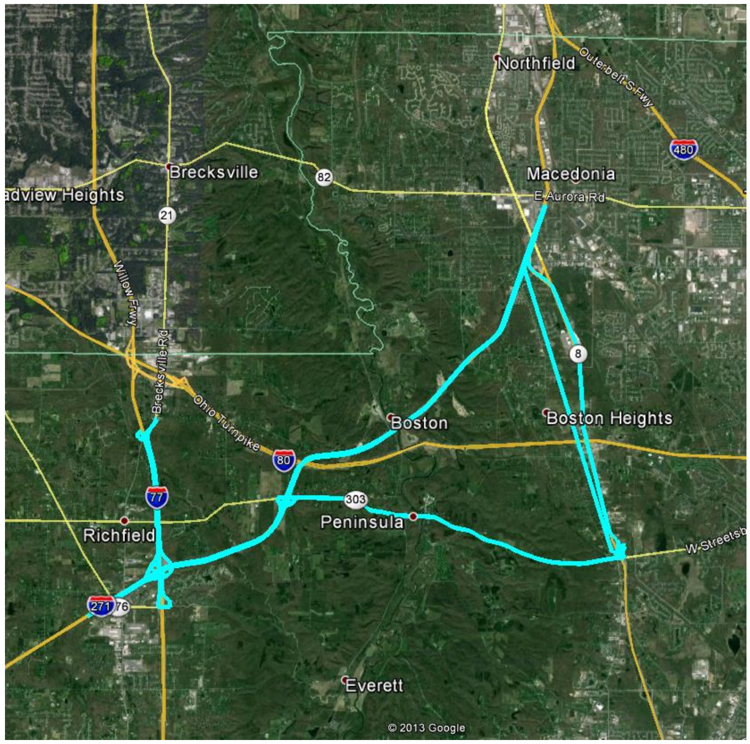


Standard Truck's Route - Aerial provided by Google Earth

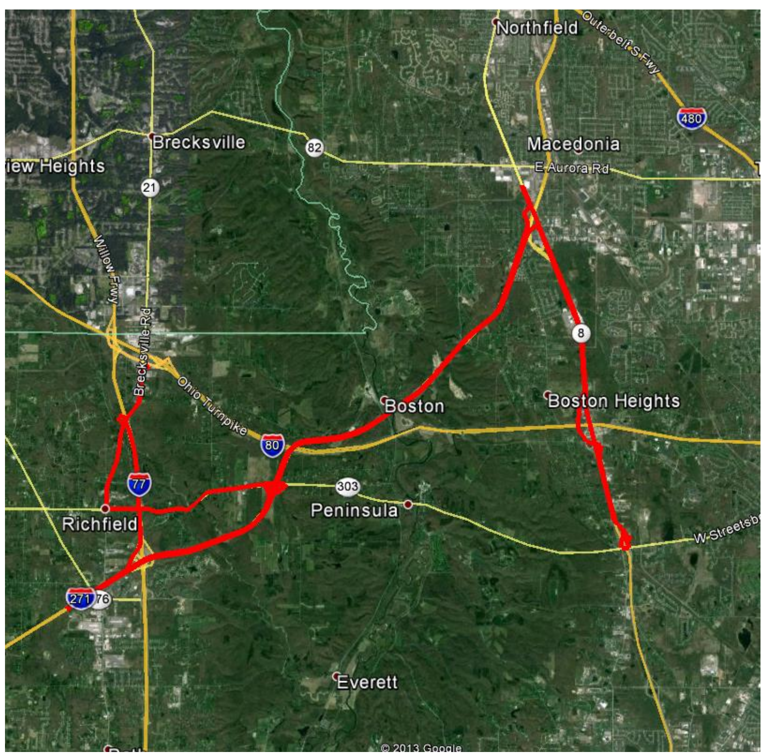
February 16, 2013





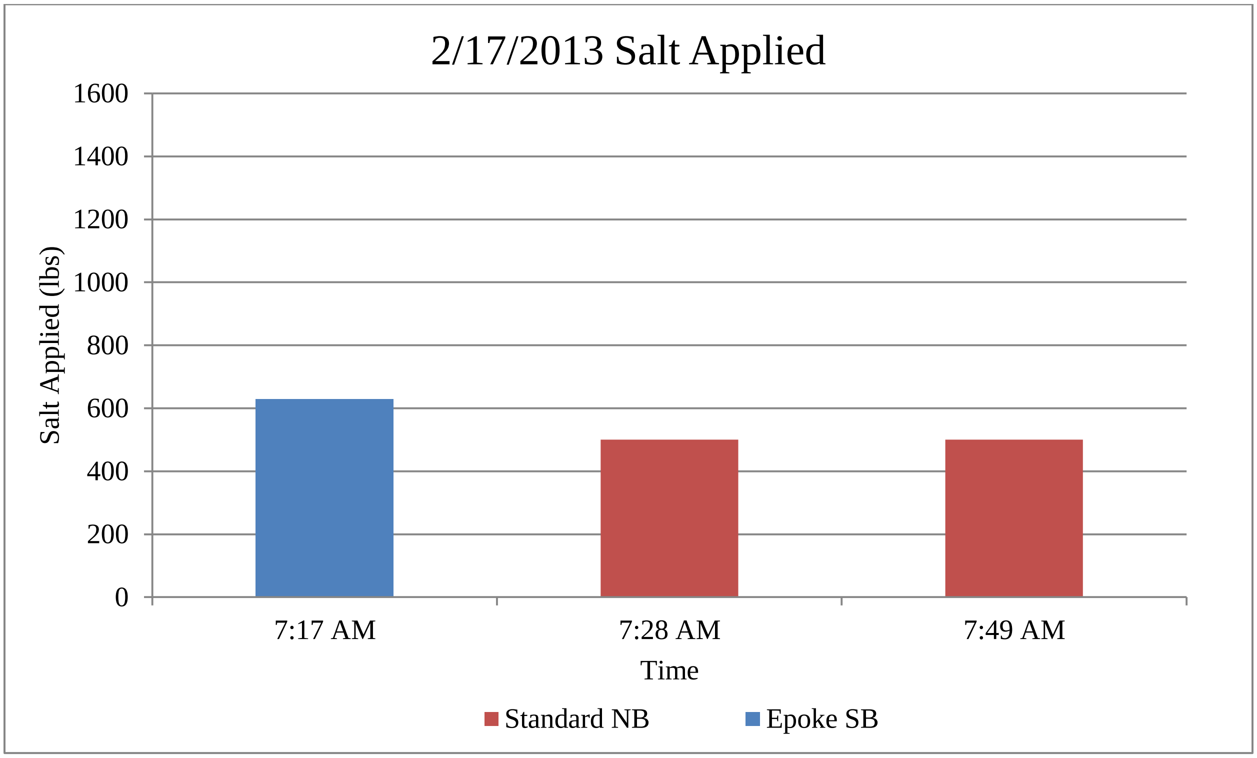


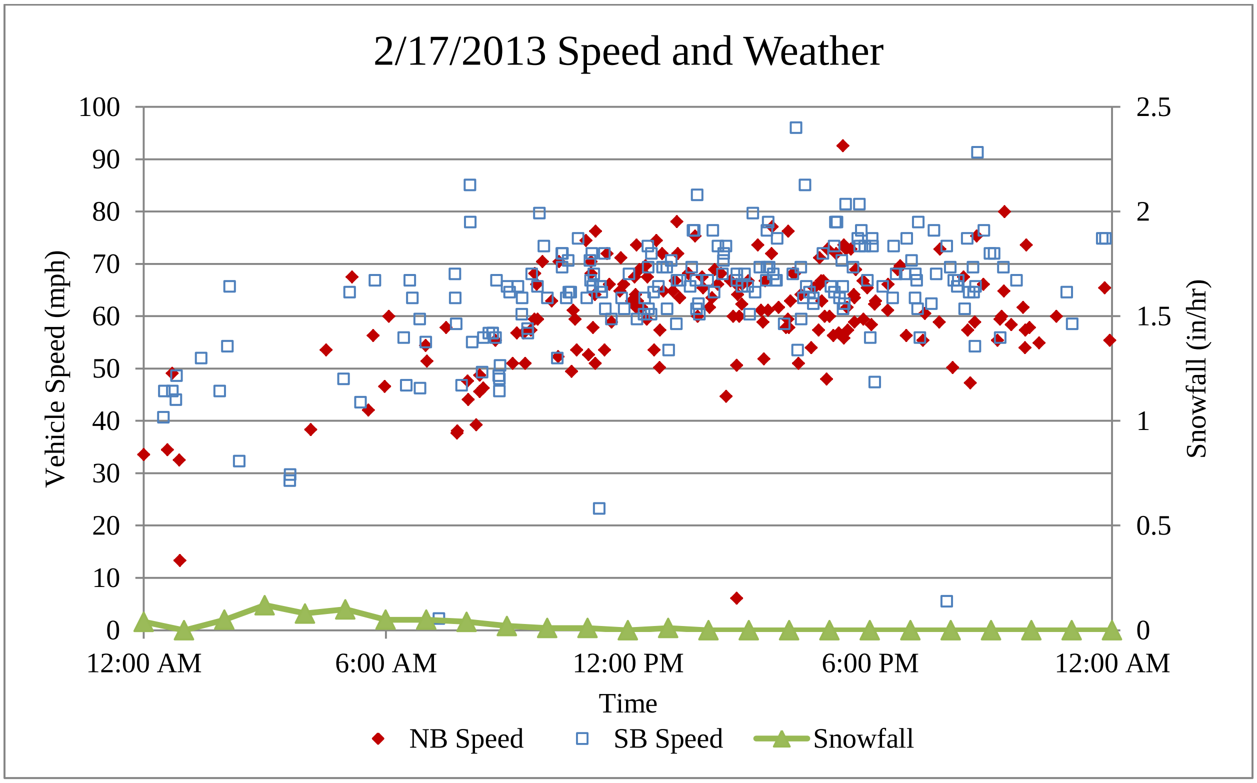
Epoke's Route - Aerial provided by Google Earth

