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Improved Deicing Methods for Snow and Ice Removal: Evaluation of the Epoke Sander/Spreader for Caltrans Operations

Daniel B. Chebot, Wilderich A. White &
Steven A. Velinsky: Principal Investigator

Report Number: CA16-2335

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The California Department of Transportation's (Caltrans) fleet of sand and salt spreading machines utilizes dated technology to handle a task that is both material intensive and important from a traveler safety standpoint. This study involved an engineering assessment of the Epoke Sirius Combi 4900 spreader (Epoke), which is being considered as a replacement for the existing fleet of salt and sand spreading equipment. The Epoke spreader and a conventional Caltrans fleet V-Box spreader were tested side-by-side to assess the improvements from one generation of equipment to another. The results of this research were positive, and Caltrans is moving to update the fleet with more modern equipment such as the Epoke Sirius Combi 4900 spreader. Incorporating the Epoke into Caltrans' snowfighting efforts will add capabilities such as combined liquid and solid pre-wet spreading, improved metering and material placement, electronic data acquisition for usage rates, vehicle location, and more, and will, overall, modernize the Caltrans' winter maintenance fleet. Beneficiaries are motorists, with improved safety and mobility, the environment, with a reduction of applied salt and abrasives, and taxpayers, through reduced snowfighting costs associated with improved efficiency and material usage reduction.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ATIRC	Advanced Transportation Infrastructure Research Center
Caltrans	California Department of Transportation
$CaCl_2$	calcium chloride
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
Epoke	Epoke Sirius Combi 4900 spreader
FHWA	Federal Highway Administration
I-80	Interstate 80
INDOT	Indiana Department of Transportation
ln-mi	lane-mile
ln-km	lane-kilometer
$MgCl_2$	magnesium chloride
NaCl	sodium chloride
NCHRP	National Cooperative Highway Research Program
PM	particulate matter
rpm	revolutions/minute

CHAPTER 1
INTRODUCTION

Snowfighting crews operating in California's mountainous regions face a complicated challenge every winter. They must accommodate a large volume of passenger and commercial traffic on roads that have steep grades, tight radius curves, and a wide variety of snow conditions. The importance of this task suggests these crews should be equipped with the best technology available. Additionally, efforts should be made to conserve anti-icing and deicing materials in an initiative to protect the environment from their harmful effects. The current snowfighting equipment fleet relies on older technology that, while very proven and robust, does not lend itself to accurate and efficient material application. The California Department of Transportation (Caltrans) is interested in reviewing new snowfighting technologies in an effort to improve traveler safety and efficiency, reduce environmental impacts, and save money.

This report documents a research effort to evaluate the value of the Epoke Sirius Combi 4900 spreader (Epoke) in Caltrans' snowfighting operations. This spreader is a potential replacement for equipment that was designed without any of the currently available sensors or microcomputers. Both the new Epoke spreader and a Caltrans' conventional Henderson V-Box spreader were tested side-by-side on a test track, followed by the deployment of two Epokes along the Interstate 80 (I-80) corridor at Donner Summit. Through the Epoke's added capabilities such as combined liquid and solid pre-wet spreading with improved metering and material placement, material waste was significantly reduced. Although the winters during the testing period were very mild, the snowfighting crews' and researchers' qualitative assessment determined that the Epoke spreader is robust and operates much more efficiently than the V-Box spreader. Moreover, spreader operators were very positive about their experiences using the Epoke.

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center was tasked with performing an extensive study of the equipment, conducting an in-service evaluation, and determining the most beneficial configuration and application of Epoke technology for Caltrans' operations. The specific tasks of this research work were:

1. Literature search and survey and Epoke acquisition
2. Development of test methods and data acquisition approach
3. Observation of Epoke use and test participation
4. Epoke engineering evaluation
5. Epoke performance evaluation
6. Documentation

This report is the primary deliverable for task 6 and documents the results of the research.

1.1 Report Outline

The goal of this research work was to develop an understanding of the efficacy of Epoke in Caltrans' winter snowfighting operations. Chapters 2 and 3 provide significant background information acquired from a detailed literature search and discussions with maintenance personnel. These chapters also define general information regarding snowfighting operations, such as typical practices and their impacts. Chapter 4 provides a description and qualitative comparison of existing technology and of the Epoke spreader. Chapter 5 describes the test procedures employed to quantitatively assess the V-Box and Epoke spreaders. Chapter 6 provides a detailed analysis of the spread patterns that resulted from the testing of the Epoke and the traditional spreader (i.e., the V-Box spreader). Chapter 7 provides details from the deployment of the Epoke in actual Caltrans operations, and, finally, Chapter 8 provides conclusions and recommendations from this research.

CHAPTER 2
BACKGROUND RESEARCH

This chapter provides the results of a detailed literature search aimed at identifying methods for maintaining road surfaces during winter snowstorms. This includes the discussion of materials and methods for maintaining roads, including deicing and using abrasives to enhance road friction. The chapter concludes with an example of a winter snowstorm response strategy.

2.1 Snowfighting in California

Studies of other states' winter driving conditions can provide some insight into the issues affecting snowfighting in California. A study in the *American Journal of Public Health* analyzed 25 years of traffic collision data, along with corresponding weather data, for the 48 contiguous states [1]. It showed that fatal crash rates were actually lower during most winter storms, with the exception being the first such storm in a given season. While fatal collisions only occurred on average 84% as frequently on snowy days versus dry days, fender benders (property damage only) and nonfatal-injury crashes increased by 78% and 24%, respectively. This was explained using the rationale that most drivers tend to slow down in snowy conditions, so when they lose control of their vehicles, they are at a low enough speed that the crash is survivable.

California is unique in that it is possible to drive through many climate zones in a short period of time, and thus an interesting conclusion can be drawn from the points made in the noted study [1]. The authors assert that "many people may be unprepared to avoid driving when the first snowfall occurs each year; others may not adapt driving procedures, such as reducing speed and braking earlier, as they will later in the snow season" [1]. The overwhelming majority of Californians live in locations where measurable snowfall is either exceedingly rare or completely nonexistent. Driving on snow is not a daily reality like it is in places such as New York and Maine. However, all Californians live in places within a 2-3 hour drive of areas where it snows a lot. Thus, places like Lake Tahoe and Mammoth Lakes are inundated with drivers who have little to no experience driving in snowy conditions. These are drivers for whom any storm can be the "first storm of the season." As such, in California, not only must the roads be kept open during some of the heaviest storms experienced nationwide, but they must also be maintained at a level by which inexperienced winter drivers can navigate them safely.

Adding to the challenge faced by snowfighting crews is the fact that California laws place strict regulations on what chemicals and foreign materials can enter the environment. This is no more evident than within the Lake Tahoe basin, a highly popular alpine region that draws large crowds throughout the year. Snowfighting crews within this area must cease spreading chemicals if the chemistry or clarity of Lake Tahoe changes too drastically. Furthermore, they must promptly clean up any salt or abrasives immediately following the return to dry pavement after a storm. In short, snowfighting crews are limited in what tools they can use to service extremely snowy roads full of inexperienced drivers.

Winter storms that include precipitation have the potential to impact nearly every aspect of daily life. Even a temporary shutdown of transportation infrastructure can have long-lasting effects on the goods and services people rely on. On a local and regional level, winter storms impede people's abilities to commute to work and participate in the economy, leading to lost wages and a decrease in productivity. On a national scale, they slow the movement of goods and resources traveling over roadways.

Snowstorms typically result in the greater frequency of traffic collisions as compared to dry weather conditions. In fact, one study conducted over the course of a winter season in Iowa concluded that collision rates during snowstorms are 13 times higher than during dry periods in the same months [2]. The study did not take into account maintenance activities, nor did it imply any relationship between certain activities and collision rates.

As related to the highways, snowfighting represents any proactive measures taken to minimize the negative effects of snow and ice on road conditions. Effective snowfighting begins before the onset of a storm and continues until roads have been deemed clear. In most cases, clear roads are defined as being free of all snow and ice [3]. In rural areas with persistent below-freezing temperatures, infrequently used roads can be left in a state where packed snow imbedded with a traction enhancing agent serves as the primary driving surface.

There are many tools and methods available to maintenance crews for use throughout a snowfighting effort. The tools and methods vary widely from region to region and even from storm to storm on a particular set of roads. Extensive accumulated staff experience plays a key role within a specific area in determining which tools and methods should be used on certain sub-sections of a maintenance district. Some of the common snowfighting practices, all of which are utilized in some capacity by Caltrans, include: anti-icing, deicing, plowing, and the spreading of abrasives.

2.2 Anti-Icing Definition and Equipment

Anti-icing is the practice of inhibiting ice before it forms via the use of chemicals applied to a dry roadway. It is a preventive method of ice control. More scientifically, "Anti-icing is the practice of attempting to prevent the formation of bonded snow and ice to a pavement surface by timely applications of a chemical freezing-point depressant" [3]. In most cases, the chemical used for anti-icing efforts is a 23% sodium chloride (NaCl) brine mixture. This brine is produced using specialized equipment. Caltrans possesses brine production equipment at the Kingvale yard located near Donner Summit on I-80.

Brine is applied to the roadway using equipment with varying levels of technical sophistication. The most rudimentary brining equipment uses gravity to deliver the chemical solution from a truck-mounted tank to the roadway. A series of valves and hoses connects the tank to a horizontal bar at the rear of the truck. This bar is either fitted with nozzles or short sections of hose that deliver the liquid to the ground in parallel stripes that extend the width of the truck. Aside from the fact that this type of equipment can only service one lane at a time, the hydraulic pressure will change as the liquid level in the tank decreases. At the end of a load, liquid will be dispersed at a much lower rate because flow rate is proportional to pressure in the lines. Additionally, there is no automated correction for the vehicle's ground speed with this simple type of system.

The more sophisticated types of brine application machines use pumps to supply brine at a flow rate that is automatically determined by a computer. This application rate is a function of ground speed, spread width, and desired application density, where application density is defined in terms of mass per unit area. Pumped liquid is either fed through tubes attached to a spinning disk at the rear of the truck or through mechanically actuated spray nozzles. These types of machines can cover multiple lanes of roadway in a single pass with a carefully metered and evenly distributed shower of anti-icing material. Some municipalities use these types of machines for routine anti-icing efforts and coat the roads multiple times per week to protect against black ice formation [4].

Anti-icing is most effective if air and road temperatures are below freezing at the onset of precipitation from a storm. This is because liquid precipitation will wash the chemicals from the road surface. Some DOTs will spread solid rock salt on wet road surfaces if a changeover from rain to snow is imminent [3]. This effectively produces brine in-situ as the salt dissolves in the surrounding water. Regardless of which method is employed, the presence of anti-icing chemicals on the road surface at the onset of a storm is a beneficial snowfighting tactic. If a layer of compacted snow forms, it will not be fully bonded to the road surface, which allows plows to clear all the way down to the pavement on their first pass.

2.3 Anti-Icing Studies in the Literature

A study was released by the Federal Highway Administration (FHWA) in 1995 following two years of pilot programs aimed at investigating the effectiveness of anti-icing practices in the United States [3]. Many conclusions were drawn from this comprehensive study. Among them, it was determined that anti-icing is particularly well suited to roads requiring a higher level of service, i.e., roads that handle a high volume of traffic and must be kept as clear as possible. Anti-icing can help achieve objectives such as maintaining bare pavement throughout a storm or returning to bare pavement shortly after a storm concludes. It was cautioned that anti-icing loses effectiveness, regardless of chemical solution used, at pavement temperatures lower than -5° C (24° F). It was also recommended that anti-icing not be deployed when it is expected that precipitation will fall as sleet or freezing rain due to the dilution of chemicals that will occur.

Anti-icing practices can lead to a drastic reduction in consumed materials because they make very efficient use of the chemicals. Unlike dry material spreading, there is hardly any scatter or bouncing after the chemical has been laid down. Most of the brine placed on the road remains there until it becomes consumed by chemical reactions with the ice and snow. It is far less susceptible to transport off the road due to traffic. Additionally, freezing point depressants are only effective once they go into a solution with the frozen precipitation. Larger particles of salt and other chemicals take longer to form a solution due to their smaller surface area to volume ratios. Anti-icing brine is already in a solution when it contacts the road surface. Even if the water in the brine evaporates and the salt recrystallizes, the particles left on the road will be much smaller than even the finest ground salt used for deicing [3]. A 1998 study by the Virginia Transportation Research Council specifically cited a key benefit of anti-icing as being the reduction of chemicals used over the course of a storm [4]. Furthermore, this study claimed that "clearing the road surface to bare pavement can be achieved quicker and with less effort with anti-icing" [4].

The industry uses unique units in defining application rates. The spread density of solids is defined in terms of mass per unit area. In Europe and Canada, this is given as either g/m^2 or kg/lane-kilometer (kg/ln-km); in the United States, it is given as lb/lane-mile (lb/ln-mi). The standard lane is 3.66 m (12 ft) wide in the United States. A lane-kilometer is the amount of area covered by a standard traffic lane that is one kilometer long. Similarly, liquid application rates are defined in l/lane-kilometer (l/ln-km) and gal/lane-mile (gal/ln-mi). The conversion rates used in this report are: 1 kg/ln-km = 3.571 lb/ln-mi and 1 l/ln-km = 0.429 gal/ln-mi.

The efficiency advantages of preventive vs. reactive deicing techniques are made evident by the recommended application rates for each method. A fairly typical application rate for anti-icing purposes is 58.3 l/ln-km (25 gal/ln-mi), though rates can vary from 23.5 to 94 l/ln-km (10 to 40 gal/ln-mi) [4]. A solution is defined as saturated when no more chemical can be diluted into it without recrystallization occurring. Recrystallization is to be avoided in anti-icing equipment because the solid particles can clog valves and nozzles in the anti-icing equipment.