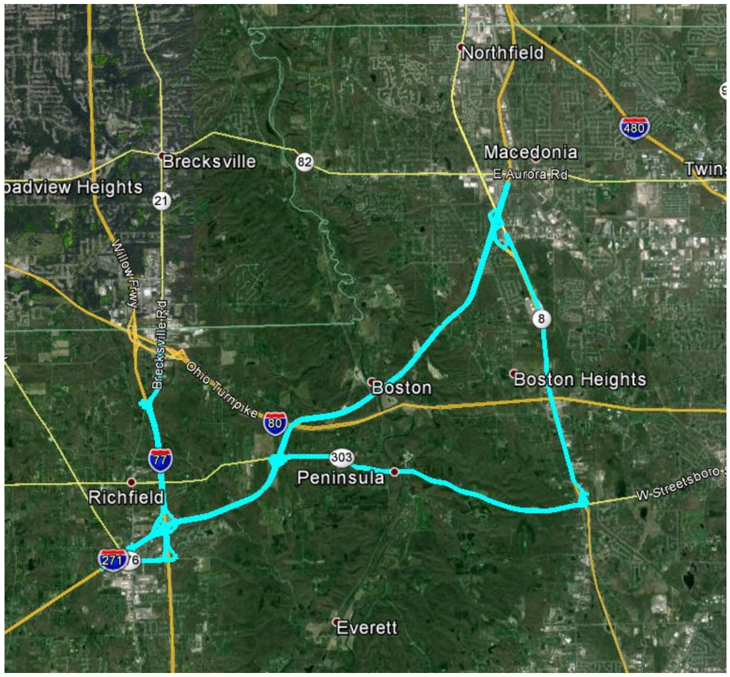


Standard Truck's Route - Aerial provided by Google Earth

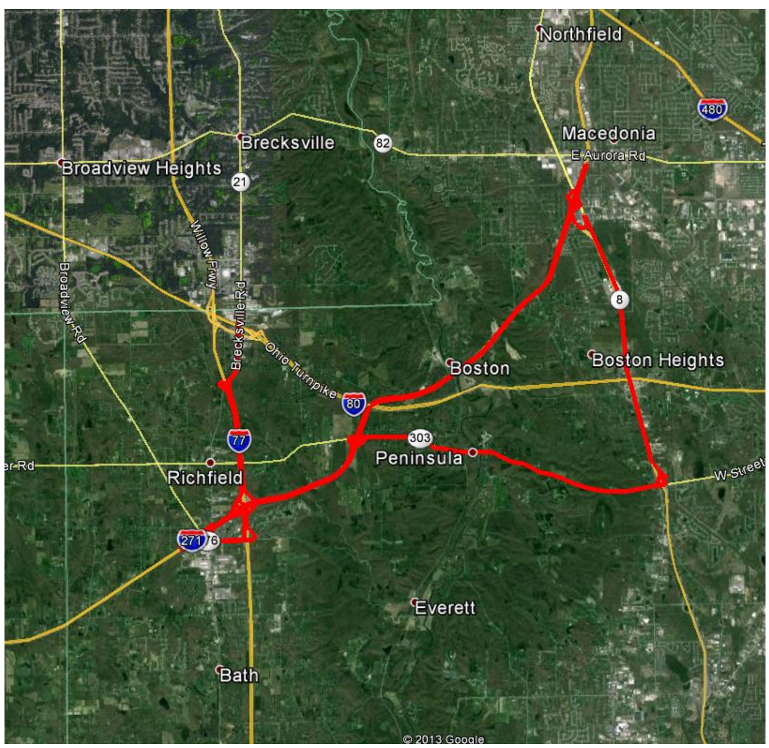
February 17, 2013





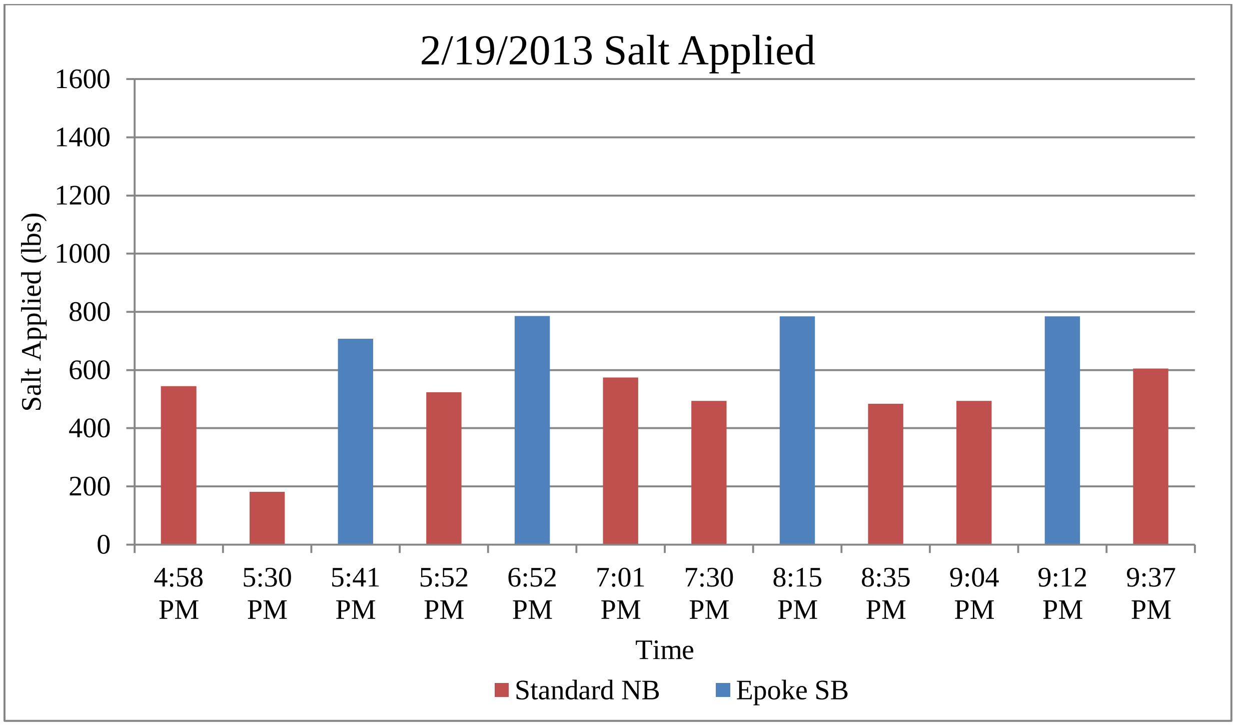


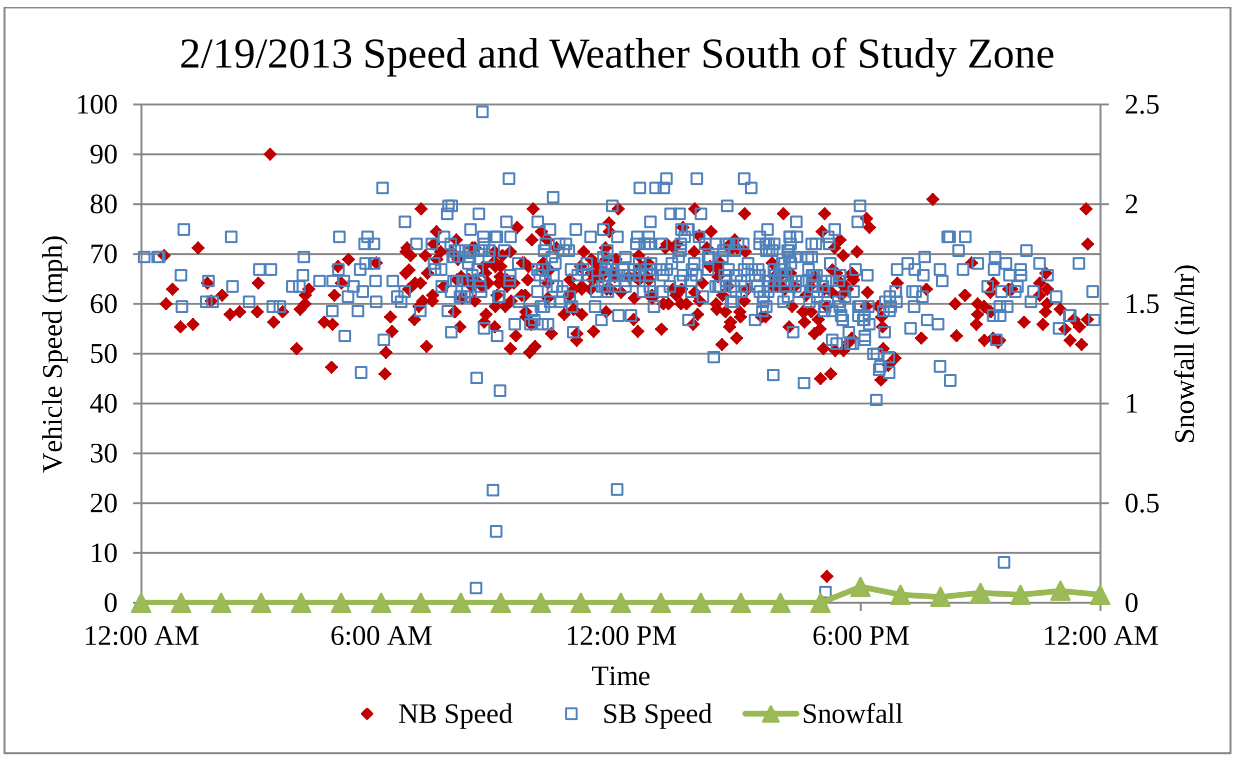
Epoke’s Route - Aerial provided by Google Earth

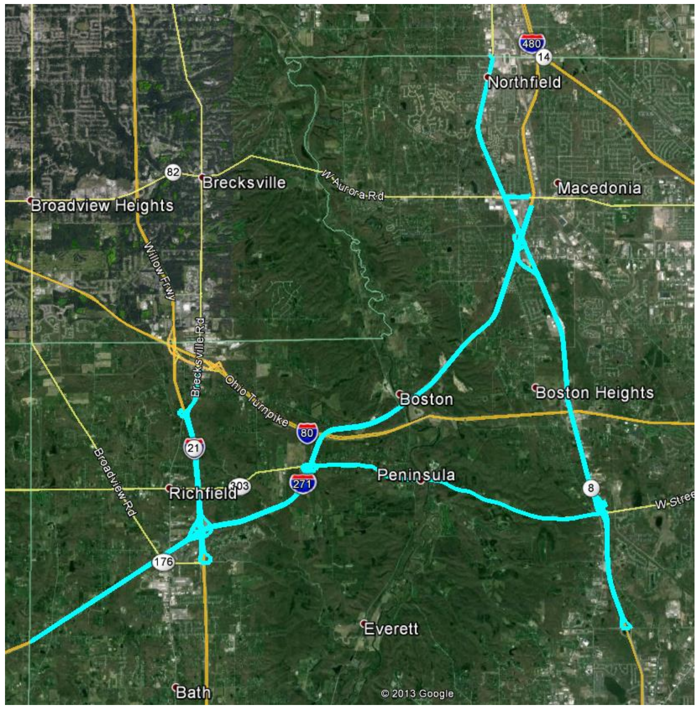


Standard Truck’s Route - Aerial provided by Google Earth

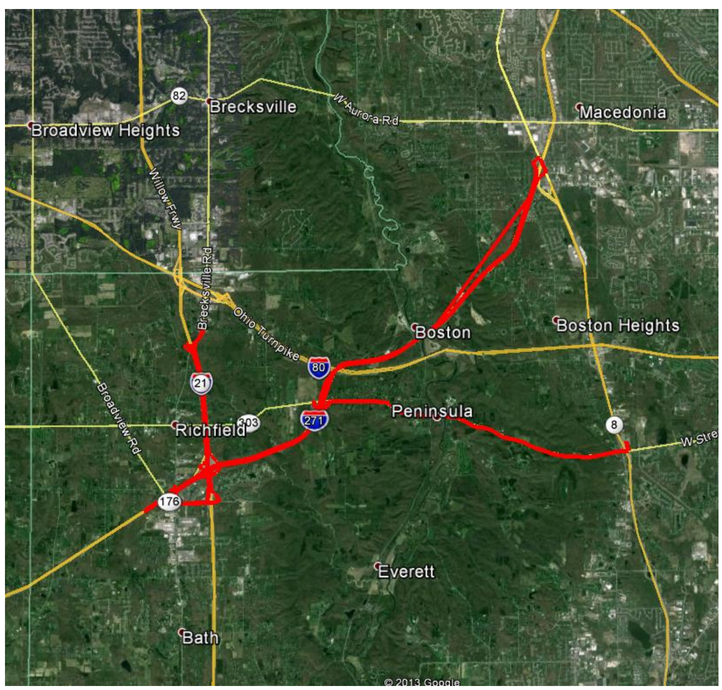
February 19, 2013





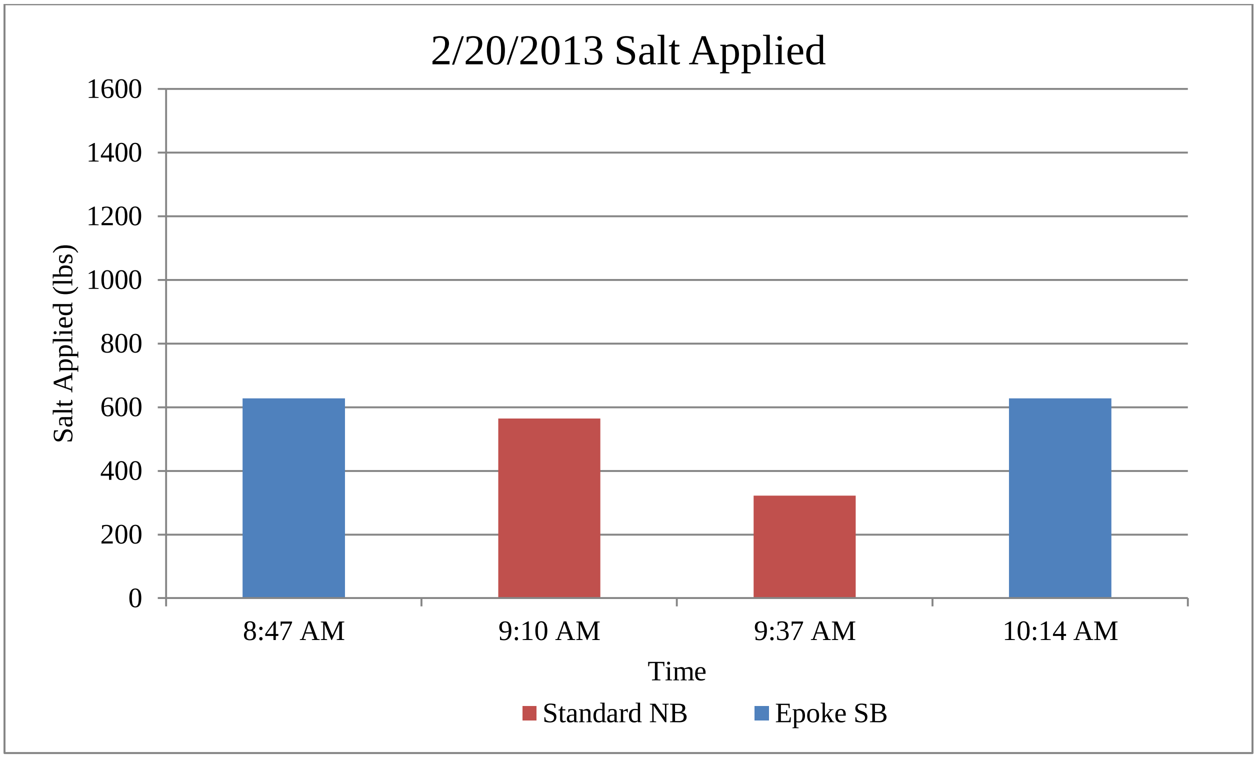


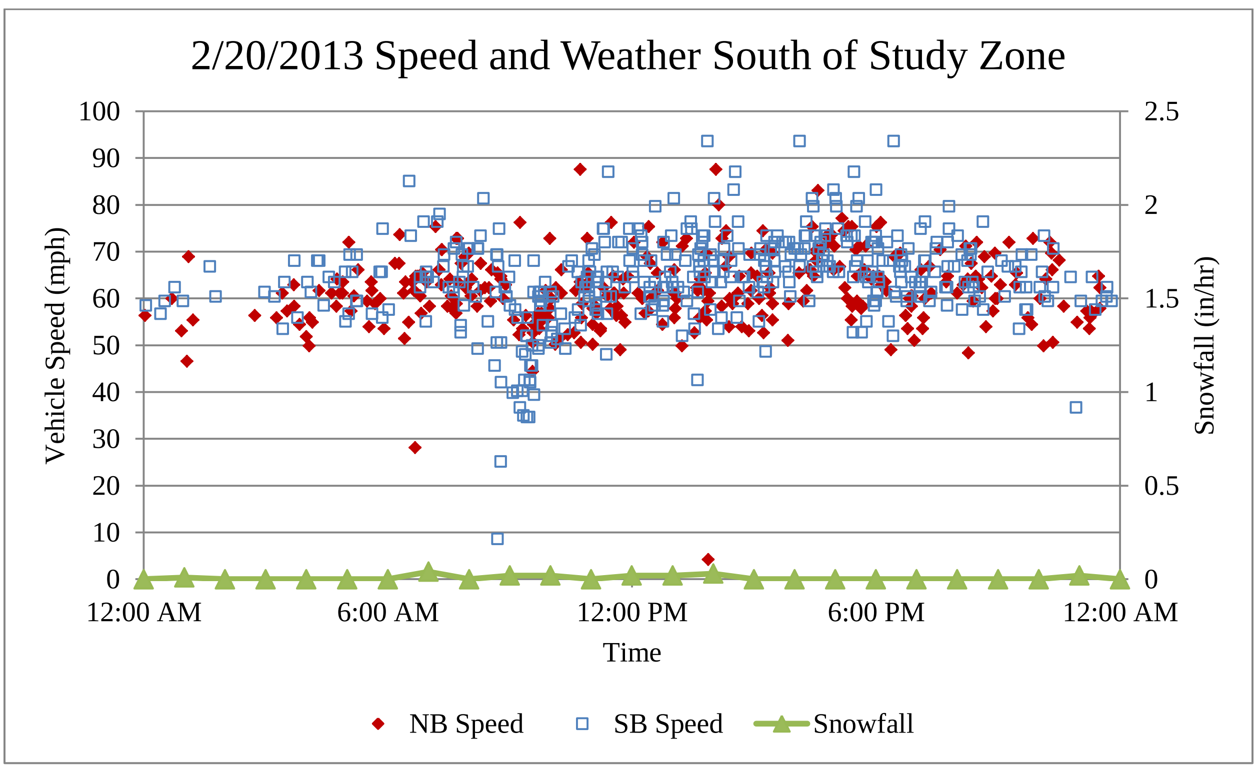
Epoke's Route - Aerial provided by Google Earth