The concentration that results in the lowest temperature at which a solution can exist while remaining completely liquid is referred to as the eutectic concentration [3]. In the case of deicing chemicals, this concentration value varies from about 20% to 30% by weight. 95 l (25 gal) of brine contains roughly 23 kg (50 lb) of sodium chloride at its eutectic concentration of 23.3%. As stated previously, this application rate has been shown to be very effective in preventing the bonding of ice and snow to the roadway for the first part of a storm. Conversely, if no anti-icing is performed and reactive methods of deicing are used, much more chemical will be required to achieve the same level of service [4].

The Iowa Department of Transportation published an application rate guide for plow trucks with salt spreading capabilities [5]. This guide takes into account both ambient temperatures and weather conditions when recommending a spread rate. The lowest rates are suggested for conditions with minimal frozen precipitation and ambient temperatures hovering around freezing (0° C, 32° F). These rates start at 14.1 kg/ln-km (50 lb/ln-mi) and increase rapidly as temperature decreases or precipitation rate increases. Application rates of 70.6 kg/ln-km (250 lb/ln-mi) are suggested for scenarios where the temperature is between -6° and -5° C (21° to 23° F) and snow is falling at a rate of 25 mm (1 in) or more per hour. Conditions like this are very frequent on the high mountain passes of the California highway system.

2.4 Deicing Definition and Equipment

Eventually, the effects of an anti-icing effort will diminish during the course of a storm. When this occurs, ice and snow compacted by vehicle traffic will begin to form a solid layer that is bonded to the road surface. It is at this point that deicing methods and tools must be employed to keep the road in drivable condition. Deicing is a reactive method commonly employed after 25 mm (1 in) of snow has accumulated and bonded to a road surface [3]. Deicing utilizes either solid or liquid chemicals in an effort to melt ice and de-bond it from the pavement while breaking up large sheets into smaller pieces. Increasingly, solid chemicals that have been pre-wet with a salt brine mixture are utilized for deicing purposes. Deicing is typically followed by a mechanical means of removing ice or snow from the roadway, such as plowing.

Certain weather patterns and topographies lend themselves to situations where a roadway ends up covered with liquid water, which then freezes into a sheet of ice as temperatures drop. Such ice, which is referred to as black ice, can form under many different circumstances that are completely unrelated to a winter storm. This ice must be removed from the road surface regardless of how it got there. Deicing methods and tools must be used in these situations, as well.

Deicing is performed using similar equipment as anti-icing, but with an emphasis placed on solid chemical use over liquid chemicals. A typical Caltrans truck used for deicing consists of a heavy-duty diesel chassis with a front plow, possibly a wing plow, and a large hopper full of a solid chemical. This chemical is dispersed onto the roadway via a conveyor belt that pulls material from the bottom of the hopper and deposits it onto a spinning disk. The angular velocity of the spinning disk dictates spread path width, and the speed of the conveyor determines the spread rate.

Worldwide, many different chemicals are used by highway maintenance crews for the purpose of deicing. Sodium chloride (NaCl), which goes by several other names including white salt and sea salt, is far and away the most common deicing chemical used [6]. This is due to the fact that it is very naturally abundant and thus readily available and inexpensive, while at the same time being very effective at melting ice. Other chemicals fall into several families—there are chlorides such as calcium and magnesium chloride ($CaCl_2$ and $MgCl_2$), acetates including potassium acetate and calcium magnesium acetate, and miscellaneous chemicals such as urea and agricultural bi-products. Despite possessing unique advantages and disadvantages, each of these chemicals melts ice using the same basic chemical principle known as freezing point depression.

Many studies have been carried out in an effort to maximize the effectiveness of the chemicals and equipment used in snowfighting operations. The aim of these studies was to gain an understanding of methods such as anti-icing and pre-wetting that were relatively new in the United States in the 1990s.

2.5 Deicing Studies in the Literature

Deicing using freezing point depressants such as sodium chloride has been practiced in the United States since 1941. Within a few years, Americans became acquainted with the concept of bare pavement shortly following the conclusion of a storm. The adoption of road salt made it possible for maintenance crews to clear away ice and snow from roads even in sub-freezing temperatures. As a result, the annual use of the material increased to roughly 10 million metric tons (11 million short tons) by the 1970s and to 23 million metric tons (25 million short tons) today. Application techniques improved steadily over the years in an effort to conserve salt lost to wind and traffic action. This led to the use of pre-wetting as well as special spreaders that apply salt at a near-zero velocity relative to the roadway [8].

The goal of deicing is to have the chemical penetrate the surface of the bonded ice and snow, and for a brine to form that is able to flow between the roadway and the ice/snow. This transport action of the brine effectively breaks the bond between the pavement and the ice, which enables and expedites the clearing of frozen precipitation by plowing and traffic action [8]. Though sodium chloride theoretically melts ice down to its eutectic temperature of -12° C (10° F), deicing practices are discontinued when temperatures approach this level because chemical activity slows to the point of near ineffectiveness. Typical application rates vary between 56.5 and 141 kg/ln-km (200 and 500 lb/ln-mi) for state highways [8].

The pre-wetting of deicing chemicals has gained widespread acceptance as a means of improving service while reducing material usage. It is considered the cutting edge in terms of deicing practices. A National Highway Cooperative Research Program (NCHRP) paper from 1995 reported that the pre-wetting of solid deicing materials was being used with great success abroad [9]. A 2001 study by the Indiana Department of Transportation (INDOT) suggested that the pre-wetting of salt helped to melt snow quicker, though it does not go on to explain why this is the case [10]. The 1996 Federal Highway Administration report on anti-icing offered a clear explanation related to chemical energy. Salt requires energy to go into a solution; it is only effective as an ice-melting agent when in this form. Dry salt, when applied to a frozen layer of ice or snow, will remain inert until a film of liquid forms. The process of going from a solid to an aqueous solution is accelerated when the entire surface of the salt particles is coated with liquid at a relatively warm temperature. NaCl and $CaCl_2$ are typically used in pre-wetting solutions. Water is occasionally used, although it can freeze in the tanks before being applied if temperatures are low enough [3].

Using brine as a pre-wetting liquid has the added advantage of helping to melt the top layer of ice while not over-diluting the solid chemical. The region of Waterloo, Canada successfully utilized pre-wetting strategies to reduce road salt use by 25% starting in 2003 [7]. When chemicals are used more effectively, fewer chemicals need to be used.

2.6 Plowing

Various types of plows are called upon to remove snow and ice from the roadways during and after a winter storm. Equipment used includes trucks with front plows and/or wing plows, graders, loaders, towed plows, and rotary plows. While the functionality of each piece of machinery varies, they share a common goal of moving frozen precipitation from a roadway to an area adjacent to the roadway through a mechanical means. While this is a completely necessary and an extremely effective part of any snowfighting effort, it also removes most of the previously applied chemicals and abrasives from the road surface. Thus, many trucks serve the dual purpose of both plowing and material application so that a road does not remain without anti-icing/deicing chemicals or abrasives after a plow pass is made.

2.7 Abrasives Use

The coefficient of friction between a vehicle's tires and the road is significantly reduced when frozen precipitation is present on the road surface. Bare pavement offers a coefficient of friction of around 1.0, while snow-, slush-, or ice-covered pavement can have less than 20% of this available grip [8]. No amount of deicing and plowing can guarantee a perfectly clear roadway at all times during a storm, so measures must be taken to ensure that traction is maintained as well as possible for as long as possible. This is accomplished through the spreading of abrasives.

According to the U.S. Army Cold Regions Research and Engineering Laboratory, "It is recognized that abrasives may be necessary when a rapid increase in friction coefficient is required, particularly at temperatures so low that chemical action is slow, and in conditions where snow or ice is strongly bonded to the pavement and cannot easily be removed" [3]. Sand is the most commonly used abrasive for winter road maintenance. Crushed stone and cinders may also be used. Abrasive stockpiles will often be mixed with white salt to prevent the pile from freezing if moisture becomes trapped and temperatures fall below zero. Abrasives are spread using identical methods and equipment as those for solid chemicals.

The NCHRP study on material selection for winter road maintenance described abrasive use as "a very visible low-cost approach to managing road friction" [9]. However, it cautioned that they provide only a temporary solution when placed 'dry' on the road surface without pre-wetting. Furthermore, it has been found that the effectiveness of abrasives diminishes almost completely as road traffic increases and speeds exceed 50 km/h (31 mi/h) [11]. The size of the abrasive particles used also has a large impact on traction due to retention on the road surface. Retention rates range from 10% for natural fine sands to up to 50% for manufactured coarse sand [11].

2.8 Some Aspects of Snowfighting in the Lake Tahoe Basin

Since a major driving force in evaluating the Epoke's use in California relates to the snowfighting efforts and their effects in the Lake Tahoe basin, an informal interview was conducted with the winter operations supervisor at the South Lake Tahoe Caltrans Maintenance station. The goal of this interview was to gain a better understanding of the snowfighting practices utilized in that area and their relation to the practices discussed in earlier sections of this report. As noted earlier, snowfighting efforts are selected based on the experience of the local highway maintenance personnel and can vary from region to region.

The supervisor said that his highway maintenance activities must always keep the water quality of Lake Tahoe in mind. The water quality of Lake Tahoe is tested frequently, and if the concentration of certain constituents known to be introduced by snowfighting climbs above a certain level, the use of those materials must cease. As a result, salt and abrasives are used very sparingly and are cleaned off the roads as soon as possible following the conclusion of a storm. The salt used is food-grade, kiln dried white salt that is manufactured rather than mined. The sand used as an abrasive must meet very high purity standards. Salt is rarely used on its own and is usually part of a sand/abrasive mixture, with ratios depending on roadway conditions and requirements.

Anti-icing is occasionally used as a preventive measure against ice and snow in the Lake Tahoe basin. According to the supervisor of the South Lake Tahoe Caltrans Station, it is only used when a storm is forecast to have snow precipitation at elevations approximately 1,000 m (3,280 ft) below Lake Tahoe and the surrounding highway mountain passes. Low snow levels correspond with a colder storm that starts as all snow, rather than a warmer storm that changes from rain to snow. Roads are occasionally pre-treated prior to the onset of warmer storms, but rather than salt brine, a mixture of 30% salt and 70% abrasive is used. Anti-icing using brine is performed by two trucks at application rates of 94 to 117.5 l/ln-km (40 to 50 gal/ln-mi). One truck is fitted with a 450 l (120 gal) tank and the other with a 5,680 l (1,500 gal) tank. They are both of the type with a horizontal spray bar fitted with a series of hoses. Brine is fed to the spray bar by an onboard pump.

Pre-wetting is occasionally used by snowfighting crews in the Lake Tahoe basin. According to the supervisor in charge of the South Lake Tahoe Maintenance Station, it is most commonly employed as a means of removing the remaining ice and snow at the end of a storm. It has been proven as an effective way to expedite the process of "dropping chains," which is the point at which roads are considered to have enough traction (coefficient of friction) to eliminate traction control requirements. Brine is used as the pre-wet liquid of choice and is applied at a rate of 7 to 8.2 l/ln-km (3 to 3.5 gal/ln-mi) in addition to a 30% salt /70% abrasive mix. This tactic is only chosen when ambient temperatures are well below freezing, and the frozen precipitation will not melt on its own. The supervisor interviewed for this section indicated that only a handful of the spreaders in his fleet are equipped with pre-wetting systems, and that they have a relatively small brine capacity of 760 l (200 gal). Brine application rates for pre-wetting would be higher, he said, if the trucks could hold more liquid.

2.9 Example of Winter Weather Event Response Strategy

A well-coordinated snowfighting effort begins before the onset of any frozen precipitation. Ideally, weather forecasts have been generated, detailing the times, elevations, and intensity of the expected precipitation.

Advances in weather forecasting offer snowfighting crews more advance notice than in the past. Since weather in the Sierra Nevada Mountains of California is typically dictated by slow-changing patterns, large snowfighting crews are not kept on standby during "dry spells." This operational plan is distinct from other areas of the country, such as the Great Lakes region, where a slight change of wind can lead to the rapid onset of a lake-effect snow event, and, therefore, higher levels of staffing are maintained at all times. At Caltrans, snowfighting crews are typically called to their posts 24 hours before the predicted onset of a large winter weather event [12]. Smaller crews are kept on location 24 hours a day to deal with issues such as blowing snow and black ice formation. According to a document released by Caltrans pertaining to its winter snowfighting operations, "the number of employees needed for a particular storm is based on a formula using the estimated snow accumulations combined with the lowest elevations that snow is predicted to fall" [12].

With forecasts in hand, supervisors and managers can begin to formulate a response plan. These forecasts include predictions of road and air temperatures at each elevation within a maintenance district. They can also prepare for the event by loading up trucks with necessary snowfighting materials and installing chains on the tires of the vehicles that are expected to be used. Brine tanks on trucks will be filled if it looks like conditions are favorable for anti-icing efforts. What follows is a rough schedule of activities that take place before, during, and after a typical winter storm.

Previously referred to studies have shown that anti-icing is an extremely effective tool to ensure that roads are as clear as possible throughout a storm while attempting to be efficient with material usage. Consequently, anti-icing techniques are increasingly being utilized. Anti-icing with liquid brine should be used before precipitation begins, and if road temperatures are above freezing when snow begins to fall, solid chemicals can also be distributed. Eventually, pavement temperatures will decrease to the point that snow will accumulate on the road's surface and ice can begin to form. Anti-icing activities should cease just before this happens.

As soon as snow and ice begins to accumulate on the road surface, the goal of a highway maintenance crew evolves to removing the snow and ice as quickly as possible while ensuring that there is adequate traction for vehicles to safely drive. Thus begins a cycle of plowing and abrasive spreading that does not stop until the storm ends. While a small quantity of deicing chemicals may be present in the abrasive mixture, pure chemical is typically not dispersed during this time. Abrasives that have been pre-wet with a chemical solution are extremely effective in these types of conditions because they adhere to the road surface much better than dry abrasives [11].

Snowfighting crews typically work in 12-hour shifts during major storms. Depending on the severity of the storm, roads are serviced based on a hierarchy of importance. Throughout a storm event, snowfighting crews use the most current weather projections for temperature and precipitation rates to manage their response to the storm. When it is clear that a storm is in its final stages, spreader trucks are loaded with deicing chemicals and redeployed. Deicing must be a well-coordinated effort because timing is very important. If there is considerable delay between the chemical application and the plowing passes, there is a chance that the melted snow and ice will re-freeze. Conversely, plowing may prove ineffective if attempted before the chemical has had a chance to fully react and go into a solution. This process of deicing and snowplowing continues until all maintained roads have been cleared.

CHAPTER 3
IMPACTS OF WINTER ROAD MAINTENANCE

This chapter summarizes the impacts of winter snowfighting operations. The impacts include direct costs, indirect costs, such as those due to traffic collisions and delays, and environmental impacts, such as effects on water and air quality.

3.1 Cost Impacts

Winter snowfighting operations are typically complex and costly. Any organization tasked with this responsibility must procure a fleet of vehicles, maintain them, fuel them, purchase large amounts of chemicals and abrasives, maintain a workforce of trained employees, and pay overtime whenever a major storm hits. An example is Caltrans' Kingvale yard, which has two 38,000 l (10,000 gal) diesel tanks that, according to a foreman on staff, are consumed once per month on average during the winter season. There are also costs associated with traveler delays, lost revenue from business, collisions, injuries, and fatalities.

3.1.1 Cost of Winter Maintenance Operations

A 1995 NCHRP study calculated the direct costs of snow and ice control on the U.S. highway system at $1.5 billion—over $2.3 billion in today's dollars [9]. This figure is consistent with other, more recent studies that list this cost at around $2 billion annually [2]. It does not take into account the indirect costs, including the corrosion of infrastructure, water quality degradation, and other environmental impacts estimated at $5 billion ($7.8 billion today) [9]. In Ontario, winter maintenance programs are estimated to exceed $100 million annually, representing 50% of the total highway budget [13].

Caltrans District 3 snowfighting crews are responsible for nearly 3,200 lane-kilometers (2,000 lane-miles) of highways and secondary routes. District 3 is located within the I-80 and Highway 50 corridors from the foothills of the Sierra Nevada Mountains in the West to the Nevada border in the East and encompasses the Lake Tahoe basin. Typically, each section of road must be serviced every two hours during a storm at the absolute minimum [12]. Over the course of a 24-hour storm, Caltrans vehicles maintain the equivalent of 38,400 ln-km (24,000 ln-mi) of road. Assuming a very conservative fuel usage of 50 l/100km (4.7 mi/gal), the diesel for a single-day storm within District 3 can cost nearly $20,000. In reality, this figure is likely much higher due to idling trucks and very large pieces of equipment such as rotary plows and front-end loaders that consume considerably more fuel than spreader trucks.

Road salt can cost between $55 and $165 per metric ton ($50 and $150 per short ton) depending on quality and seasonal demand. Nearly 730 metric tons (800 short tons) of salt will be used if two deicing passes are made on every route in District 3 following the conclusion of the storm. The total rises to over 2720 metric tons (3,000 short tons) when anti-icing and the 70:30 abrasive to salt mixture employed during plowing are taken into account. This salt comes at a cost of approximately $150,000 to $450,000 for just a single 24-hour storm. The 4080 metric tons (4,500 short tons) of abrasive used adds to these costs. Additionally, during winter snow removal operations in District 3, many equipment operators receive substantial amounts of overtime pay [12].

The consideration of the entire snowfighting effort shows that any means of reducing material usage or operator hours can go a long way towards saving money. Even a material savings of 10% can have an impact of over $50,000 for District 3 alone in a single day.

3.1.2 Cost of Traffic Collisions and Delays

Every winter, over 115,000 people are injured and more than 1,000 killed in the United States due to traffic collisions on snowy or icy roads [6]. A price cannot be placed on loss of life on this scale, though the financial impacts of property damage can be calculated. In Canada, it is estimated that weather-related injuries and property damage are in the range of $1 billion per year [13]. A seminal study conducted in 1992 found that collision rates are about eight times higher before deicing than after [14]. Injury rates are nine times higher before deicing has been performed, and the overall severity of collisions is reduced following the treatment of roads. Winter road maintenance was shown to pay for itself in as little as 25 minutes after motorists start reaping the benefits of salt spreading. This is because road users save $6.50 for every dollar spent on two-lane undivided roads and $3.50 for every dollar spent on multi-lane divided freeways.

Traffic collisions notwithstanding, snow storms take an economic toll on the states they impact. According to an American Highway Users Alliance report [15], a one day major snow storm leading to the closure of major roads can cost a state between $300 and $700 million in indirect costs such as lost sales tax revenue and business slowdowns. Additionally, hourly workers are the worst affected by snow-related shutdowns, accounting for nearly 2/3 of the direct economic losses. The report concluded that the economic impact of winter weather events far outweighs the cost of timely snow removal geared towards providing a high level of service. A 2006 study concluded that anti-icing, pre-wet salting with plowing, and abrasive use have significant effects on reducing the number of collisions [13].

3.2 Environmental Impacts

Any anti-icing chemical, deicing chemical, or abrasive dispersed on a roadway will eventually be removed from the pavement. If it is not swept up, it will be pushed, blown, or washed off the roadway and begin to incorporate itself into the environment, possibly with detrimental effects. Nearby soil can become contaminated by salt and other chemicals, which can impact local vegetation. Abrasives can be reduced to dust, which may negatively affect local air quality and could end up coating plants in a layer of dust. Wind is capable of transporting salt spray over distances greater than 150 m (164 yd) under very windy conditions [11]. Most importantly, chemicals can be transported into groundwater and surface waters far from the road to which they were applied. This has implications for aquatic plants and fish life. While the United States does have general legislation in place prohibiting the contamination of land, air, and water, few of these regulations specifically address winter maintenance chemicals [11]. The state of California's stance on chemical use for snowfighting is to use as little as possible while still striving to ensure roads are safe for drivers.

3.2.1 Effects on Water and Aquatic Life

A study carried out in 2002 addressed the long-term effects of road salt usage in the Mohawk River watershed of New York State [16]. Specifically, it investigated the concentrations of the ions Na^+ and Cl^- in surface water spanning the years from 1952 to 1998. Concentrations of other ionic constituents were measured as well to ensure that any changes in the quantity of Na^+ and Cl^- could be traced to a specific cause rather than a general trend of minerals entering the water through some other means. The study estimated that, on average, 39 kg/km^{2}day (223 lb/mi^{2}day) of road salt was used within the watershed. Over the course of the study, salt usage increased from 16 kg/km^{2}day (91 lb/mi^{2}day) in 1952 to a peak of 46 kg/km^{2}day (263 lb/mi^{2}day). The authors concluded that this increase in salt export was solely responsible for the observed rise in concentration of Na^+ and Cl^- by 130% and 243%, respectively. Meanwhile, other ions present in the ecosystem had either remained constant or decreased over the same time period.

A deicer evaluation carried out by the NCHRP in 1992 included aquatic vertebrate mortality tests when exposed to varying concentrations of NaCl (salt) [17]. This study showed that over 50% of flathead minnows started dying when 10 g/l (10,000 ppm) of salt was present in the water. The Mohawk River study found concentrations of NaCl in surface water at the exit of the watershed area to be on the order of 33 mg/l (33 ppm), or around three orders of magnitude lower than necessary to harm fish in the river [16]. The 10 g/l (10,000 ppm) figure determined by the NCHRP study is an unrealistically high concentration for any body of water located away from roadways. However, concentrations could feasibly approach these levels in roadside ponds and streams during periods of high chemical application.

This idea of locally higher salt concentrations was corroborated by a 2008 study [18]. It identified a standard set by the Minnesota Pollution Control Agency of 860 mg/l (860 ppm) of chloride for acute events and 230 mg/l (230 ppm) for chronic pollution. The study revealed that small streams flowing through urban areas exceeded both of these standards periodically during winter months. Furthermore, the lakes into which these streams drained became prone to prolonged or reduced mixing, both of which are undesirable conditions. One such lake was found to have a layer containing 3000 mg/l (3000 ppm) of chloride.

3.2.2 Effects on Soil and Vegetation

Salt has been used to intentionally retard the growth of vegetation for thousands of years and is commonly suggested as a means of controlling weeds on residential properties. Salt use has been linked to twig dieback in hardwoods and needle browning in pines along Minnesota roadways [19]. A Swedish study similarly concluded that the salting of roads has a direct and measurable impact on vegetation up to several hundred meters from where the salt is applied [20]. Air is the main mode of transport, so prevailing wind directions dictate where the most damage takes place. Furthermore, groundwater and soil 1.65 m (5.4 ft) from the surface were found to contain greatly increased sodium and chloride levels in the area adjacent to the roadway.

3.2.3 Effects on Air Quality

A 2005 study by an international collaboration of researchers examined the impacts of winter road maintenance on air quality in the Lake Tahoe basin [21]. This study listed re-suspended road dust as a main contributor to ambient particulate matter (PM). It used roadside and mobile sensors to compare ambient PM levels with those following snowstorms in which deicing and abrasives were utilized. These post-storm data were taken after the snow had been cleared and the road had a chance to dry off. It was determined that PM emissions doubled for a 24-hour period following the drying of a road surface. Air quality data were again taken following locally mandated street sweeping operations that must be performed in the Lake Tahoe basin following the application of any deicing or abrasive materials. It was found that the PM levels temporarily spiked following street sweeping, a phenomena that can be attributed to the agitating action of the sweeper bristles that mechanically remove dust from the roadway. Ambient PM levels were observed to gradually subside over the weeks following the end of the snow season. Interestingly, this study suggested anti-icing practices be employed as a means of reducing particulate matter levels by alleviating the need for traction aids during the later parts of a storm.

CHAPTER 4
SPREADER COMPARISON

This chapter provides descriptions of the typical Caltrans V-Box spreader and of the Epoke spreader. Also included are the results of preliminary testing to understand the spreading rates of the sand spreader units. The Epoke's sand spread pattern is discussed, as are the expected benefits of its use.

4.1 V-Box Spreader Description

The Caltrans' District 3 maintenance fleet is in possession of 63 salt and sand spreading trucks. They are typically a 10-wheel dump body chassis with one or more plows and a granular spreading body mounted to the chassis. The granular spreading body is referred to as the V-Box spreader. The V-Box spreader is comprised of 1) a stainless steel hopper for carrying the load of sand, 2) a means of conveying the material from the hopper, and 3) motorized spinner disk for casting granular material. The hopper has a capacity of 5.6 m^3 (7.3 yd^3). The bottom of the hopper is shaped like a 'V' so that material is funneled onto a chain conveyor that rests on the bottom. While some spreaders of this type have an auger in place of a conveyor, the spreaders in Caltrans' fleet do not. One of the disadvantages of this type of spreader is that the entire weight of the load is constantly supported by the conveyor at all times. When material is requested, the conveyor begins to move, and whatever is loaded into the hopper begins to dispense out the rear of the machine. This material travels through a chute where it lands on the spinner. This spinner is a heavy rubber disk roughly 0.9 m (30 in) from the road surface and is enclosed with moveable louvers. The louvers provide a rudimentary means by which the operator can 'aim' the dispersed material. The more vertical the orientation of the louvers, the more material is deflected downwards and thus prevented from traveling horizontally. The disk itself is molded with six vertical 'flights,' which help to direct the material in an outward path.

4.2 Description of Muncie Hydraulic System Controller

The V-Box spreaders are controlled by a Muncie hydraulic system controller, commonly known as a Muncie or Muncie controller. They are made by a company called Muncie Power Products, and several generations of their spreader controller units are present in the Caltrans spreader fleet. Features vary from unit to unit, but general functionality is similar. These controllers utilize open loop control with no sensor on the conveyor or spinner and, therefore, no feedback in the control system. Spinner and conveyor speeds are determined by the position of a hydraulic valve. The position of this valve is calculated by the controller as a function of road speed, desired spread rate, and calibration to the material being spread. The controller does not receive any information regarding the actual speed of either the spinner or the conveyor. Depending on the engine speed, hydraulic load, or changes in calibration, the actual spread rate may differ greatly from what is requested by the operator.

A calibration is performed at the beginning of the snow season after a V-Box spreader has been fitted to a chassis. The controller is typically left in the cab throughout the year, and thus it is necessary to calibrate the controller to ensure that the V-Box spreader's material usage is accurately controlled. Furthermore, the specific V-Box spreader used on a given truck may vary from year to year. Calibrating a Muncie/Spreader combination is done by accessing a special menu within the controller's user interface. A special code must be entered to access this part of the menu, and only certain Caltrans staff have access to these codes. The calibration program works by assuming that all material expelled from the spreader will be collected and weighed at the end of the calibration cycle. Prior to the test, the truck is loaded with material and, upon pressing the dispense button, the conveyor begins to move while a timer starts counting on the controller display. It is suggested that calibration cycles be run for as long as possible. The truck's engine should be idled at 1500 revolutions/minute (rpm) during calibration to simulate the hydraulic pressure that will be available during actual operation in the field. After 60-120 seconds, the operator stops the test using the Muncie controller. Then, the material expelled during the test must be weighed. This value is then entered into the calibration menu.