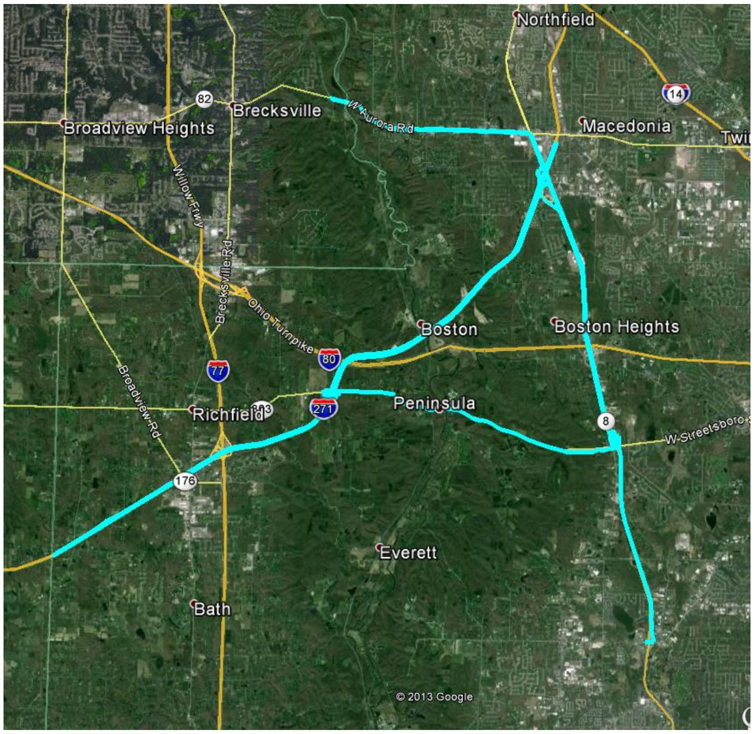


Standard Truck's Route - Aerial provided by Google Earth

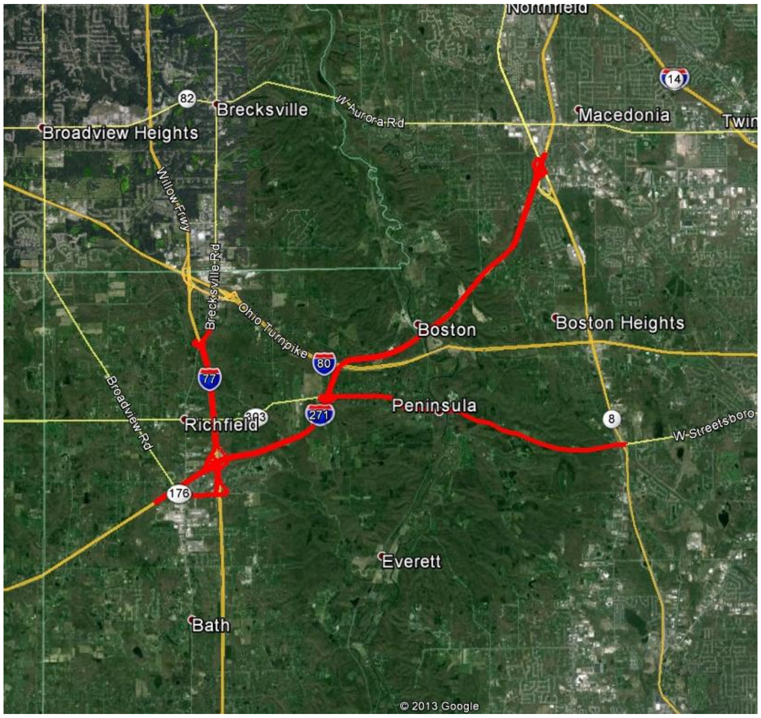
February 20, 2013





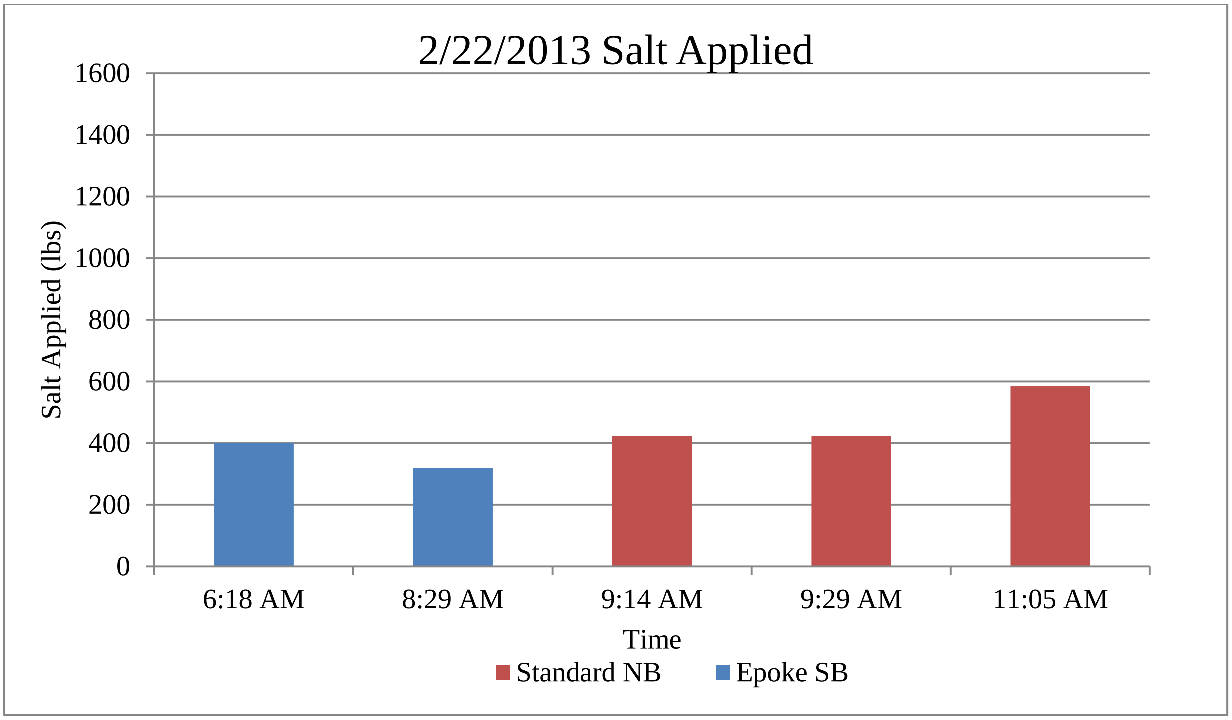


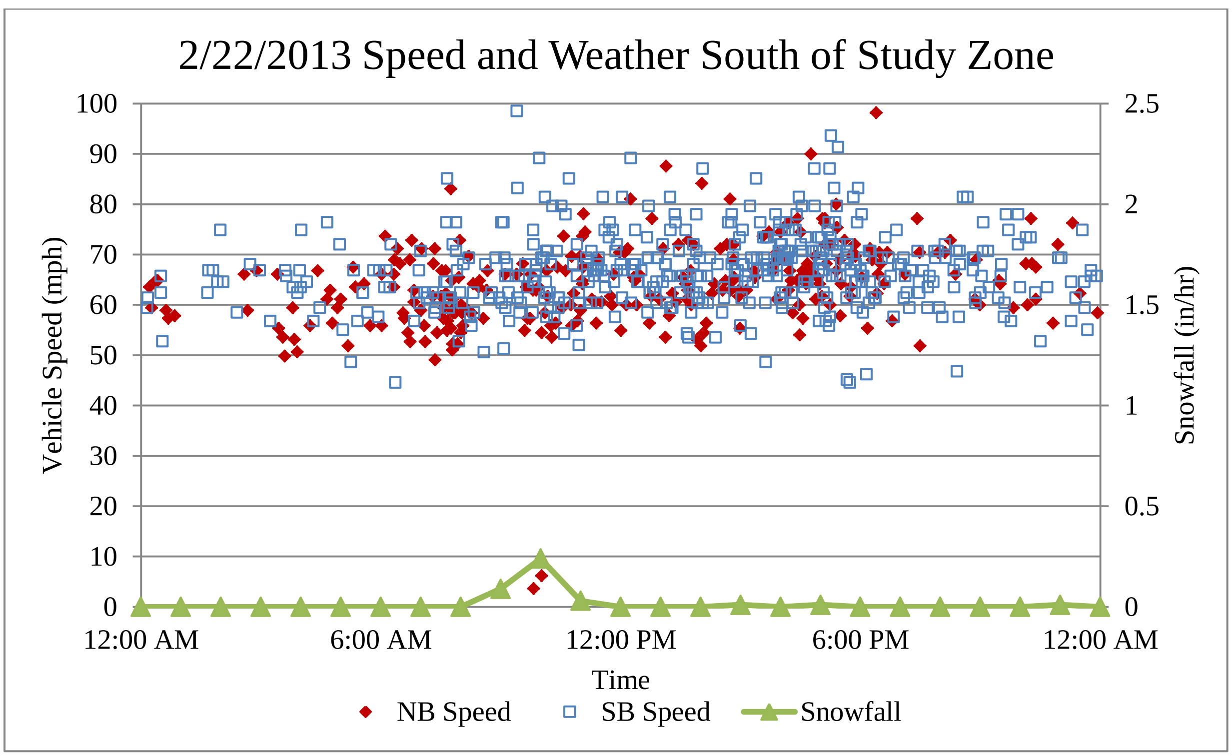
Epoke’s Route - Aerial provided by Google Earth



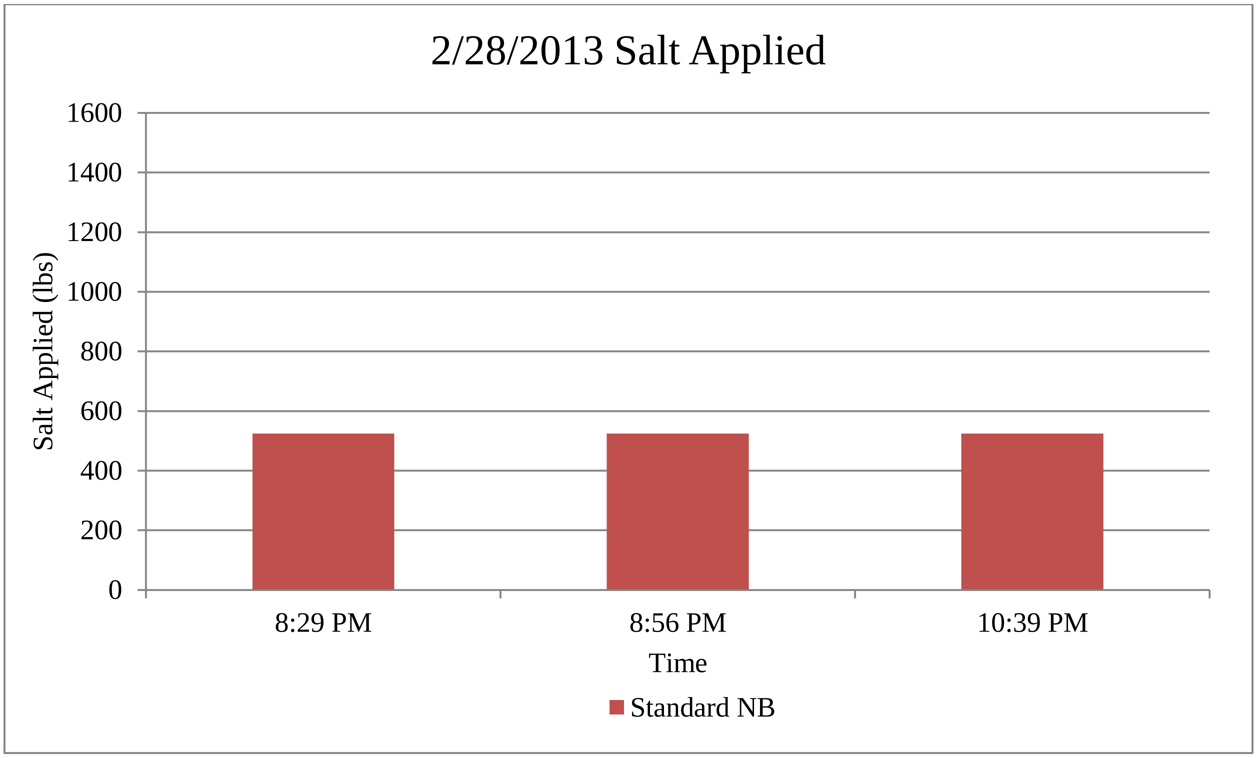
Standard Truck’s Route - Aerial provided by Google Earth