Conveyor speed determines the rate at which material exits the spreader at a given time. The dimensions for this are mass/time. The dimensions for vehicle speed are distance/time, so dividing rate by speed results in mass/distance, or how many pounds of material are distributed every mile. Because roads can be thought of as two-dimensional planes, another dimension needs to be added to account for the width of the spread path. Spread density is defined in terms of mass per unit area. The problem with the Muncie controller is that conveyor speed does not change as spread width is increased or decreased. This means that if the conveyor is set to deliver 200 kg/ln-km (714 lb/ln-mi) across one lane, but then spread width is increased to two lanes, each of those lanes will only be seeing 100 kg/ln-km (357 lb/ln-mi), or half the desired density. The operator must increase the conveyor speed in proportion to the increase in the lane width setting. They use the dials on the controller as a rough guide only and rely on visual cues to make sure enough material is being distributed.

4.3 Spinner and Engine Speed Correlation Experiment

The hydraulic gear pump used to power the truck's auxiliary equipment is directly linked to the engine's output shaft for this type of spreader. Therefore, pressure and flow rate within the hydraulic system are directly proportional to engine speed, and engine speed will vary with vehicle speed. It is very difficult to keep engine speed perfectly constant throughout an entire spreading pass. Since the hydraulic system powers the conveyer and spinner, their speeds also vary during operation. The positions of the hydraulic switches used to control conveyor and spinner speed are set using an algorithm within the controller that does not take engine speed into account. Thus, a test was devised and carried out to investigate the effects of engine speed on spreader performance empirically. An AHMCT staff member put the spreader truck in neutral and ran the engine at various speeds while toggling through four different spinner speed settings. Engine speed values of 600, 1000 and 1500 rpm were used, as well as spinner speeds of 25%, 50%, 75%, and 100% spread width setting. An optical tachometer was used to measure the speed of the spinner disk by means of a piece of silver tape placed on the outer edge of the disk. Table 4.1 contains the test results. Interestingly, results were fairly consistent for any given spread setting except for 100%.

Table 4.1: Spinner Speed (rpm) as a Function of Engine Speed and Spread Width Setting

	Spread Width Setting			
Engine Speed (rpm)	25%	50%	75%	100%
600 (idle)	190	358	496	496
1000	218	360	517	650
1500	201	360	503	634

4.4 Description of Caltrans' Utilization of V-Box Spreaders

The trucks that carry these spreaders serve a dual purpose as plow trucks. They are used from the moment snow begins to accumulate on the roadway until after the storm has ended and the roads can be cleared down to the pavement. The material being spread changes throughout the course of the storm. Typically, an abrasive mixed with salt is utilized while snow is still falling to increase traction. Pure salt is used at the end of a storm to help clear the roads. Spread rate is determined by several factors. Brake checks—a maneuver wherein the truck's brakes are abruptly applied—are used by operators to determine how much traction is available in certain spots. This tactic is heavily used in known trouble spots. Such trouble spots are named and their locations memorized by operators due to their high concentration of collisions and tendency for conditions to be much worse than on surrounding sections of road. Aside from the road conditions, operators must take into account the length of their route when deciding which spread rate to use.

The Caltrans V-Box spreader trucks typically have no brining capability. Caltrans is in possession of several brining trucks that belong to the family of rudimentary systems described in Section 2.2. These trucks have no solid material spreading capability, so supervisors must decide which tool to use at a given time. Caltrans occasionally uses pre-wetting methods by parking the hopper of a spreader truck under a spray bar and showering the load with either water or salt brine. It is imperative that the entire load be used before the vehicle is parked in the yard, because otherwise the remaining material will harden and become very difficult to remove.

4.5 Epoke Spreader Description

The Epoke model purchased for this test was the Sirius Combi 4900. It is capable of spreading solid material, liquid chemical, and allows for the pre-wetting of solid material using the onboard liquid storage tanks. The capacity is 4 m^3 (5.2 yd^3) of solid material and 3,600 l (950 gal) of liquid chemical. It features a novel system of solid material metering whereby the weight of the entire load does not rest on a conveyor belt, but rather on a delivery roller that runs the full length of the hopper. This delivery roller is a central component of the manufacturer's 'Epoke Principle' and helps ensure that the spread rate is controlled as accurately as possible.

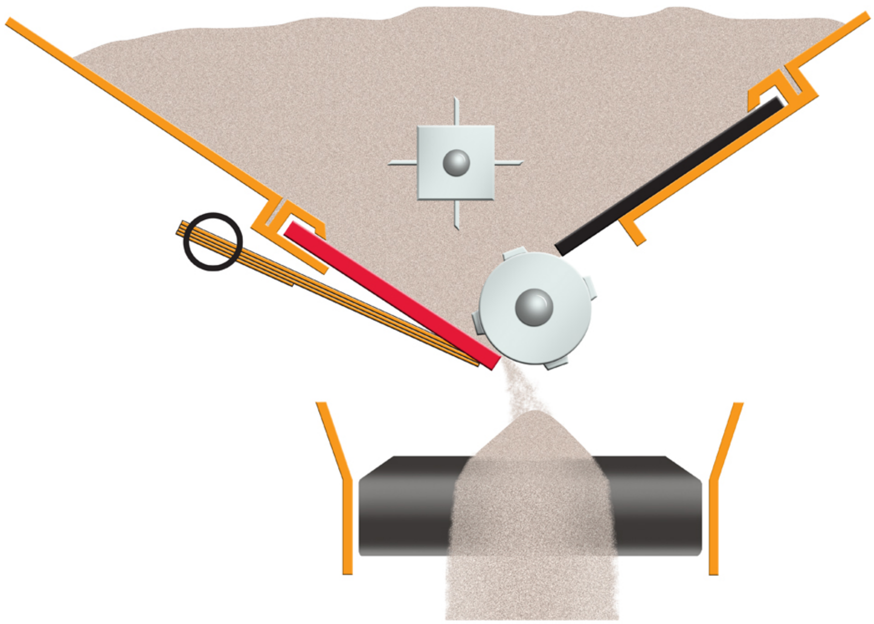

Figure 4.1: The Epoke Principal

Figure 4.1 shows the Epoke components. The roller, agitator (the square part in the middle of the hopper), and conveyor are all driven by the same motor and are linked with a timing chain. Material is dropped down onto the conveyor by the rotation of the delivery roller. As it spins, material is forced past a strip of stiff rubber (the red part at the bottom of the hopper). The squeezing force between this rubber and the roller is controlled by a set of finger springs that can be moved to adjust resistance. It is important not to change the position of these springs after calibration has been performed in order to avoid invalidating the calibration. The Epoke Principle assumes that the ratio between the revolutions of the delivery roller and the movement of the conveyor remains constant. This ensures that the same amount of material is on the belt at all times, regardless of spread rate. If more material is needed, either through an increase in vehicle speed or spread rate, the entire system speeds up. Calibration of this system involves calculating the amount of material that is on the belt at a given time. The controller is able to use this information to calculate the speed at which the entire system should run at any given time.

The Epoke spreader installation is similar to the typical V-Box spreader. The one exception is that the hydraulic system power requires a prioritized hydraulic supply circuit that cannot be shared with other truck components, such as the actuators for the plow blades. In the case of the Caltrans trucks, which use gear pumps, the single-section gear pumps were replaced by pumps with two separate sections.

Unlike the typical V-Box spreader with a Muncie controller used by Caltrans, the Epoke is an integrated system. Aside from the Epoke controller in the cab, this machine has a computer located onboard the spreader. This computer utilizes a closed loop control system to ensure that material is being delivered at precisely the requested rate. Encoders are used to sense speed on the spinner, the liquid pump used for liquid delivery, and the motor that drives the conveyor, agitator, and delivery roller. The Epoke controller calculates the desired speed of each part of the system and constantly adjusts the hydraulic valves to ensure that the mechanical components are moving as desired. Readings from the encoders are fed back into the controller, so even as variables like hydraulic pressure and operator-dictated spreader width change, the correct spread rate is maintained.

The Epoke is equally effective as an anti-icing or pre-wetting machine. The units purchased by Caltrans hold 3,600 l (950 gal) of liquid, which is enough to treat nearly 65 lane-kilometers (40 lane-miles) at the fairly typical rate of 58.3 l/ln-km (25 gal/ln-mi). Liquid is loaded through a two-inch cam lock fitting with a check valve to ensure there is no back-flow. When liquid is requested, either for anti-icing or pre-wetting, a large pump located at the rear of the Epoke spreader turns on. According to the manufacturer, this pump is very durable and can be run dry because it has its own on-board oil reservoir. Liquid is pumped down to the spinner disk through a rotary coupling. The underside of the spinner disk has stainless steel tubes extending radially from the central coupling. Liquid flows into these tubes and is flung outwards by centrifugal force. This leads to an even distribution of liquid, as opposed to the pattern of rudimentary gravity-feed spray bar brining machines, of which an example can be seen in Figure 4.2.

Figure 4.2: Stripes of Liquid Behind a Low-Tech Brining Truck

The merits of pre-wetting were discussed in a previous section. The Epoke handles pre-wetting by simultaneously spreading solid and liquid materials. The dry solids come into contact with the liquid chemicals mid-flight due to the angles of the liquid tubes on the bottom of the spinner disk. Pre-wetting can be adjusted using the controller (described later), and is defined by a percentage value ranging from 10% to 30%. This value equals the percentage of solid material by mass that is replaced with liquid chemical. So, if solid chemical is being spread at a rate of 140 kg/ln-km (500 lb/ln-mi) and pre-wetting is turned on at 30%, solid material used will decrease by 140*0.30 = 42 kg/ln-km (150 lb/ln-mi). Accordingly, there will be 98 kg/ln-km (350 lb/ln-mi) of solid material dispensed. The 42 kg/ln-km (150 lb/ln-mi) of solid is replaced by 42 kg/ln-km (150 lb/ln-mi) of liquid. Using the brine density of 1.2 kg/l (10 lb/gal), the liquid volume application rate is 35 l/ln-km (15 gal/ln-mi).

One of the most important features of an Epoke spreader is its ability to adjust the direction in which material is dispersed. This is known as the Epoke symmetry function, and the mechanical components are shown in Figure 4.3. An electronic actuator articulates a mechanism that accurately dispenses the solid and liquid material in the correct direction and over the correct widths. For solid material, the chute that deposits sand or salt onto the spinner disk moves either towards the center or outside of the disk. This action changes the amount of time the material spends on the disk, and thus alters the dispensing direction. The same linkage controls the position of a rotary coupling to bias the position at which each tube is filled with liquid, and this alters the direction of the liquid spreading.

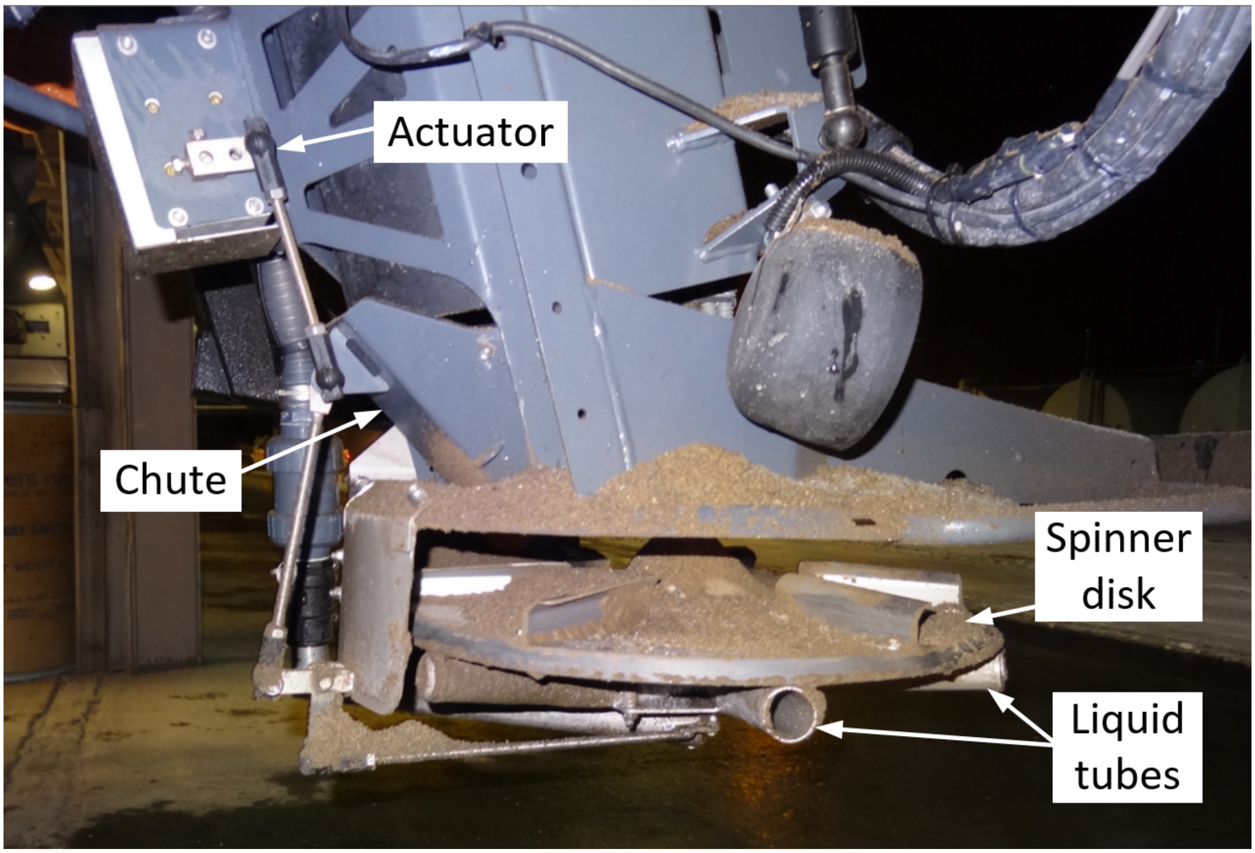

Figure 4.3: Epoke Components Used to Change Direction of Spreading

The advantages of this system from a flexibility standpoint are significant. Material can be spread either directly behind the vehicle, behind and to one side or the other, or even completely to one side and not behind the vehicle. The width can range from a narrow strip to up to three lanes wide. A graphic representation of this ability can be seen in Figure 4.4. Additionally, the vertical ‘flights’ on the spinner disk can be adjusted to better suit the common practices of a particular maintenance district. Regardless of the spread pattern, the controller is able to vary the speed of the material delivery system to ensure that the spread rate remains constant throughout the entire pattern.