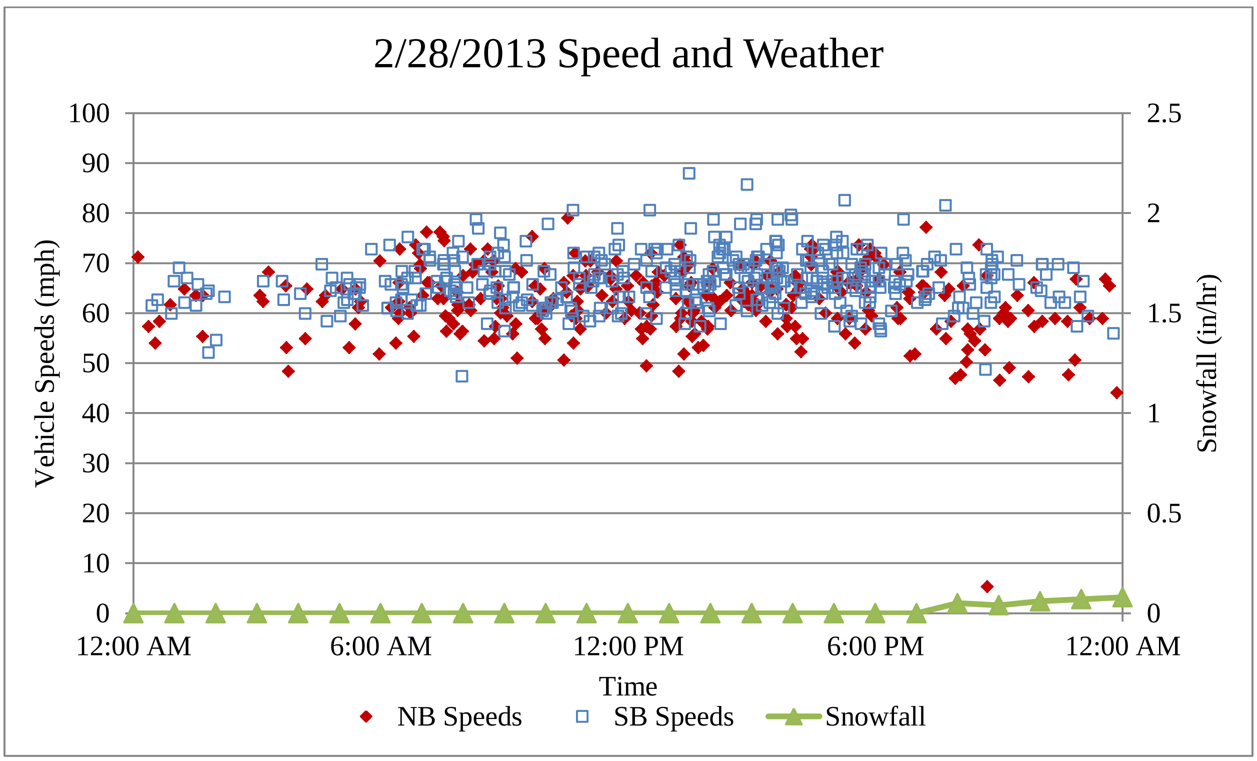
February 22, 2013

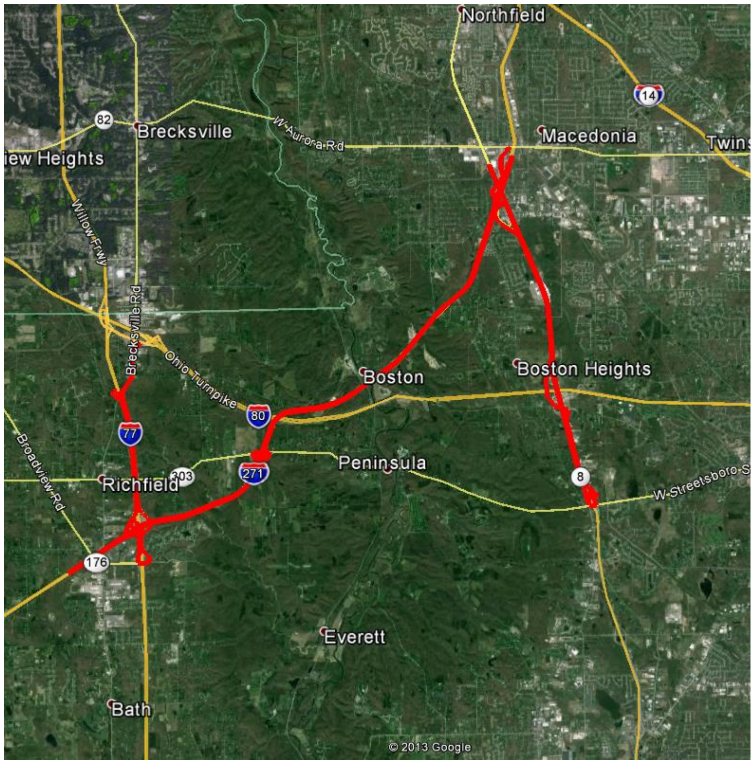




February 28, 2013

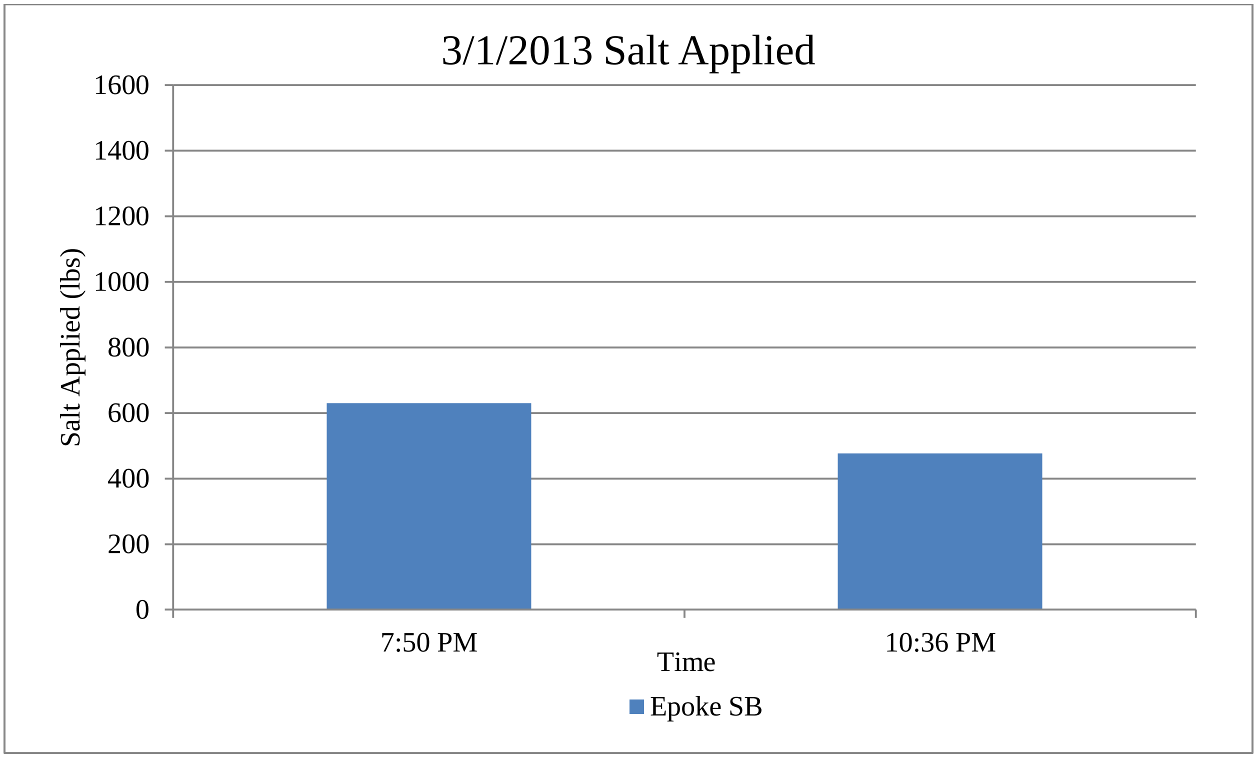




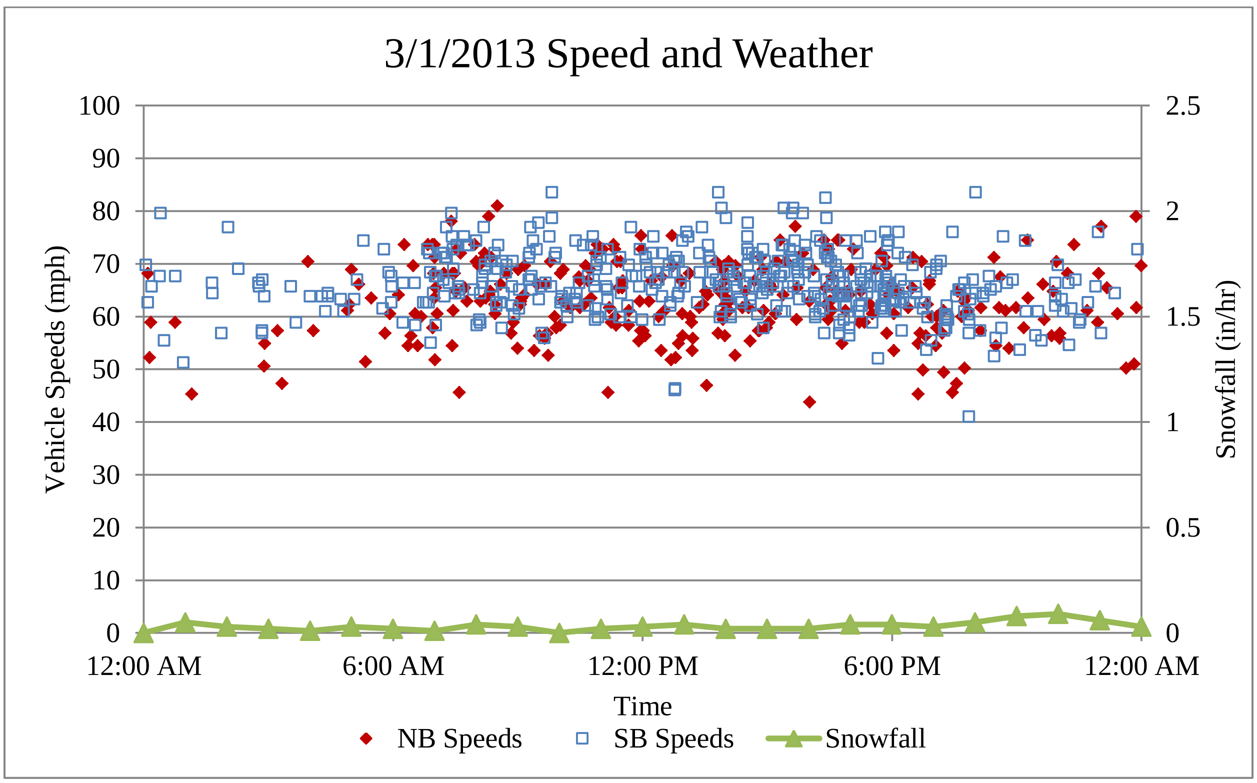


Standard Truck's Route - Aerial provided by Google Earth

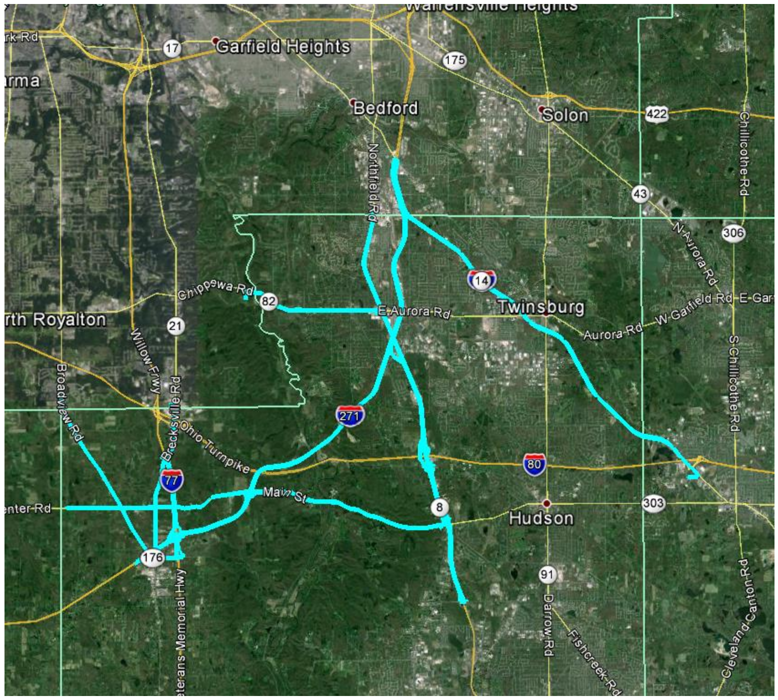
March 1, 2013



3/1/2013 Salt Applied
1600
1400
1200
1000
800
600
400
200
0
Salt Applied (lbs)
7:50 PM
10:36 PM
Time
Epoke SB

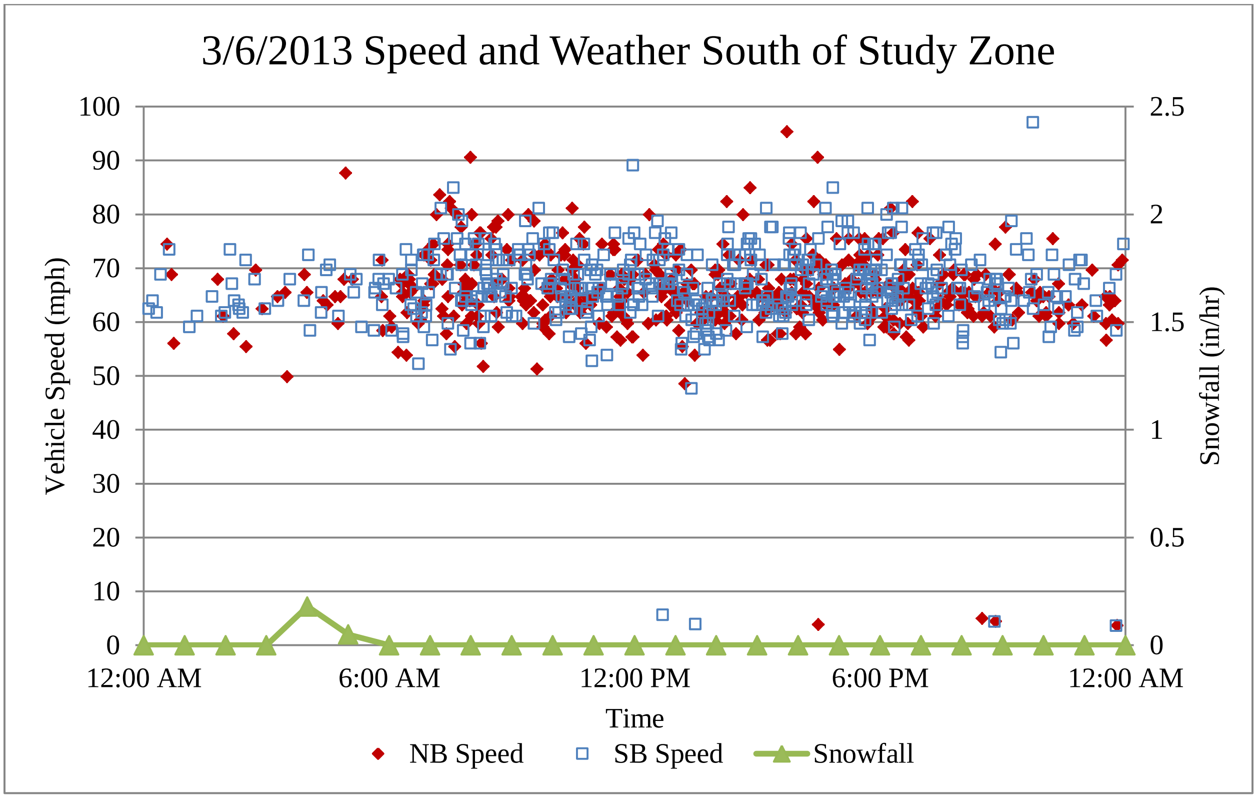


3/1/2013 Speed and Weather
100
90
80
70
60
50
40
30
20
10
0
Vehicle Speeds (mph)
2.5
2
1.5
1
0.5
0
Snowfall (in/hr)
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Time
NB Speeds
SB Speeds
Snowfall