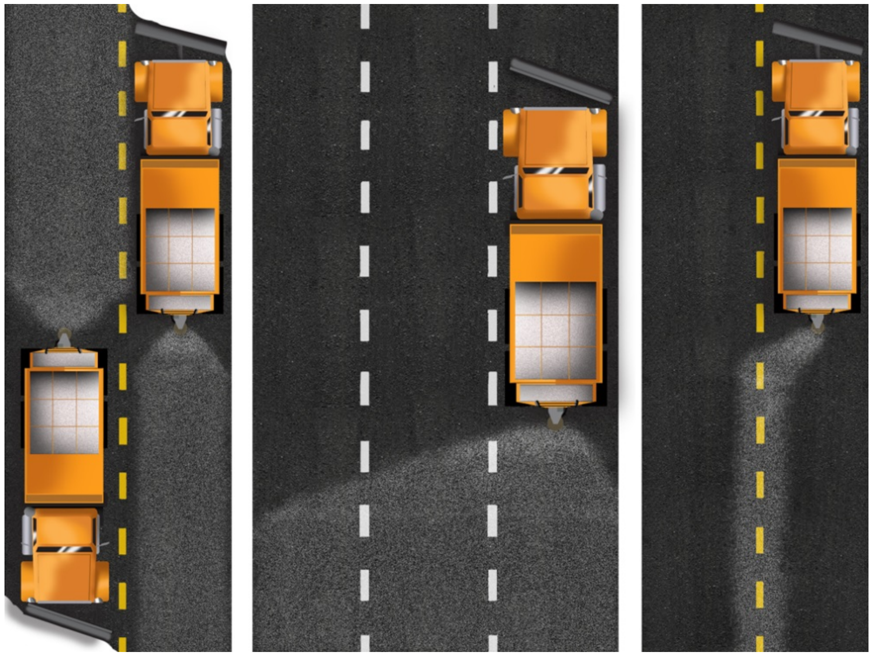

Figure 4.4: Manufacturer's Illustration of Possible Spread Patterns

The in-cab EPOMaster controller, shown in Figure 6.8, has a simple yet effective user interface. Two separate buttons activate the dry material spreader and the liquid spreader functions. Using dials, increments of spread rates and width can be easily selected independently for either solid or liquid materials. A third dial is used to adjust the spreading direction. When applying dry materials, pre-wetting can be turned on or off with the press of a button. Sensors in the hopper and brine tanks alert the operator when materials are running low. The controller application rate settings are programmed as needed, depending on the needs of the snowfighting operation.

4.6 Expected Advantages of Epoke Spreaders

Epoke promotional literature places a large emphasis on the machine's ability to closely control the spread rate and material placement. It was previously discussed that the Epoke achieves spread rate accuracy by using a carefully regulated metering system and closed loop control. Numerous studies have been carried out in the past two decades about the precise material spread rates needed to achieve optimal levels of road service while minimizing adverse effects to the environment.

V-Box spreaders are designed to produce a symmetrical spread pattern. Material is delivered to the spinner disk through a fixed chute. The disk itself has flights that are not adjustable, so the spread pattern cannot be changed through this method. The only way to aim material is by exiting the truck and moving the louvers that surround the spinner. Through this method, it is possible to block material from traveling to one side or the other. This presents another problem, which is that all the blocked material will end up roughly behind the truck. Suppose that an operator is trying to spread material across two lanes while driving in one lane or the other. They will have to adjust the spread width so as to cover 3 lanes, then exit the vehicle to adjust the louvers. One third of the material will immediately end up on the shoulder or roadside if the louvers are left in the open position. Assuming the correct adjustment is made, the 1/3 of material that is deflected before traveling off the road will now end up directly behind the vehicle. Therefore, 2/3 of the total material will end up behind the truck in its lane of travel, and only 1/3 will end up in the adjacent lane. An Epoke's symmetry function enables an operator to spread across several lanes while maintaining a consistent rate across the entire pattern.

The ability to switch between solid and liquid spreading or to pre-wet solid material at the push of a button gives operators flexibility in the snowfighting effort. Previously referred to studies have demonstrated the material savings achieved when making the switch from a dry chemical and abrasive-based delivery methodology to one with an emphasis on pre-wet and liquid materials [11]. Furthermore, Caltrans personnel have commented that, while straight chemicals are rarely used during a storm, every maintenance route includes sections that are known to be more troublesome for motorists. These sections can receive deicing materials even when the truck is loaded primarily with abrasives due to the presence of brine tanks. This on-the-fly adaptability will lead to both safer roads and more efficient service.

4.7 Caltrans' Potential Uses

Similar to conventional V-Box spreaders, the Epoke spreaders are mounted to a truck chassis that serves a dual purpose as both a spreader and a plow. Unlike the older equipment, these trucks can be put to use before a storm begins as part of the pre-storm anti-icing efforts. Currently, this job is carried out by specific equipment that must be fueled and maintained separately. Once an operator is trained on an Epoke, he or she can be put to work earlier in a storm. The benefits of this are reduced overhead in terms of idle personnel and equipment. After the onset of precipitation, the Epoke can seamlessly switch to being used as a conventional plow/spreader truck.

CHAPTER 5
SPREADER COMPARISON TESTS

This chapter reports on testing conducted to validate manufacturer claims regarding the accuracy of the spread rate and material placement. In previous studies on salt spreading equipment, such tests have been referred to as "spread picture" and "spread pattern mapping" [10]. This study will refer to such tests by the latter term. The goal of this type of test is to see how material is distributed within the spread pattern, as well as how much of the material settles within the desired area. Both the V-Box spreader and Epoke spreader were tested at the Advanced Transportation Infrastructure Research Center (ATIRC) over the course of several weeks. Testing involved a combination of both empirical and qualitative examinations, with an aim of learning as much about both types of machines as possible. This chapter provides details of this testing procedure, and the following chapter provides the results.

5.1 Spreader Test Criteria

The Epoke Sirius Combi 4900 should offer a high level of control and uniformity of the dispersal of materials, as its manufacturer claims. This spreader allows the operator to use only the material that is necessary to manage existing or expected conditions while minimizing waste. Waste, in this case, is defined as any materials that are consumed yet do not benefit the snowfighting operation. Such materials may be spread past the edge of the roadway, may be laid down in a thick layer prematurely (thus allowing the flow of traffic to push the material off the road before chemical action occurs), or may be distributed unevenly across the width of the roadway. In order to compare the machines, identical tests were carried out with both the V-Box spreader and the Epoke spreader. The following three subsections describe the criteria used to compare the machines.

5.1.1 Accuracy of Material Dispersal

The Epoke controller allows for very specific application width, rate, and placement of the material stream. The manufacturer claims the spreaders have the ability to evenly spread material in the lane in which the truck is driving, both in that lane and an adjacent lane to either side, or in three lanes. A comprehensive sampling of scenarios should be tested to ensure that the machine is capable of performing this task as claimed. This involves measuring the distribution of materials across the targeted lanes as well as how much wasteful 'overspray' is lost off the side of the road.

5.1.2 Uniformity Within Targeted Spreading Area

Ideally, materials will be distributed evenly across the targeted sections of road. If this is not accomplished, the edges of the roadway may receive a lower application rate than other lanes, leading to reduced traction or allowing snow/ice buildup. Even a very high spread rate has minimal value if strips of ice form where vehicles might drive. Therefore, the machine should be able to maintain an even distribution across all lanes serviced.

5.1.3 Ease of Use of the Spreader

Simple but effective equipment reduces the amount of initial and refresher training required for staff and increases operator acceptance and usage. The primary interface of the user is with the machine's controller. As such, the controller interface should be intuitive enough that an operator can quickly navigate the various functions without diverting too much attention from the road. Menus should be easy to navigate and buttons should be clearly labeled.

5.2 Dry Material Spreading Test Procedure

The following test plan was implemented to assess each spreader's ability to meet the above criteria. A 70/30 abrasive/salt mixture commonly used by Caltrans was used for all tests due to the fact that it is typically available in all winter snowfighting yards and is utilized frequently throughout the course of winter storms. The calibration of any spreader should be performed with all materials expected to be used throughout winter snowfighting operations. As the Epoke used in this study was brand new, calibration was performed upon the delivery of the machine using the exact material used for testing. Both machines were calibrated per the manufacturer's operating instructions.

Spreading tests were carried out on the ATIRC test track. The spread rate was determined prior to each test based on observations from the previous test and the priorities for which modes should be examined. The road section available at the facility is 9 m (30 ft) wide and long enough for the trucks to safely accelerate to and decelerate from 40 km/h (25 mi/h). Cones were placed to form a lane only marginally wider than the truck because it was important that the truck drive in a straight line down the very center of the measuring area. The boundaries of the test section were marked with cones so the spreader operator knew when to commence and halt spreading. A subsection of this spreading area was the closely controlled and marked measuring area. This area was thoroughly cleaned before each test using push brooms and high-velocity air.

The measuring area was 7.9 mm (26 ft) wide and 7.3 m (24 ft) long. It was bordered on either side by 0.5 m (1.5 ft) tall plywood barriers designed to stop material from exiting the measuring area. Figure 5.1 shows the layout of the measuring area. It was assumed that all material that would potentially deposit beyond the barrier was located within 0.30 m (1 ft) of these barriers.

The first half of the measuring area, 3.65 m (12 ft) long, was kept clean between tests to avoid the introduction of material from a previous test into the sampling area, or the second half. The sampling area was marked by precisely applied road marking paint, dividing it into 26 segments. These markings served as locating features for the vacuum guides. The markings were in the form of two rows of small circles placed at 0.30 m (1 ft) increments. Pieces of wood with identically sized holes were affixed to the ends of the vacuum guides, so proper alignment could be guaranteed by lining the correct paint circles with the sighting holes.

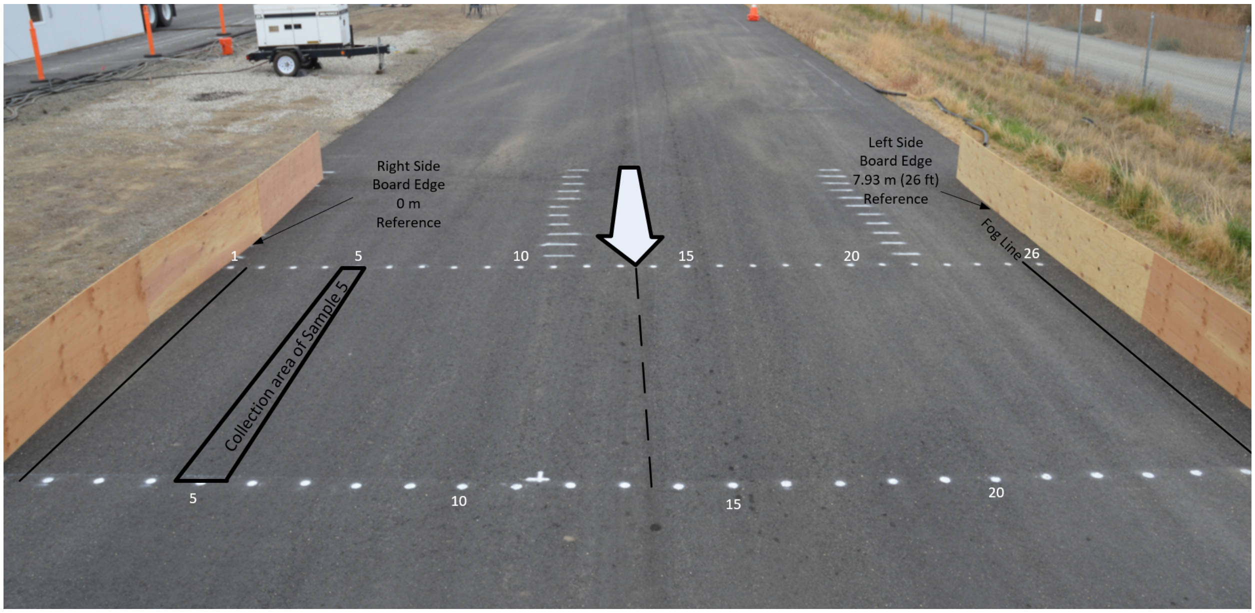

Figure 5.1: Measuring Area Used for Spreader Tests

These vacuum guides enabled the careful measuring of dispersed material over a fixed area. The guides measured 3.65 by 0.3 m (12 by 1 ft). They were constructed of kiln-dried wood—a material that is easy to work with, stiff enough to ensure dimensional stability, and light enough for portability. The previously listed dimensions are the internal dimensions of the guide frames. The borders of the guides were lined with bristles (similar to those found on door sweeps) to ensure that all the material within the guide could be vacuumed up and that material from adjacent zones was not disturbed.

Every test run of both spreaders was filmed using a GoPro video camera mounted above the spinner disk. The extremely wide field of view of this type of camera, combined with a 60 frames per second capture rate, allowed the careful review of each test. The film was reviewed immediately following every test run to ensure that the spreader had functioned properly. In the case that it had not, the measuring area was cleaned thoroughly without taking any measurements. This footage was extremely helpful in making qualitative assessments of the equipment after the empirical testing had concluded.

A careful process of material collection was carried out following each successful spreader run. Care was taken to not disturb the distributed material in any way by restricting walking and driving over the sampling area following each run. The vacuum guide was oriented parallel with the road and moved in 0.30 m (1 ft) increments in the direction perpendicular to the road. Measurements were taken by placing the guide on the road surface using the previously described locating features and vacuuming all the material contained within the guide frame. Between 60 to 90 seconds were spent vacuuming for each measurement. After the area within the frame was deemed adequately clear of sand and salt, the vacuum was turned off and a few seconds were taken to let the material filter through the cyclone dust collector and into the collection bucket. Twenty six samples were collected per test, one for each segment. These tests were meant to reproduce spreading across two lanes with a 0.30 m (1 ft) ‘overspray gutter’ on each side.

5.3 Pre-Wet Material Spreading Test Procedure

To test the Epoke pre-wet function, the controller was set to 30% pre-wet by mass, and the spread rate was set at 110 kg/ln-km (393 lb/ln-mi). It was proposed that adequate time be taken to ensure that all the water evaporated before sand collection occurred, but, during testing, it was a dry day, and the water evaporated almost immediately. Measurement was carried out in the manner described in the previous section.

5.4 Liquid Spreading Test Procedure

Quantitatively measuring liquid output and distribution would be extremely difficult. A special surface would need to be developed that could trap water without allowing it to evaporate if hot and dry conditions were present. As such, qualitative testing that utilized observations as well as photographic documentation were relied upon. As the main goal of this liquid spreading assessment was to determine the uniformity of spread, a procedure was developed to do so. First, the Epoke would make a pass down the test track at the prescribed liquid application rate. A person other than the vehicle operator would be standing by safely off to the side of the test track as the pass was made. Immediately after the truck has passed through the test zone, the second researcher would carry a ladder into the middle of the track roughly 10 m (30 ft) away from the start of the test zone. The researcher would use a digital camera to take pictures of the test zone from the top of the ladder every thirty seconds. This would continue until all of the water had evaporated from the road surface. By collecting data in this manner, it would be possible to look at the pictures in sequential order and determine if any areas of the test zone dried faster than others, which would signify an uneven distribution of liquid within the zone. This test was not performed.

5.5 Test Methodology Discussion

The spread rates chosen were between 60 and 120 kg/ln-km (214 and 429 lb/ln-mi) and are representative of those used by snowfighting crews worldwide during sanding and deicing operations (actual spread rates are given in Chapter 6). Caltrans uses application rates between 28 and 140 kg/ln-km (100 and 500 lb/ln-mi). Spread rates chosen for tests could have been higher or lower, as could have been spreader truck velocity. Accuracy with regards to typical operating conditions was the most important factor considered when choosing the aforementioned criteria. When testing the Epoke spreader, spread offsets to both the left and right were tested in order to gauge the functionality of this feature. Not every combination of spread width, direction, or density could possibly be tested due to the considerable time required for sample collection after each test and the brief window in which the machine was available.

Time was also spent becoming familiar with the controls and functions of each machine. This involved reading manuals, learning, and performing calibration procedures, taking photos and videos of various moving parts, and speaking with operators. It was important to become proficient in the use of the Epoke spreader in the case that a company representative was not available to answer questions for the maintenance crews who would be receiving the machines.

Visual observation of the spreading operation was used to assess its quality. Video captured by the camera in section 5.2 was used to document the pattern of material leaving the spinner. A consistently regular pattern of material leaving the spinner was judged to be ideal; the observation of any clumping of material entering the spinner was considered less ideal.

5.6 Hardware Developed for Tests

5.6.1 Vacuum Frames and Dust Collection System

Many different methods of measurement were considered for the spread pattern mapping test. These methods included a computer vision system to count particles without disturbing them, a segmented road surface that could be removed after each spreader pass, and the eventually selected vacuum system. A similar study carried out by the Indiana Department of Transportation in 2001 utilized spread pattern mapping to analyze and compare several types of salt spreaders, with an emphasis on evaluating Zero Velocity spreaders [10]. This study used a vacuum to collect samples from within each grid space on their test road, but each sample was stored in a separate vacuum bag. These bags are both expensive obtain and time consuming to change in and out. In the case of the Epoke study, hundreds of bags would have needed to be purchased at a cost of several dollars per bag. The decision was made to use a vacuum system, but with a bagless design.

A relatively inexpensive product called the Dust Deputy, sold by Oneida Air Systems, was identified. It is essentially a miniaturized version of the large cyclone dust collectors commonly found in wood shops. Cyclone dust collectors utilize carefully designed chambers, inlets, and outlets to capture material. Dirty air laden with dust particles enters through the side of the collector, and a vortex forms next to the outer wall. This vortex spirals down towards the base of the ice-cream-cone-shaped chamber, at which point its velocity drops and particles fall into the trap below. The air then forms a second vortex in the center of the chamber that travels up into the air outlet that is connected to a vacuum. By using a dust collector to trap the sample material, a much smaller vacuum could be used, so long as it possessed a sufficient flow rate. There was concern that a measurable percentage of the sample material would be lost to the vacuum's main chamber, but after collecting 250 samples over the course of weeks of testing, the inside of the vacuum was almost totally empty.

5.7 Long-Term Data Logging

A part of this study has to do with the usage and performance of the new Epoke spreaders. Quantifying performance under controlled conditions and in a field environment is necessary to capture a full range of data. This can be accomplished by utilizing the Epoke's EPOMaster controller. It has an RS-232 port that constantly outputs a stream of data containing the current operational settings. These data can be captured and sent wirelessly to servers that allow AHMCT personnel to access it in real time or to download usage logs. To accomplish this, telemetry equipment that is capable of reading the data stream, storing it, and establishing a connection with external servers via the 3G data network must be installed in the trucks.

An extensive search was conducted to find all available telemetry service providers. These providers, who often operate under the title of 'Fleet Management Solutions,' have developed proprietary data logging devices that can be installed into a piece of equipment such as a truck. These devices either include or are connected to external wireless data modems that allow the transfer of data from the equipment to a central data center operated by the service provider. Back-end software created by the provider allows these data to be visualized on a customizable web page, enabling anybody with a password to view the operational status of a piece of equipment in real time. Another feature of such software is that historic data can also be viewed and totals (e.g., miles driven in a month, total sand dispensed) can be calculated. Some telemetry service providers support the downloading of raw data from their websites. This is the most crucial feature to the AHMCT team, because this raw data is what will inform the eventual recommendation.

DM&T Services was determined to be the best choice of telemetry service provider for the Epoke study. It satisfied the research needs, and the equipment and service costs were reasonable. Also, the manufacturer was responsive and engaged, despite the fact that the AHMCT account would be a relatively small one. Finally, their hardware appeared flexible enough to allow the addition of many other sensors that might be deemed necessary for this study. Two units were purchased and installed in the cabs of the vehicles that carry the Epoke spreaders.

CHAPTER 6
SPREAD PATTERN TEST RESULTS

This chapter reports on detailed test results to establish the pattern of material spread by the V-Box and Epoke spreaders. The goal is to establish whether the spreading of material by the Epoke will result in more uniform and better dispersed material and thus better overall road traction.

The results of the testing should be used carefully since the machine was tested at ATIRC with the factory default settings, as the unit had not yet been calibrated by the vendor. The tests were performed in October 2013, and access to both spreaders was limited to about 10 days due to Caltrans' needs for the approaching winter.

6.1 Test Results

Eight tests were conducted as part of the spread pattern mapping study: three with the Muncie/V-Box spreader and five with the Epoke. Table 6.1 contains the parameters for each test such as spread width, application rate, and spread direction. Data was collected for each test using the procedure described in Section 5.2.

Table 6.1: Summary of Spreader Tests Conducted

Test #	Spread Width Setting (m (ft))	Application Rate Setting (kg/ln-km (lb/ln-mi))	Truck Location and Spreading Direction
#1 V-Box 1	7 (23)	60 (214)	Truck at center. Spreading centered.
#2 V-Box 2	7 (23)	120 (429)	Truck at center. Spreading centered.
#3 V-Box 3	7 (23)	120 (429)	Truck at center. Spreading centered.
#4 Epoke 1	7 (23)	110 (393)	Truck at center. Spreading centered.
#5 Epoke 2	5 (16)	110 (393)	Truck at center. Spreading centered.
#6 Epoke 3	5 (16)	77 (275)	Truck at center. Spreading centered. 30% pre-wet.
#7 Epoke 4	5 (16)	110 (393)	Truck in right lane. Spreading to left.
#8 Epoke 5	5 (16)	110 (393)	Truck in left lane. Spreading to right.

Tests #1 through 4 are representative of spreading a path two lanes wide. The Epoke controller is used to select spread widths in one-meter (3.3 ft) increments; the 7 m (23.0 ft) distance is almost 2 lanes wide, whereas a lane is 3.66 m (12 ft) wide. The narrower 5 m (16.4 ft) spread width (equivalent to 1.4 lanes) was selected to test the Epoke's ability to shift the spread pattern left and right. This is also the width that the Epoke would plow with the wing plow deployed. In all tests, the center of the spread pattern was in the center of the sampling area. In all tests except #7 and #8, the V-Box and Epoke were driven down the center of the test area, as represented by the arrow in Figure 5.1.

More than 250 samples were generated throughout the course of testing. Each was placed in a labeled cup and stored for later analysis. Also, it was decided to analyze each sample for gradation. This analysis involved the use of a sieve (screen mesh) to separate the large particles from the small ones within each sample. The mesh opening size was 1.4 mm by 1.4 mm (0.055

in by 0.055 in), which is approximately a # 14 sieve. Figure 6.1 shows an example of the separated particles.

Figure 6.1: Example of Separated Large and Small Particles within Samples

Data were compiled in an Excel file and are presented in Appendix A. After recording the measured values of the total sample weight and the small particle weight, it was possible to calculate the large particle weight as the difference between these two values. After this, the data were manipulated in various ways to determine the performance of each spreader. One calculation performed involved normalizing the data by calculating the percentage of the total mass collected present in each segment for each respective particle size. Other calculations included the computation of waste percentage, the ratio of small particles to large within each segment, and the disparity between the actual spread rate and the requested spread rate.

In the tests described in this chapter, waste is defined as the material collected beyond the target spread width. These waste values are not representative of what is expected for either machine in actual field operations.

In Tests #1 through 4, the first and last rows in each data set represent the wasted material present in the measuring samples adjacent to the deflection barriers, samples 1 and 26. Essentially, since the border material was 0.3 m (1.5 ft) high, any material that would have otherwise spread beyond the barriers bounced back on the road surface; thus, the material in these adjacent segments is considered waste. Waste was computed as the percentage of total material collected that was found in these two segments. Waste was also sieved to separate large and small particles. Then, the large particle waste was calculated as that portion of large particles that was found in the two segments, as compared to all large particles distributed.

In Tests #5 through 8, the waste area was defined as the sample areas 1-5 and 22-26, which represent the area beyond the 5 m spread pattern. Table 6.2 presents the waste percentages for each test that was run.

Table 6.2: Waste Material Calculations for Total and Large Particles

Test #	Total Material		Waste Material		Total Waste	Large Particle
	g	oz	g	oz	%	Waste %
#1 V-Box1	1071	37.8	101	3.5	9.4%	na
#2 V-Box2	745	26.3	63	2.2	8.4%	12.4%
#3 V-Box3	630	22.2	47	1.7	7.5%	10.3%
#4 Epoke1	1514	53.4	141	5.0	9.3%	14.9%
#5 Epoke2	919	32.4	433	15.3	47.1%	52.6%
#6 Epoke3	768	27.1	398	14.0	51.8%	56.3%
#7 Epoke4	1053	37.2	272	9.6	25.8%	32.9%
#8 Epoke5	685	24.1	233	8.2	34.0%	46.0%

The plot of material distribution in Figure 6.2 provides the easiest manner to demonstrate the effectiveness of the Epoke's symmetry function. The data from both Tests #7 and 8, in which the symmetry function was utilized, are compared with Test #5, in which the Epoke and spread pattern were centered between the lane lines. For the symmetry tests, the Epoke drove within the lane at an offset of half a lane (2 m [2 yd]) and spread towards the center of the road. In Test # 7, the truck was in the right lane, and the spread was shifted left, which was the opposite of Test #8. In this plot, the data from #7 and #8 was shifted to align the location of the spinner, and the shift of spread pattern can be seen clearly. The purpose of the symmetry function is to allow spreading in two lanes while allowing traffic to pass in the other lane.

Observations pertaining to other performance metrics were largely qualitative. The following sections include a discussion of the various results of this study. Plots of all the data can be found in Appendix A alongside tables of recorded and calculated values.