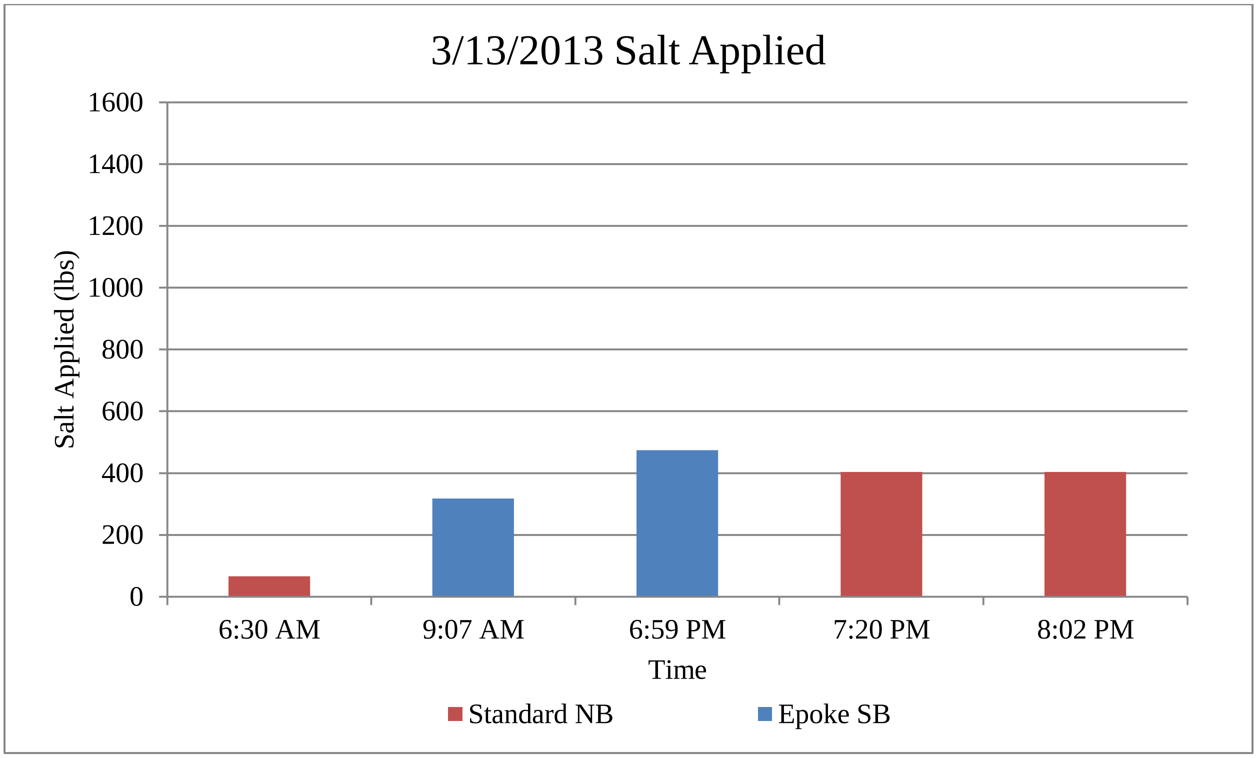
Epoke’s Route - Aerial provided by Google Earth

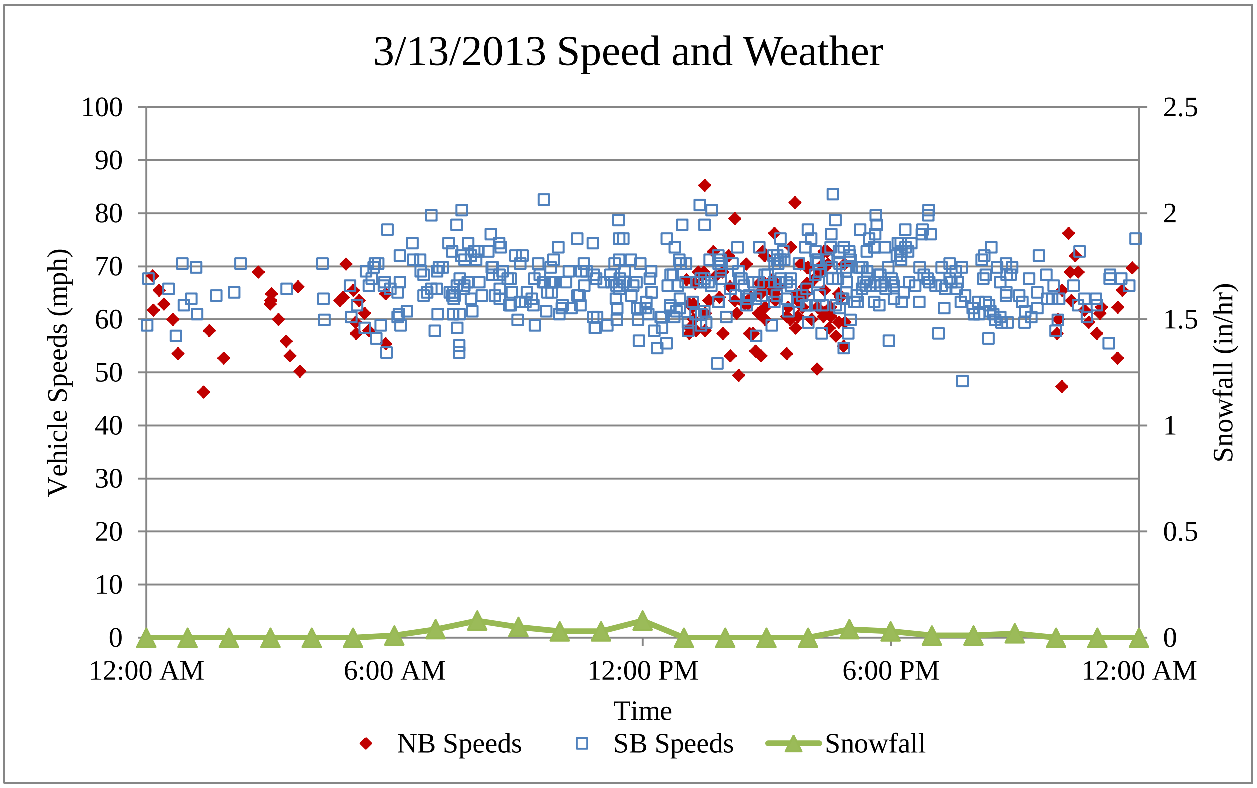
March 6, 2013

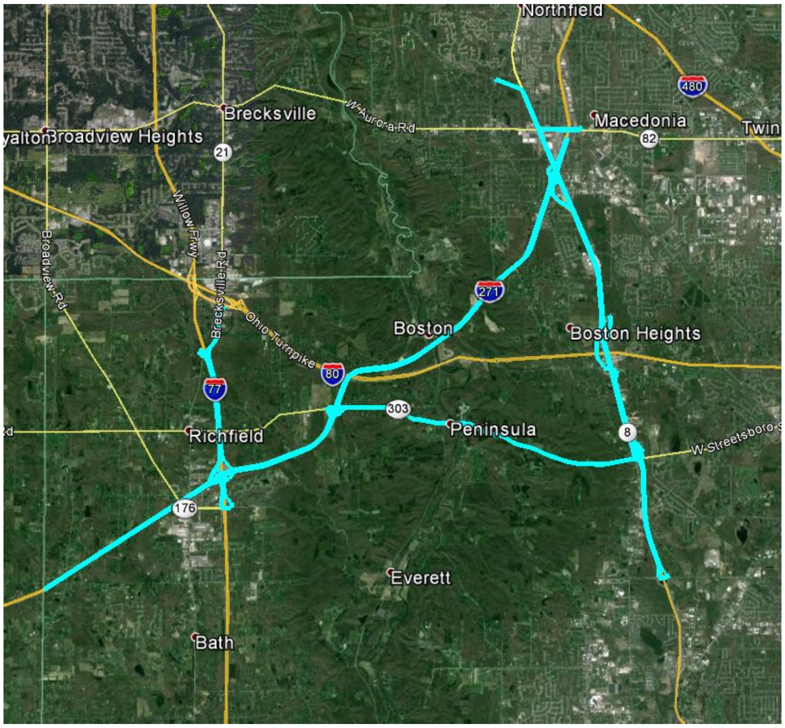


3/6/2013 Speed and Weather South of Study Zone
Vehicle Speed (mph)
100
90
80
70
60
50
40
30
20
10
0
Snowfall (in/hr)
2.5
2
1.5
1
0.5
0
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Time
NB Speed
SB Speed
Snowfall

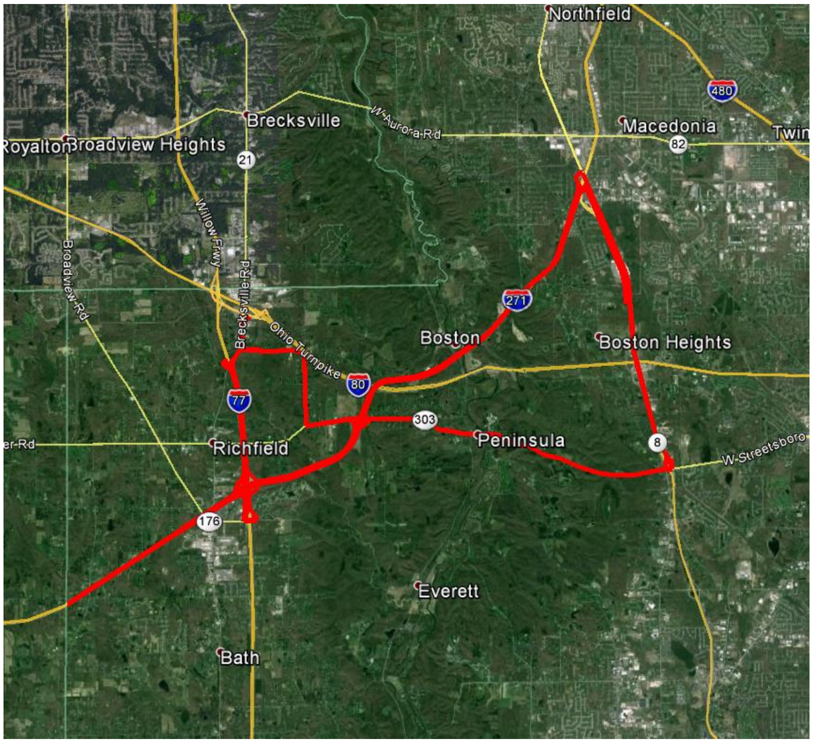
March 13, 2013





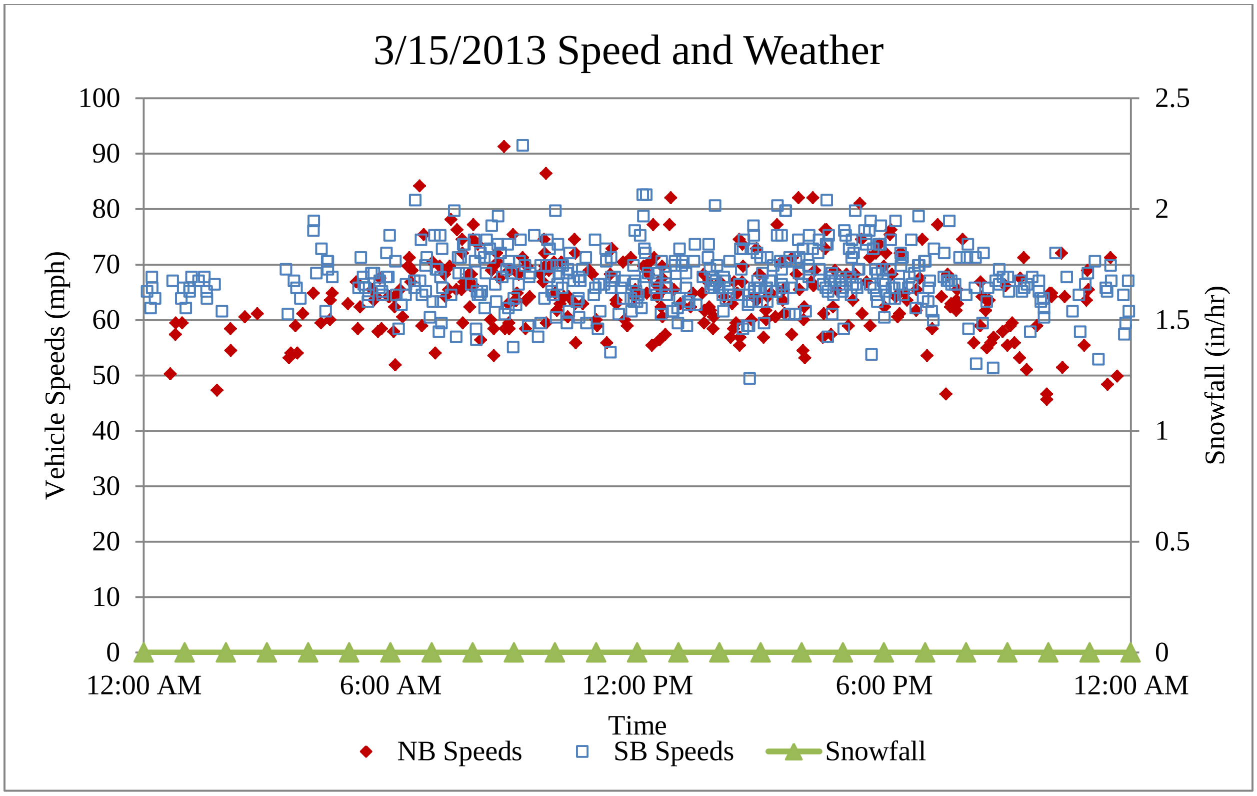


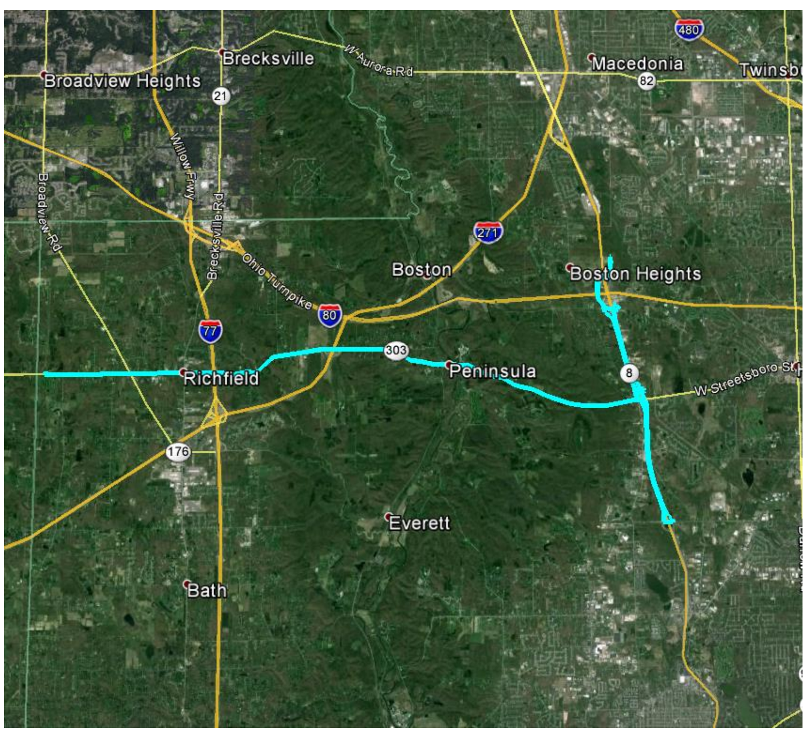
Epoke's Route - Aerial provided by Google Earth