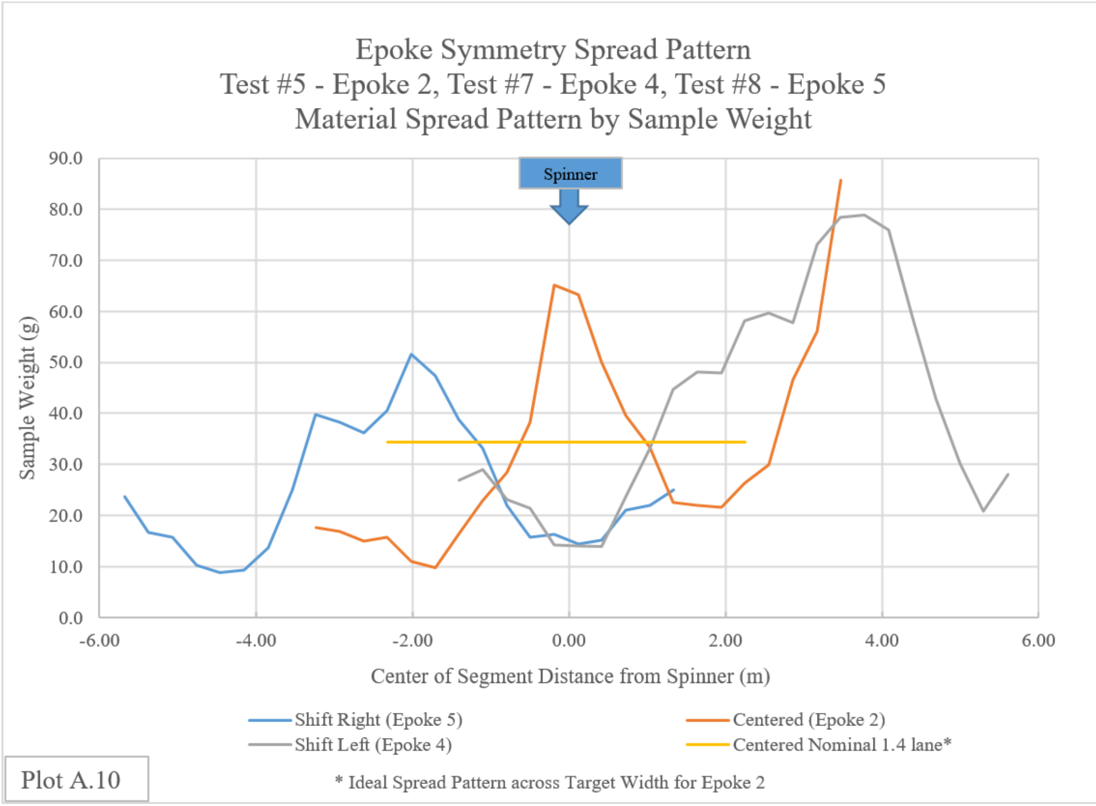

Figure 6.2: Plot of Data from Tests Utilizing Epoke Symmetry Function

6.2 Discussion of Results

Qualitative observations from on-board cameras and general user experience play a large role in the overall assessment of this machine. The analysis of video footage recorded by a camera mounted directly above the spinner disks on both spreaders during operation was informative. It showed that the material stream exiting the conveyor of the V-Box spreader was erratic. When the material near the hopper bottom had been compressed by the weight of the load on top of it, sand frequently came out on the conveyor as a solid, extruded mass that would periodically break off in large chunks that would fall into the spinner and disintegrate. This distribution created surges of material being deposited on the road.

The Epoke design ensures that material has been de-clumped prior to spreading. As a result, no clumping was observed, allowing for consistent spirals of material exiting the spinner disk. Figures 6.3 and 6.4 clearly illustrate the even manner in which material leaves the Epoke spinner, in contrast with the uneven nature of the V-Box's material application rate. Of note is the chunk of material breaking off the end of the conveyor on the V-Box spreader. Photographs and observations readily revealed the cause and effect of this problem.

Figure 6.3: Material Being Spread Behind the Epoke Spreader

Figure 6.4: Material Being Spread Behind the V-Box Spreader

It was hypothesized that spread testing would reveal clear differences between the V-Box and Epoke spread patterns and quantify the effect of the uneven spreading by the V-Box spreader. The normalized plots of the spread patterns shown in Figure 6.5 suggest that the Epoke pattern may be less random, but the results are distorted by the difference in spread width. The Epoke spread width was too wide and seems to be biased to the left (towards the 8 m mark), but it does appear to have a defined center, unlike the V-Box. It also appears that the walls at the sides of the test section may be causing particles to bounce back beyond the outermost samples, which further distorts the patterns. The effect of the symmetry function was very apparent.

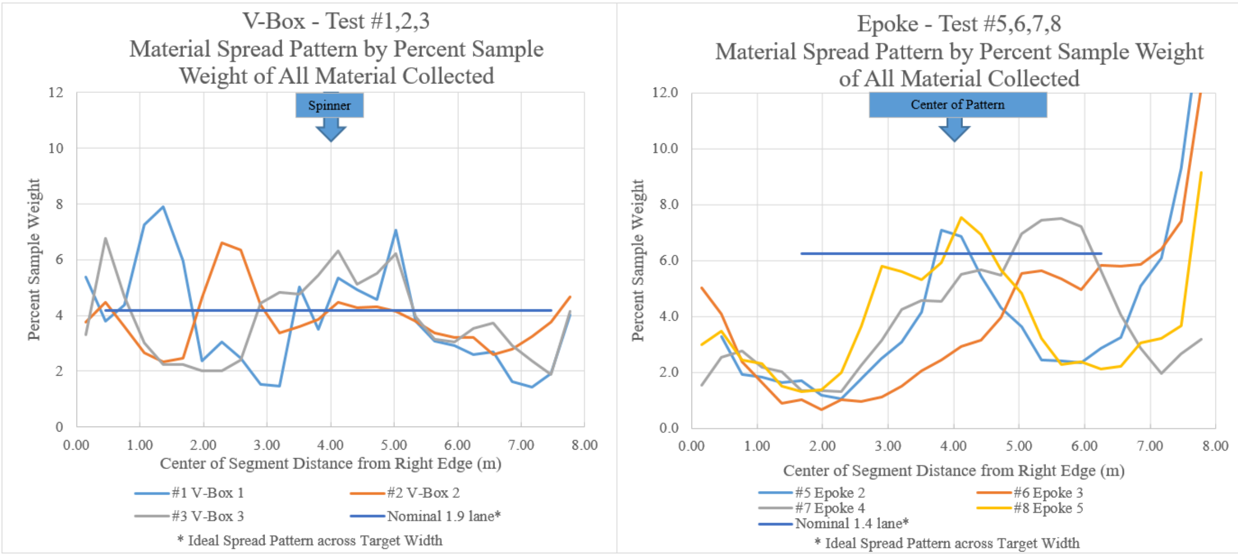

Figure 6.5: V-Box and Epoke Spread Patterns Normalized

The measured application rate for the V-Box ranged from 75% to 255% of the set value, whereas the Epoke ranged from 124% to 199% of the set value. This much wider range of values for the V-Box is probably the result of its erratic spreading characteristic identified visually and shown in Figure 6.4. This suggests that taking additional samples along a longer test section is required to define the spread patterns definitively.

The spread patterns of both spreaders were too wide, which resulted in a waste of 7.5 to 9.4% in the first four tests. The Epoke waste rate was up to 56% in the second set of tests. As noted previously, the vendor calibrations and adjustments on the Epoke were not done prior to these tests. It is very likely that the spinner speed setting, which is a function of installed height from the road surface, was not correct. Although these tests were not repeated, in field testing (discussed later in this report), the spread width, and the material application rates were consistent with the values defined on the controller.

Engineering intuition dictates that large particles should travel further from the spinner disk than small ones. This is due to increased momentum, which allows the particles to overcome air drag and bounce further across the road surface. A plot that demonstrates the effect of travel distances on the ratio of large to small particles is presented in Figure 6.6. The separation of the particle becomes very significant beyond the 4 m mark. Operators indicated that they would not typically spread beyond these distances.

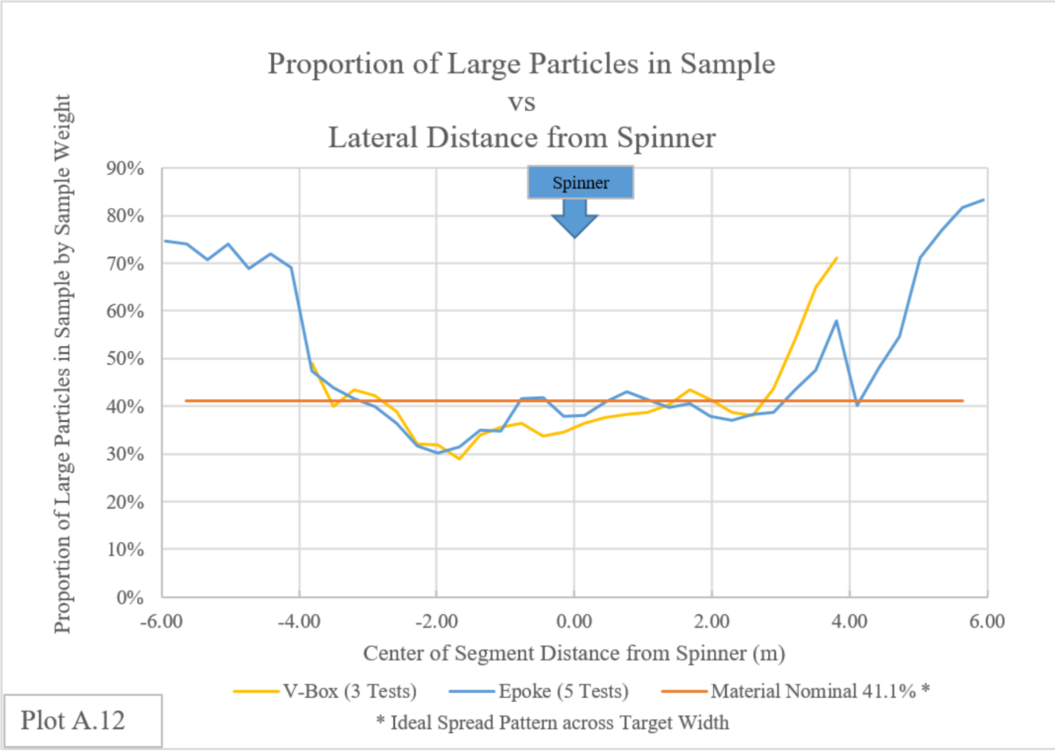

Figure 6.6: Plot Showing Varying Proportions of Large Particles

One of the main motivations for the sieving and the further analysis of samples was a phenomenon observed throughout the tests regardless of the type of spreader used. This phenomenon was termed 'sand striping' and was characterized by the finer particles in a given spread pattern gathering in narrow strips. This uneven distribution is caused by the aerodynamic effects of the material entering the turbulent wake of a large truck. The flow is made incredibly 'dirty' by the large cross-sectional area of the truck, the fact that the rear of the truck is essentially a vertical wall, and the presence of both a front and wing plow. Plow truck operators later revealed that plow position plays an important role in spread pattern. In the rare situations when a truck is spreading but not plowing, operators typically tilt the front and wing plows in various orientations to help aim the material being spread. Searches in the literature revealed that special devices have been utilized in other countries to alter the aerodynamic properties of spreader vehicles in an attempt to improve spread pattern consistency [9]. Although the test results do not clearly show the effect, a picture of sand striping can be seen on the road before the test section in Figure 6.7. The material seen has been deposited in multiple passes and the pattern shifts after every pass. In traffic, the material will move to the sides of the road. As discussed previously, using brine in the pre-wet function reduces the movement of particles, as seen here.

Figure 6.7: Sand Striping Observed on Test Track for Epoke Test #3

The assessment of the controller interfaces for both machines comes down to operator preference. The fact that neither controller had ever been seen or used by the AHMCT staff prior to this study allowed for an unbiased comparison. Figure 6.8 shows the controllers. The Muncie interface is familiar to Caltrans spreader operators but offers much less functionality than the EPOMaster controller found in the Epoke vehicle.

Research staff noted the following. The display on the EPOMaster controller is larger and clearer. The Epoke allows for precise spread rate settings but requires significantly more operator interaction than the simply adjusted Muncie dials. However, the Muncie only allows a small number of adjustments and spread rate settings are based on a percentage of the maximum. The Epoke controller informs the operator of an empty hopper or brine tanks, a feature that the Muncie controller lacks.

There are several confusing aspects of the EPOMaster controller. These include buttons with identical icons that control different functions and buttons that are not used for functions on the Caltrans Epokes. Adding labels to the buttons could alleviate confusion. Operators use only the knobs and a few buttons when spreading, and they adapted quickly to the Epoke controller.

Figure 6.8: Muncie and Epoke controllers

CHAPTER 7
EPOKE DEPLOYMENT

This chapter reports on experience gained during deployment of the Epoke spreaders in actual Caltrans operations. The installation and setup of the two Epoke spreaders onto Caltrans trucks was completed in January 2014, which allowed for operation during the winter storms that year. Although that winter and the following winter of 2014-15 were relatively warm and dry, the crews gained enough experience to identify some of the advantages of the Epoke design over the standard V-Box spreaders. The feedback from all personnel involved with these machines was very positive.

7.1 Epoke Operation

The Epokes were installed on nearly identical trucks outfitted with front and right wing plows, as seen in Figure 7.1. They were assigned to the I-80 corridor operating out of the Kingvale and the Truckee East yards. These yards provide continuous coverage from just west of Donner Summit to 13 km (8 mi) east of Truckee.

Figure 7.1: Caltrans Plow trucks Outfitted with Epoke Spreaders.

The yard at Kingvale, the closest to the summit, is the snowfighting operations center for the I-80 corridor and is typically the western end point for chain control during the start of most storms. Each winter, researchers provided training to about a dozen operators at the start of the season and then rode along with Kingvale plow operators during several storms. At various times during the course of the winters, meetings at Kingvale were held with the Epoke representatives, Caltrans employees, and the researchers. This gave the operators chances to share their experience and provided the vendor greater insight into the unique operating conditions in California. Feedback from the operators and others was collected during these and other meetings with Caltrans employees and is presented here.

Because the storms usually deposit large amounts of heavy, wet snow in short time periods, Caltrans does not attempt to keep the roads clear with salt. Instead, chain controls are put in place, and the roads are plowed continuously during the storm to minimize the accumulation of packed snow. Sand is deposited behind the snowplows for traction during the storm, and salt is applied at the end when the pavement is cleared. The high rate of sand application is one of the unique aspects of Caltrans operations. Caltrans attempts to reduce the use of both salt and sand while maintaining safe travel conditions.

All of the snowstorms witnessed by researchers were preceded by rain and the snowfall and typically began after sundown, with no opportunity for anti-icing operations. The witnessed operations focused on plowing and spreading sand for traction. The operations observed followed a typical process.