Standard Truck's Route - Aerial provided by Google Earth

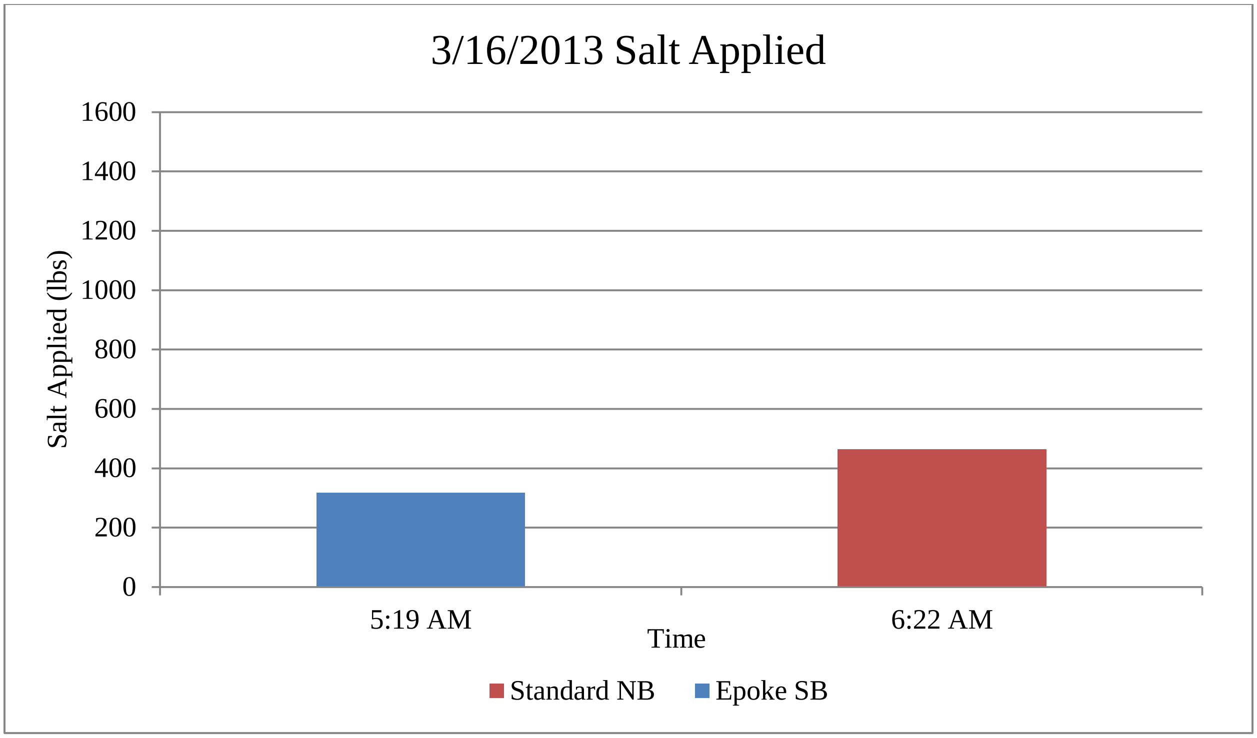
March 15, 2013

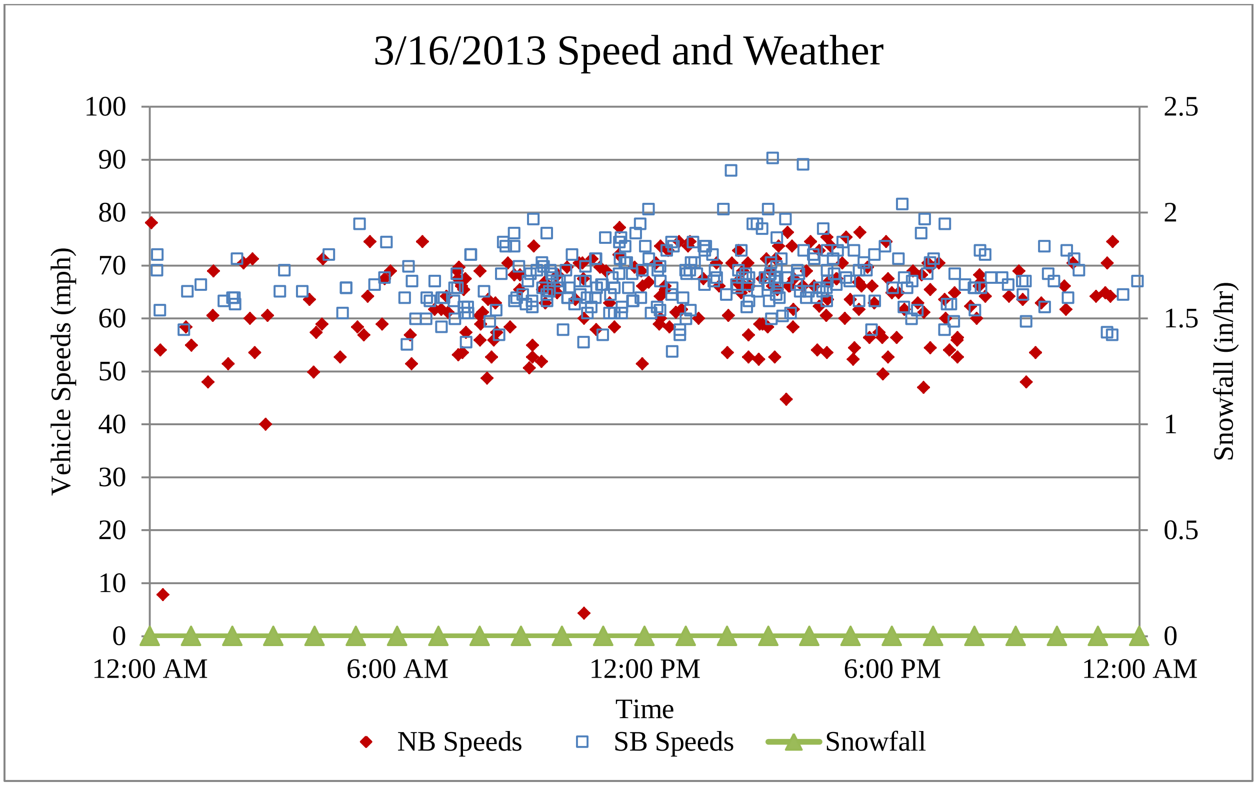


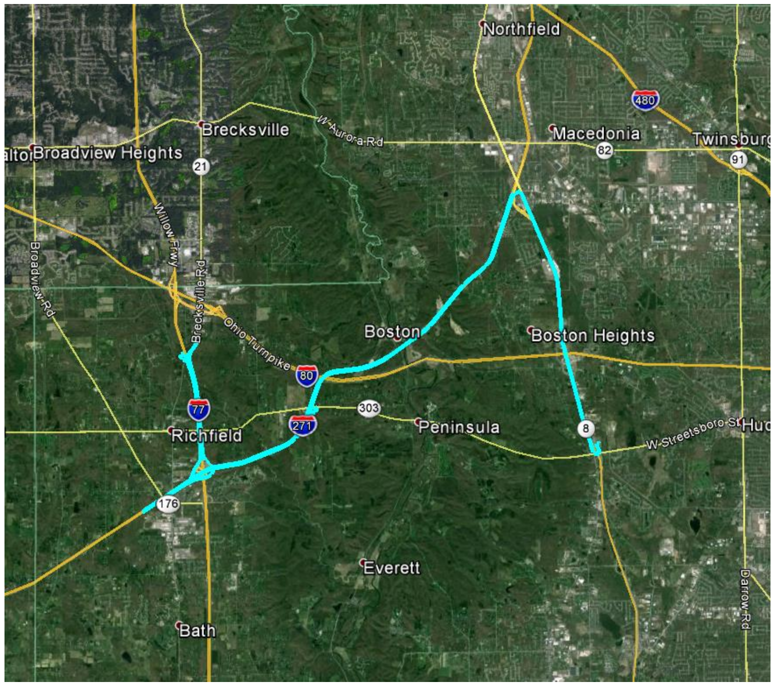


Epoke's Route - Aerial provided by Google Earth

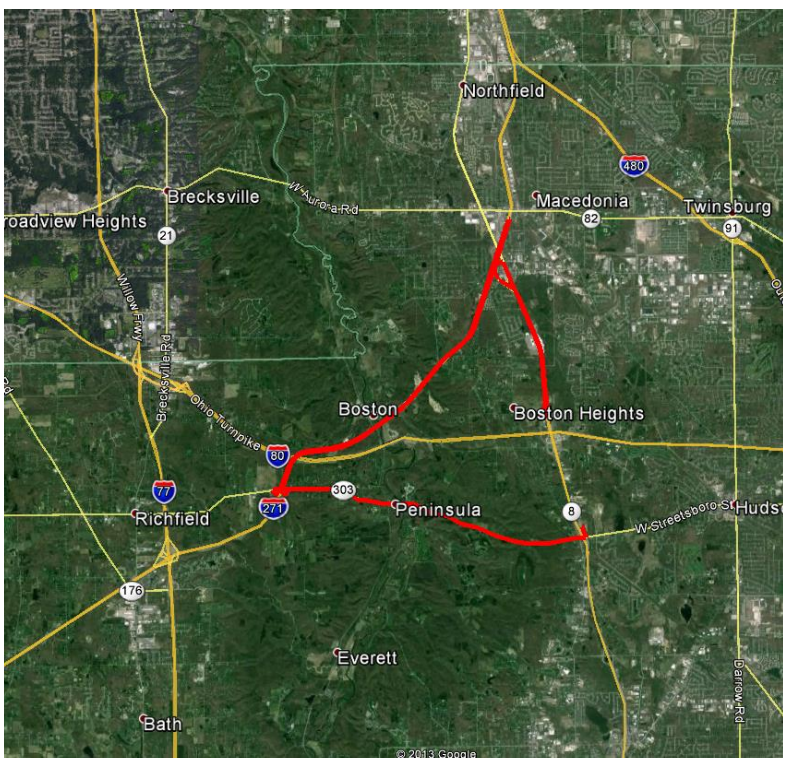
March 16, 2013





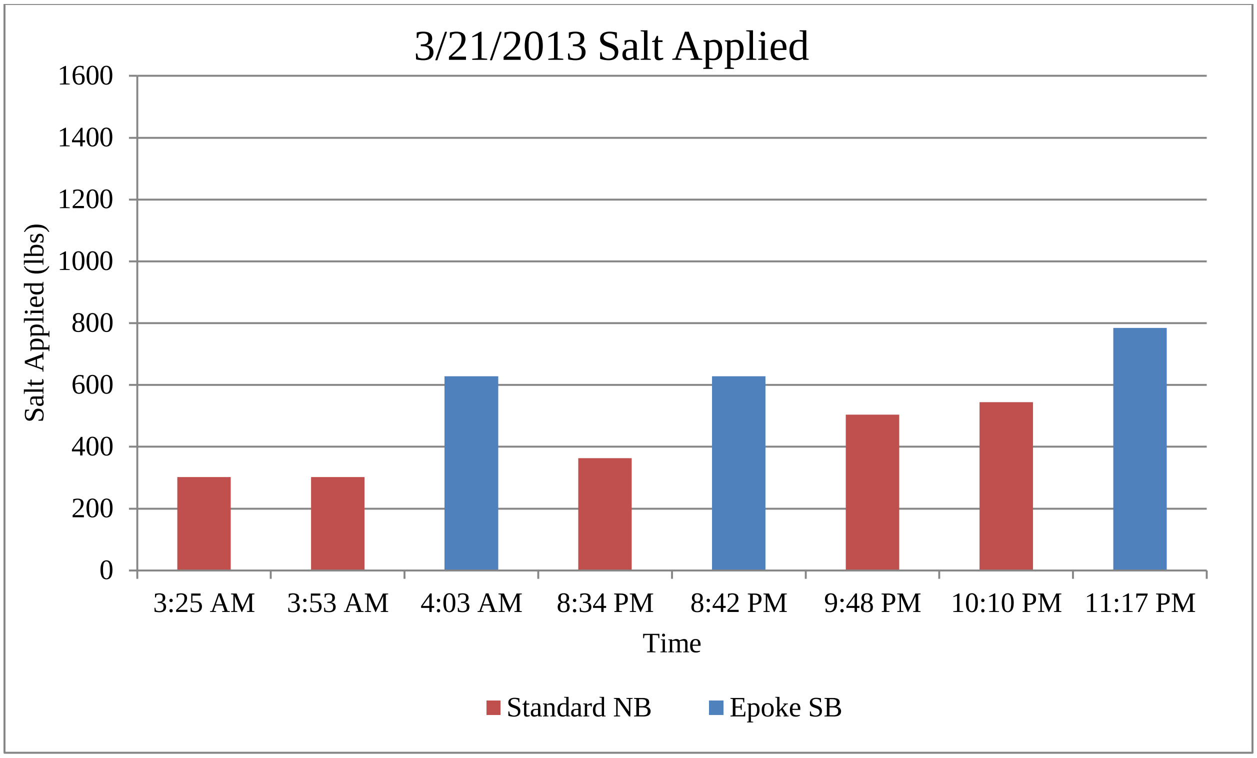


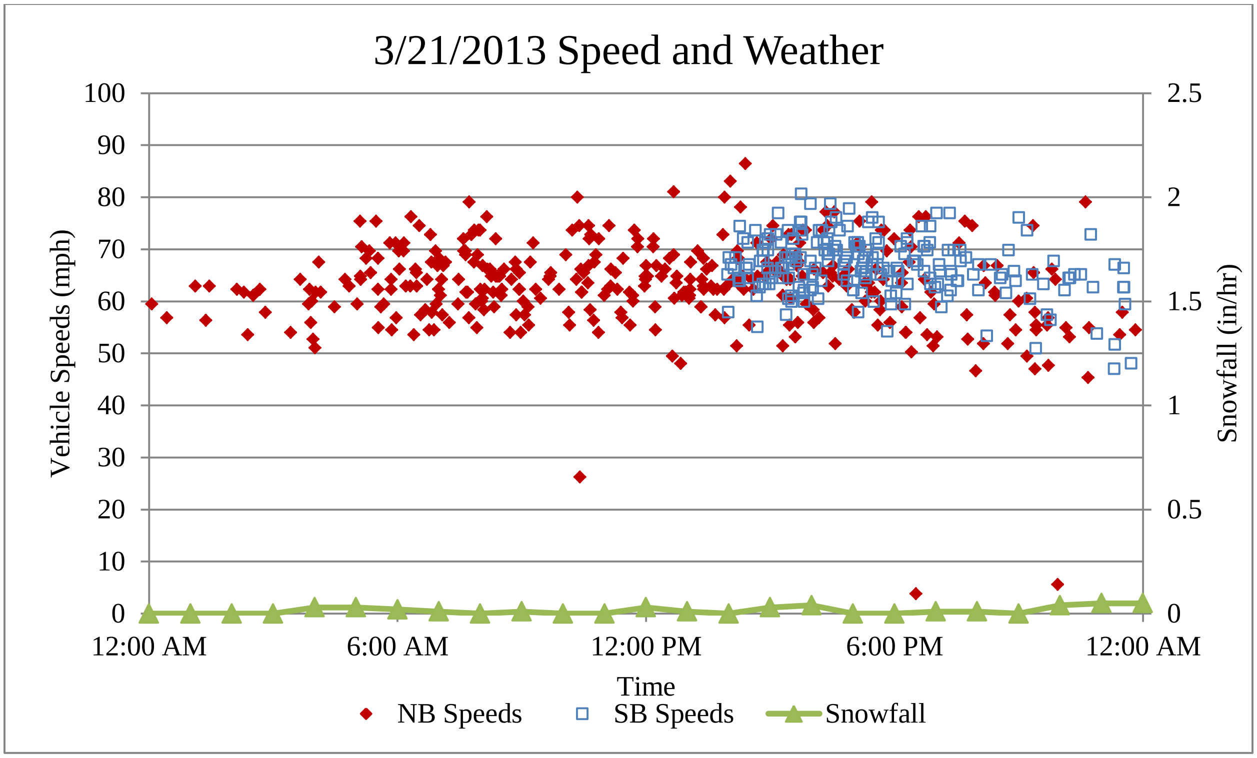
Epoke’s Route - Aerial provided by Google Earth

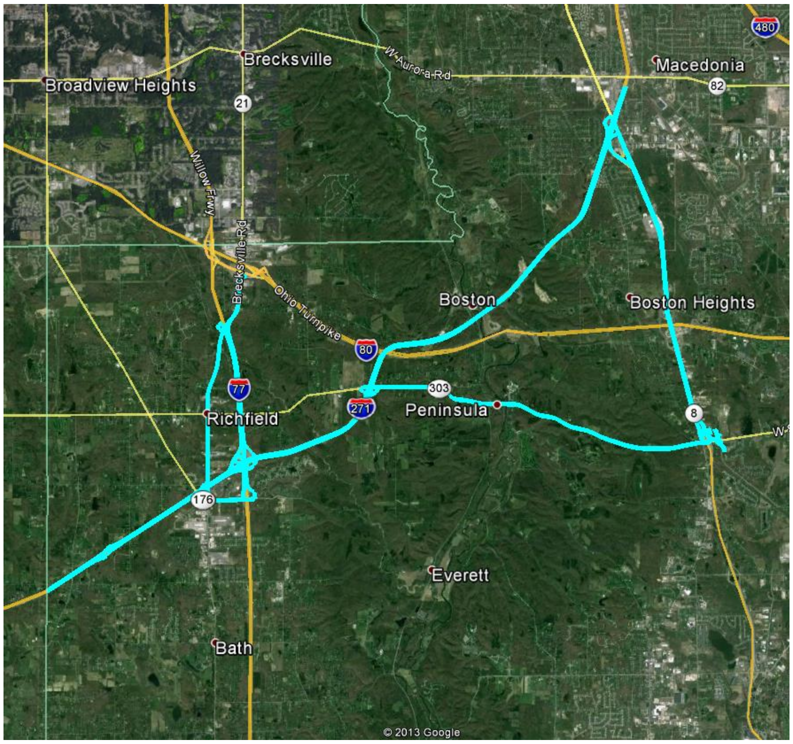


Standard Truck’s Route - Aerial provided by Google Earth

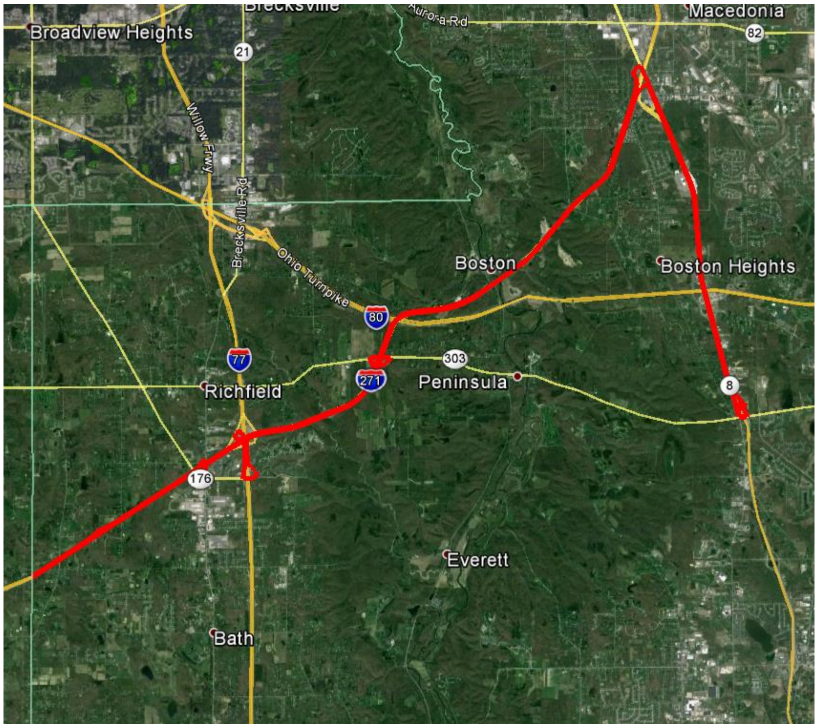
March 21, 2013



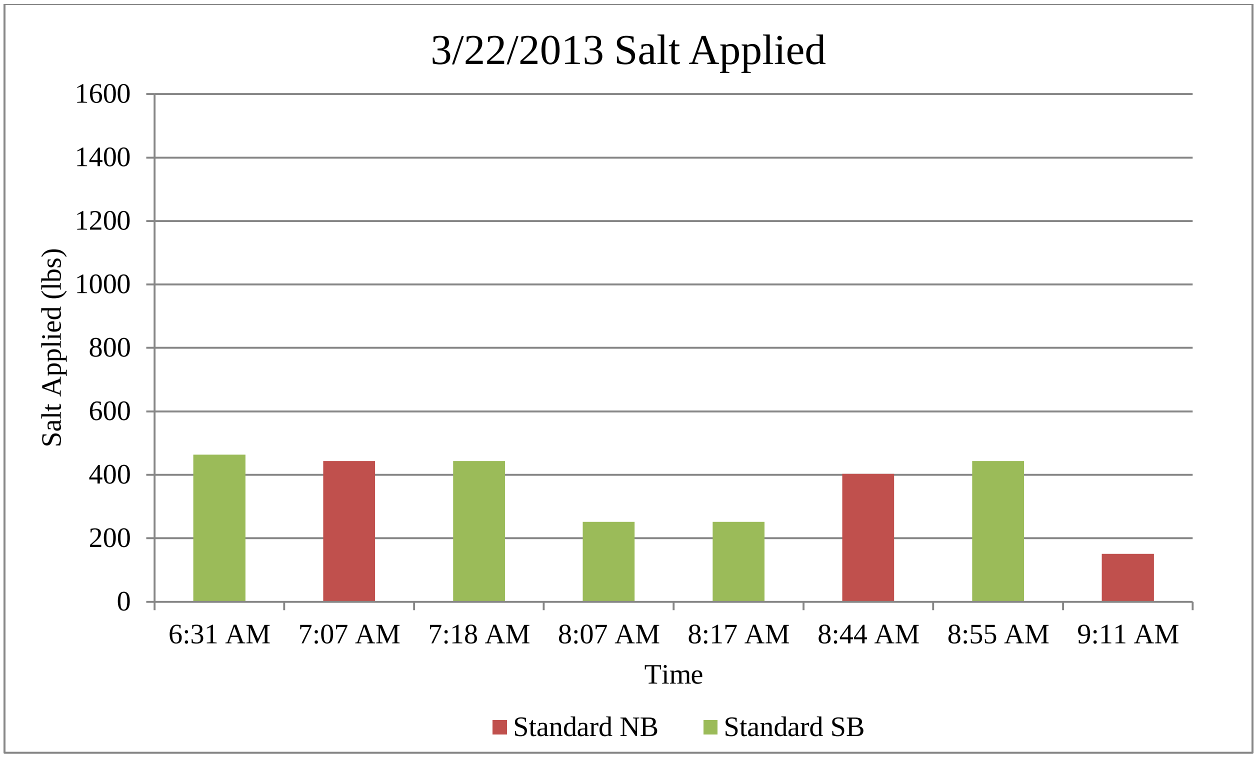


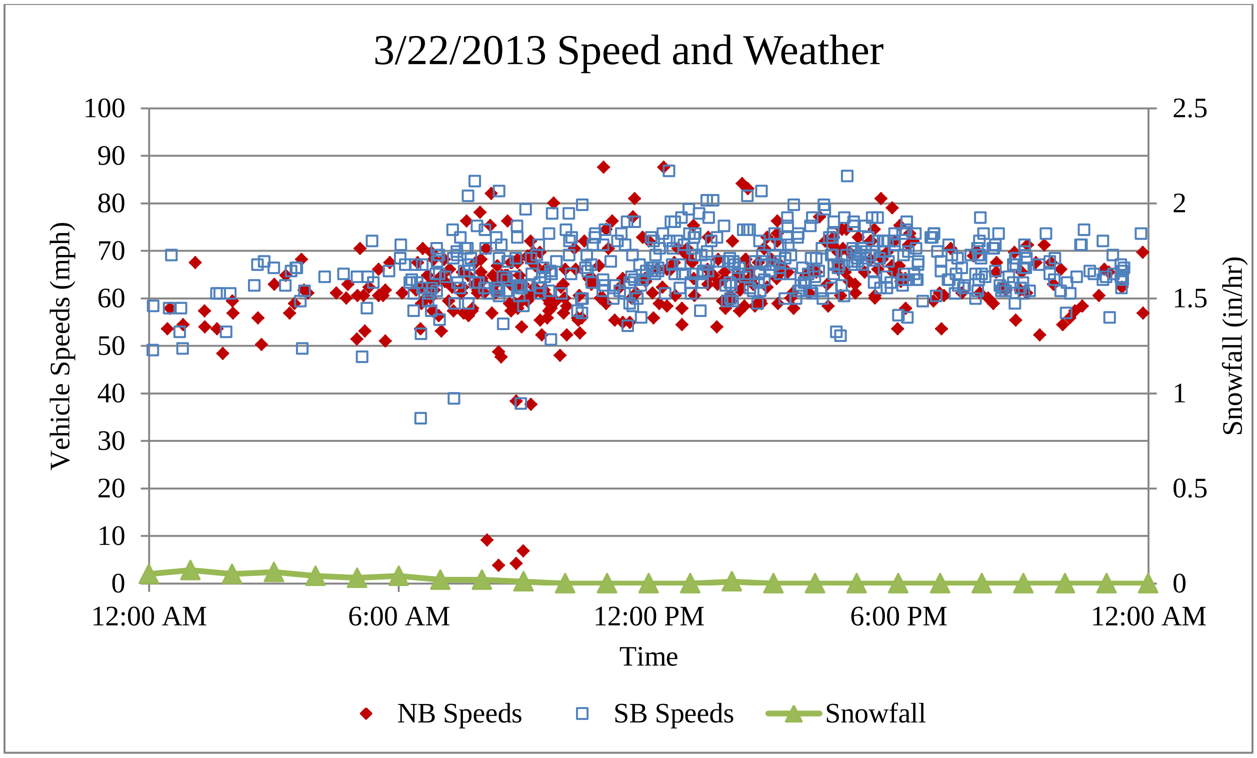


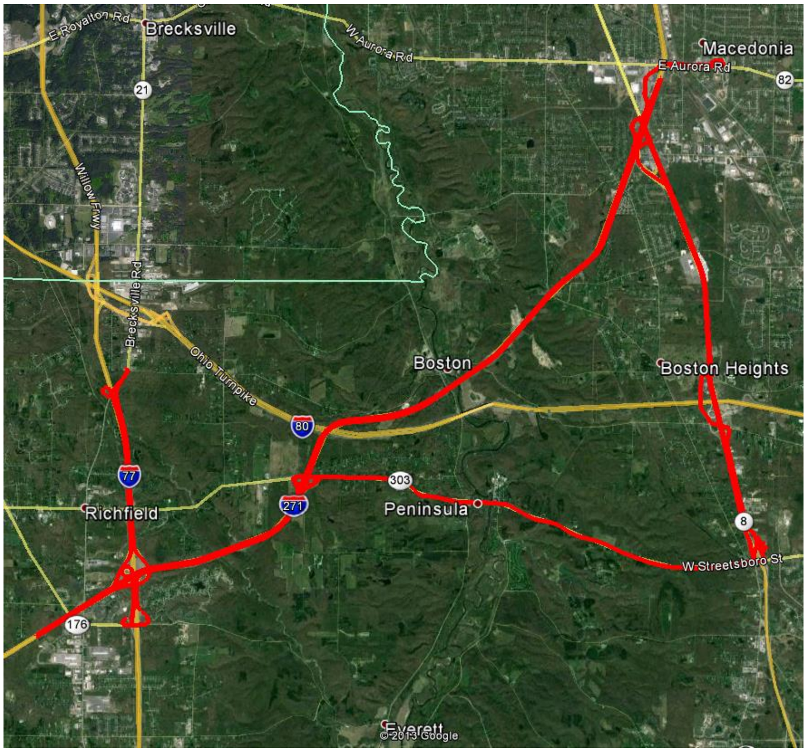
Epoke’s Route - Aerial provided by Google Earth



Standard Truck’s Route - Aerial provided by Google Earth

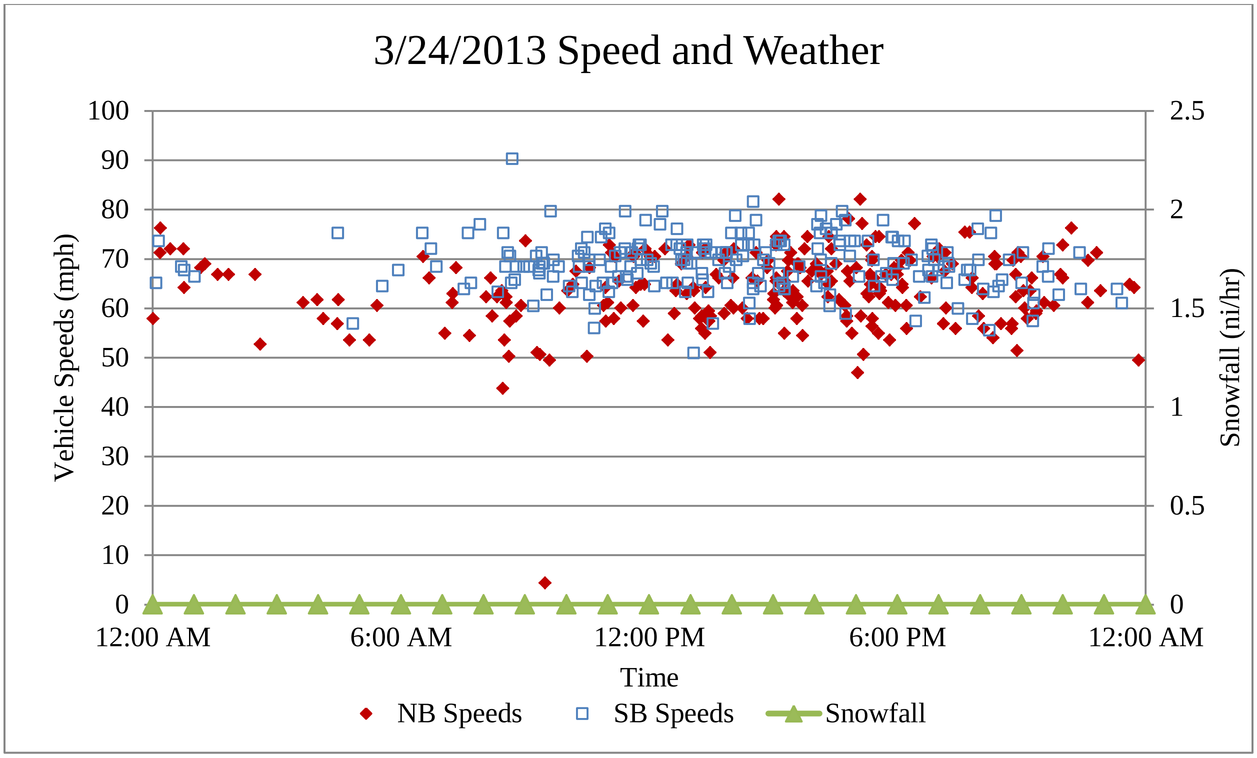

3/22/2013 Salt Applied
Salt Applied (lbs)
1600
1400
1200
1000
800
600
400
200
0
6:31 AM
7:07 AM
7:18 AM
8:07 AM
8:17 AM
8:44 AM
8:55 AM
9:11 AM
Time
Standard NB
Standard SB


3/22/2013 Speed and Weather
Vehicle Speeds (mph)
100
90
80
70
60
50
40
30
20
10
0
Snowfall (in/hr)
2.5
2
1.5
1
0.5
0
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Time
NB Speeds
SB Speeds
Snowfall

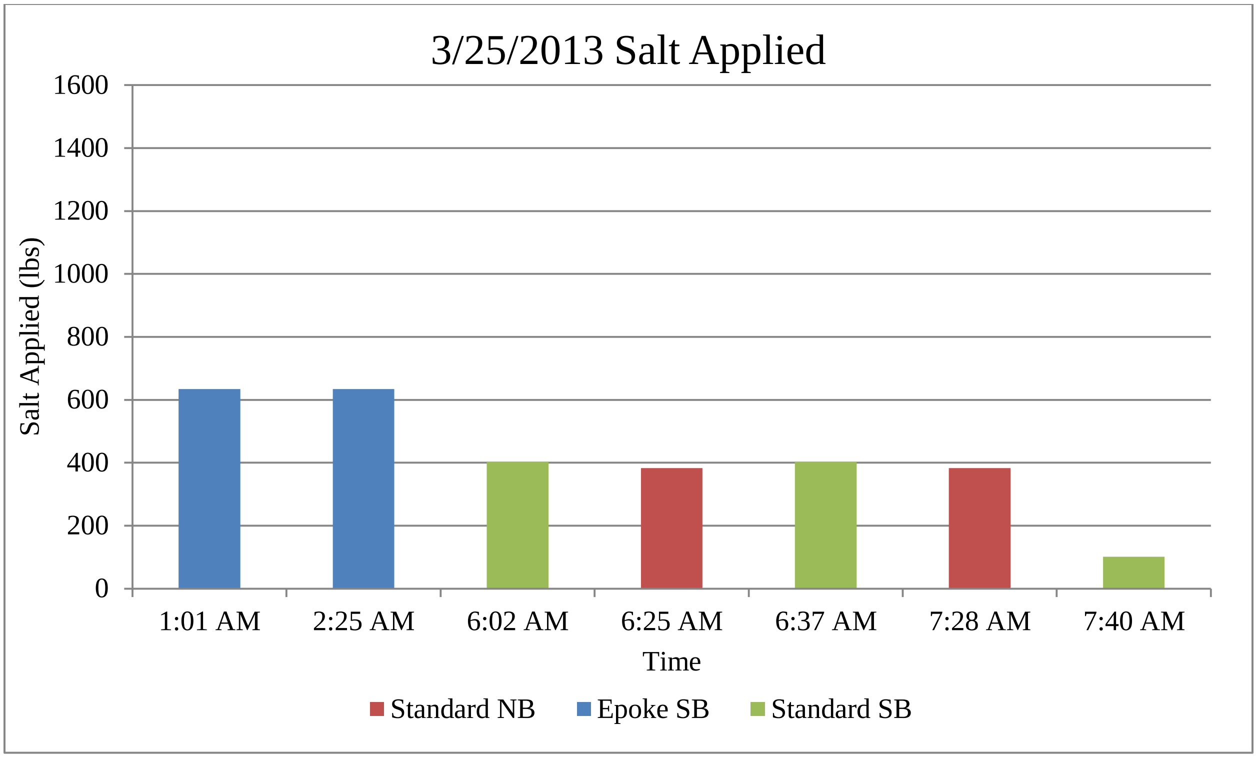


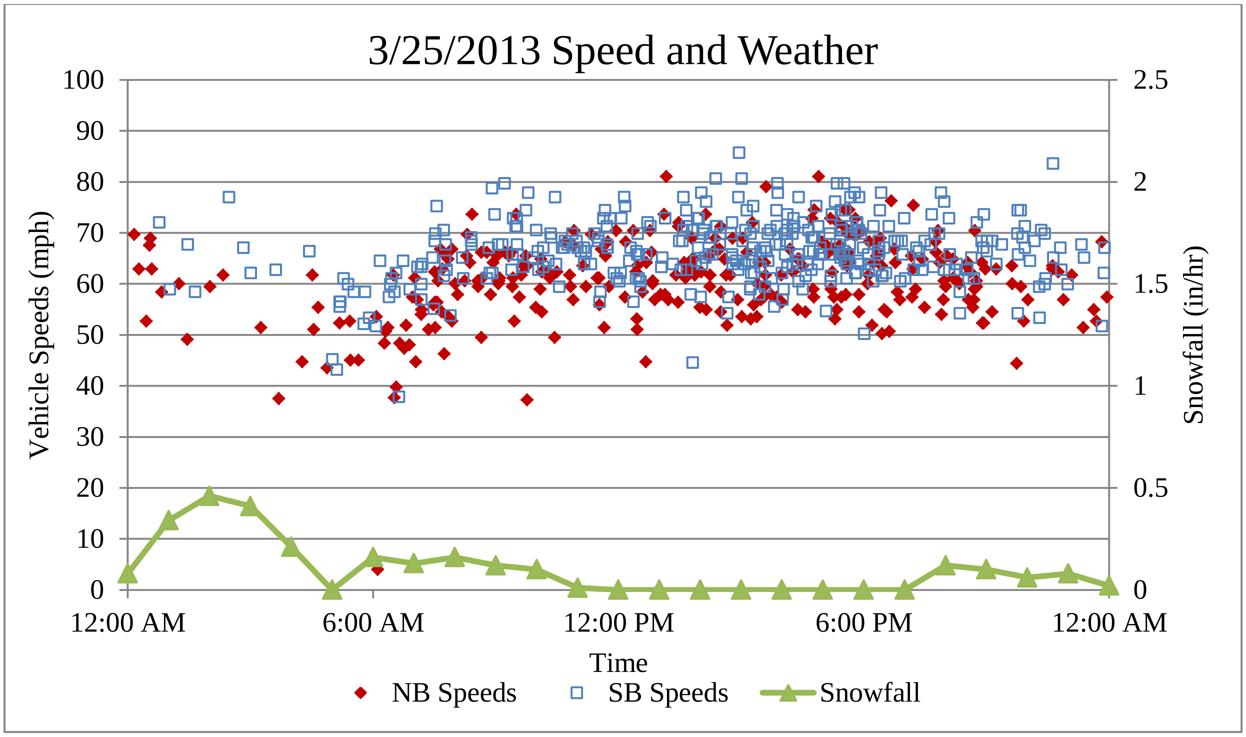
Standard Truck's Route - Aerial provided by Google Earth

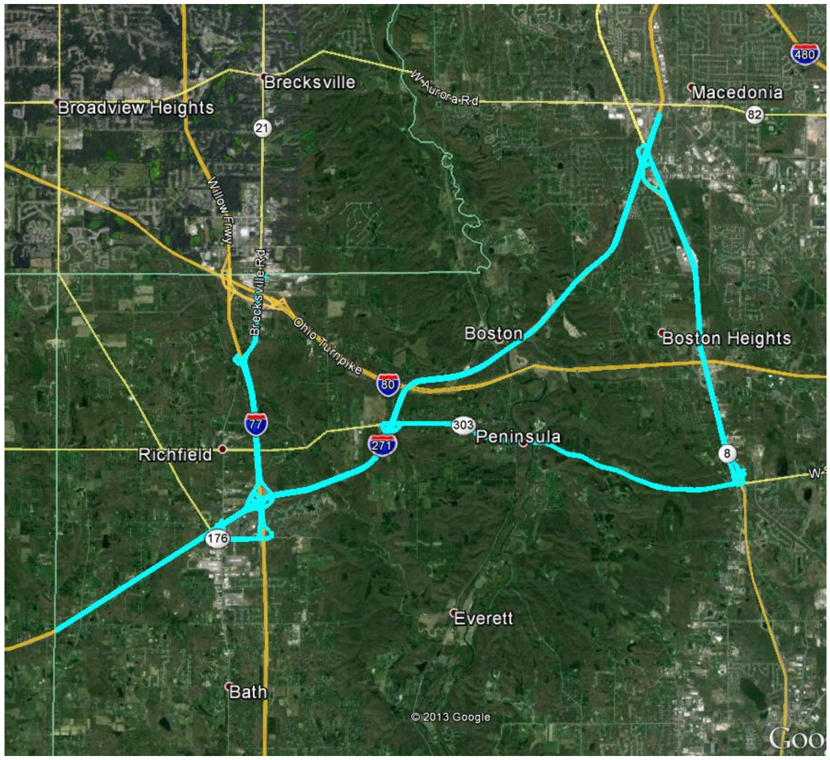
March 24, 2013



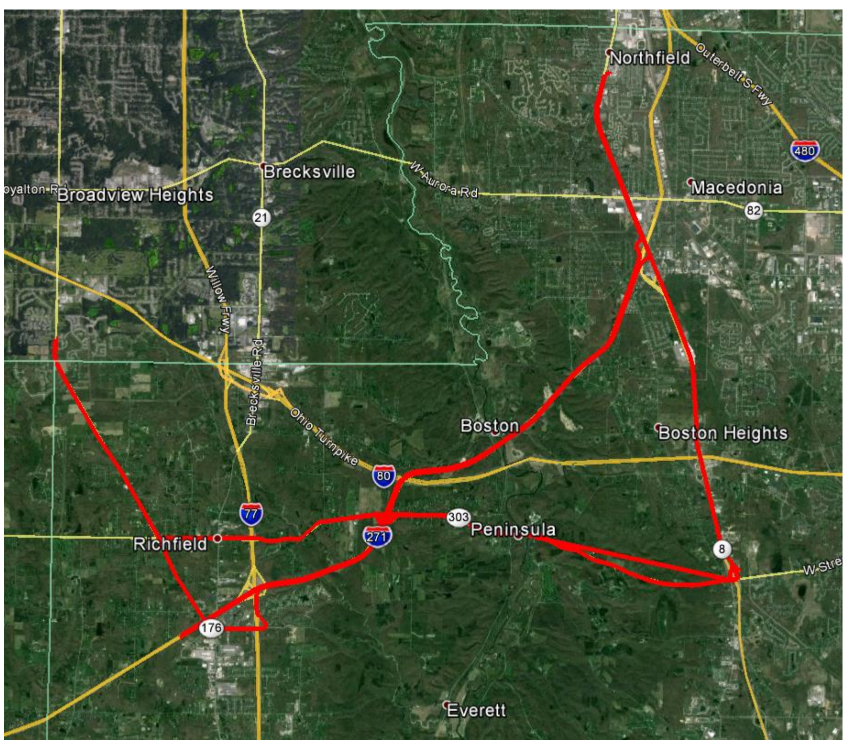
March 25, 2013







Epoke’s Route - Aerial provided by Google Earth



Standard Truck’s Route - Aerial provided by Google Earth