As the snow began to stick on the road surface and the snowfall rate was high enough to start building up on the road, chain control went into place. The snowpack was allowed to build up enough to minimize the wear of the chains against the pavement. Sand was applied as needed, and the plowing operations attempted to prevent further buildup of the snowpack.

The transitional phase, before vehicles are forced to chain up, is extremely dynamic and problematic because some drivers will inevitably lose control of their vehicle and have a collision. If the collision stops traffic, the tractor-trailer trucks on the steeper grade sections often become stuck, as their traction is inadequate to allow them to move from a stop. During these traffic jams, any light snow that would normally not build up under the wheels of moving traffic may start collecting on the surface, causing further challenges for drivers. Applications of sand are critical in this phase, and plow trucks will patrol continuously during the lead up to the heavy snow accumulation.

The plow trucks typically operate in a pack of four units that clears two to three travel lanes in one pass, followed by a second pass to clear shoulders, which are very wide in some locations. Each round trip is about 32 km (20 mi), and the two rounds are completed in about 75 minutes. The trucks then return to the yard for sand refills, fuel, chain repairs, equipment checkout, and breaks for the operators.

During these operations, each truck in the pack sands in the lane behind it. Left and right wing plows work on the corresponding edge of the pack. Since Caltrans does not sand the shoulders, placing sand behind the wing plow is usually not done. As the Epokes have right-side wing plows, they were usually placed on the far right and rear of the pack. From this position, the Epoke would often exit and re-enter the freeway to clear the ramps. When plowing the ramps, the directional spreading feature was fully utilized. The sand could be placed on the road cleared by both front and wing plows. This Epoke directional spreading capability avoids the typical wasting of sand experienced with V-Box. To sand behind their wing plow, the V-Box spreaders simply increase spread width, wasting sand placed in the direction opposite the wing plow. Louvres may be set to deflect this sand downward onto the plowed surface, as described in section 4.1. This results in the over-application of sand beneath the louvers.

During the winter season, the operators were asked to verify that the rate and lane width selected corresponded to the expected total sand consumption. The lane width selection ranged from ½ to 3 lanes in 1 m (3.3 ft) increments. As noted previously, the Epoke spreader interprets the rate setting as a material weight per area value and adjusts material flow automatically. By tracking the consumption per pass, the operators confirmed that the Epoke delivered the materials correctly and consistently throughout the season. Researchers verified this by visual estimations of sand loads during some of the runs.

7.2 Observations of Spread Pattern

The operators consistently commented on the smooth spread patterns of the Epokes. This impressed them, and they repeatedly suggested that, given the consistency of the spread pattern, creating the equivalent traction would take less sand from an Epoke spreader than from a V-box spreader. Figure 7.2 shows the typical irregular pattern of sand placement seen behind a V-Box spreader. As such, there is a variation in the coefficient of friction across the road surface. This uneven distribution pattern was observed by the researchers during the ride-alongs, and it was much more obvious than the pattern observed during the testing at ATIRC. It is suspected that the winter moisture and temperature conditions caused the problem to worsen.

Figure 7.2: Irregular Placement of Sand Seen Behind V-Box

As noted previously in Chapter 6, the flow of sand out from the Epoke is a faster stream of material with a much smaller cross section than that from the V-Box. On the Epoke, any clumping material will be broken up before it lands on the conveyor, and material like salt will be broken up into smaller granules as it passes through the feed roller. Figure 7.3 provides a visual image of the difference between the two at approximately the same scale. The V-Box spreader extrudes the material through the gate at the back of the truck. As the height of the material in the hopper drops, the vertical load on the V-Box chain conveyor lessens. This change in conveyor loading and changes in the consistency of the material will vary the spread rate under the V-Box open loop control system. The fact that the material breaks off in chunks as it rolls off the end of the belt partially explains the uneven spread pattern.

Figure 7.3: Comparing Load on Belt—Epoke (left), V-Box (right)

The ability to feed the small, fast moving stream of material through a relatively narrow chute allows the Epoke to effectively aim the sand spread in different directions. However, this design introduces a weakness that results in the plugging of the system under wet conditions. As can be seen in the Figure 7.3 image of the Epoke conveyor, the sand is wet and sticking to the belt scraper. This sticking phenomenon on the walls of the chute below the belt will cause it to plug up under some conditions, which disables the spreading action and requires the operator to return to the yard to flush out the wet sand and reload with drier sand. Caltrans' abrasive sand contracts specify very dry sand to prevent it from solidifying under winter conditions. Although the spreader trucks are generally garaged when not on the roads, the sand in the hopper of a spreader on patrol will get wet during the rain showers that precede the snow. Normally, rain is a problem only early in the season, but due to the unusually warm weather, the problem occurred several times during the two winters of this study. Several ideas for covering the load were suggested, but the operators agreed that the simplest solution was to simply be cognizant of the problem and reload with fresh, dry sand if exposed to an excessive amount of rain, particularly if the hopper is close to empty.

7.3 Application Rates and Potential Cost Savings

The operators tend to have different habits and opinions regarding the material application rate settings on the V-Box spreaders. The Muncie controller allows the selection of an application rate (0 to 100%) or spread width (0 to 100%). There is no compensating function that ties the two together, so, if the width is increased, the rate setting has to be increased by an undefined amount. Additionally, controls can be set to an automatic mode in which the system adjusts for road speed. Some operators will choose to run in the manual mode. Whenever they slow down and stop, excessive amounts of sand will be deposited unless the operators remember to dial back the rates or turn the system off. The open loop control will result in varying application rates due to factors like changing hydraulic pressure and flow or changing load conditions.

Operators use the rear-view mirrors to watch the material dispersion and make necessary adjustments based on their experience. By periodically inspecting the hopper at turnarounds, the operators define a setting that will allow them to end the usual two passes before running out of material. Often, a lead worker will follow the pack of spreaders to make visual observations of the material delivery rates. Operators will then be directed to adjust the rates based on the lead worker's assessment. Operators are aware of the need to avoid over-applying materials, but there is always the tendency to be conservative and increase the application rate. The conflicting requirements imposed on them are reflected in an idea shared by one of them: "Assume that you are paying for the sand out of your paycheck, but that your grandmother will be traveling on the road behind you." This philosophy results in a tendency to over-apply materials if the application rate is not precisely controlled by the spreader. On a simple route that is run repeatedly, the operator can regularly stop to check the hopper to see how much material has been deposited. Each truck will have different optimal settings and operators do not run the same truck every shift. As such, the variables in equipment function make it difficult to apply an optimal rate.

The precisely controlled delivery system of the Epoke removes the burden of continuously monitoring and adjusting the V-Box control systems. Once the material and rate is selected, the machine automatically adjusts the material feed rates as the vehicle speed and spread width settings change. The brine flow rates adjust automatically based on pre-wet settings or applications-rate settings. The Epokes were programmed to allow the operator to select an application rate of 28, 85, 114, or 142 kg/ln-km (100, 300, 400, or 500 lb/ln-mi). These settings are programmed in at a supervisor level, and the operators simply make a selection. This functionality allows operators to apply materials efficiently in a wide range of circumstances.

Operators have consistently reported that the Epoke spread patterns are much better than those of the V-Box spreaders. At the end of the first season, some operators reported that they would need to use half as much sand to maintain the same quality of road traction during plow operations. Operators commonly used the 85 kg/ln-km (300 lb/ln-mi) setting, which is 40% less than the maximum setting of 142 kg/ln-km (500 lb/ln-mi). On the runs out of the Kingvale yard, the Epokes were successfully operated using 25% to 33% less sand than the V-Box spreaders.

The data logger was used by the researchers to periodically monitor the operation of the Epokes, and it has the potential to provide Caltrans very accurate details of spreader operations that use the EpoMaster controller. It was determined that the accurate data logging capability of the Epoke is not useful in present-day Caltrans operations.

An estimate of the cost savings due to reduced material usage is based on the operation of the Kingvale Epoke. During the winter of 2013-14, snowfall was about half of normal, and the Kingvale Epoke data logger recorded the application of 343 metric tons (378 short tons) of dry material. Since the Epoke applied at least 25% less than a V-Box spreader, it reduced material usage by 114 metric tons (126 short tons). Assuming that 80% of the material was sand at $33 per metric ton ($30 per short ton) and 20% salt at $110 per metric ton ($100 per short ton), material costs were reduced by at least $5500. The savings in material costs alone would be $11,000 in a typical winter, which equates to $110,000 over an expected 10-year life cycle.

7.4 Brine Application

The Caltrans Kingvale yard was the first outfitted to use brine; they created the standards for brine operations, including during the use of the Epoke spreaders. The Epoke brine tanks were sized to carry enough brine to cover about 32 km (20 mi) at 116 l/ln-km (50 gal/ln-mi), which allows for the typical single pass, but they are outfitted with pumps that delivered up to 171 l/min (45 gal/min). During the two winters, researchers did not have the opportunity to observe the use of brine, but a few operators did describe instances of using brine in a pre-wet mode with salt in deicing operations. Since the ability to apply the brine at high rates is a new capability, the results impressed the operators.

7.5 Maintenance

The machines have been simple to maintain, and while Caltrans does not have extensive experience operating Epokes, Caltrans contacts in Nevada maintenance operations have confirmed the vendor's claims of Epoke robustness. Regular greasing and wash down is typically performed once a shift, but the brine pump system does not require any flushing. The lubrication of drives and brine system flushing is done at the end of the season.

The material feed system of V-Box spreaders is known to be a point of wear due to the abrasive and corrosive properties of sand and salt. Another view of the Epoke feed roller and agitator which run the full length of the hopper is seen in Figure 7.4. Although this design is unique and more expensive to manufacture, it has been noted by Caltrans personnel that, since the belt is so lightly loaded, it should not need the regular expensive repairs that the V-Box chain conveyor system requires. Only minor wear has been observed to date, but, of course, the machines will see more usage during normal winters.

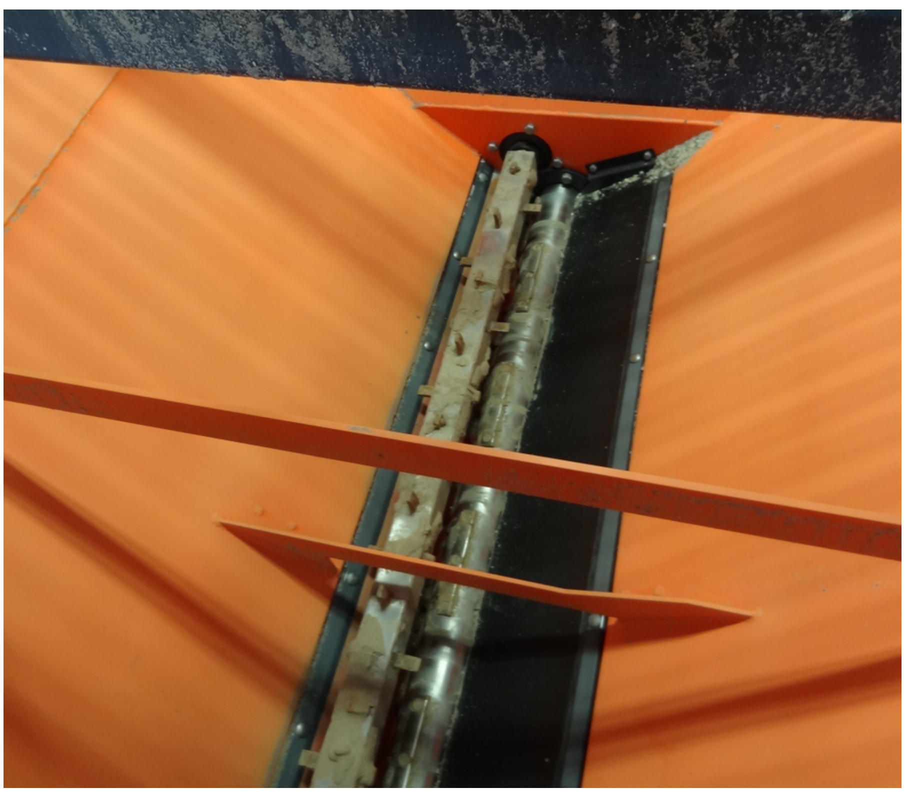

Figure 7.4: Epoke Feed Roller and Agitator

7.6 Sizing of Epoke Spreaders

The Epokes were installed on typical plow truck chassis usually reconfigured during the summer months to operate as 7.6 m^3 (10 yd^3) dump trucks. Figure 7.5 shows a profile view of the Kingvale truck before and after its conversion to an Epoke spreader. The trucks have gross vehicle weights about 23,154 kg (51,000 lb). The typical V-Box hoppers are at least 2.3 m^3 (3 yd^3) larger than the 4 m^3 (5.2 yd^3) Epoke hopper. This smaller hopper was selected to allow for the additional weight of the 3,600 l (950 gal) of brine. The one complaint heard from the operators is that the sand capacity is too low and that an Epoke with a 6 m^3 (7.8 yd^3) hopper would be ideal. This type of system would most likely be limited to pre-wet operations due to the reduced brine capacity.

Figure 7.5: Profile of Kingvale Plow Truck with V-Box (above) and Epoke (below) Spreaders Installed

7.7 Operator Training

AHMCT provided training support each winter, and about a dozen operators were trained to use the Epokes. During one storm event, a new operator was given 15 minutes of instruction and began operating the spreader. Although not a difficult system to understand, the Epoke is significantly different than the standard V-Box spreader, and it is thus important to properly train new operators.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions of this Study

The Epoke Sirius Combi 4900 spreaders apply an increased level of automation to Caltrans winter snowfighting operations. The machines allow the application of sand, salt, and brine in all the configurations useful in anti-icing, deicing, and dry or pre-wet material application operations. Based on the experience with Caltrans operations in this research, a dry material savings of at least 25% may be possible when using the Epoke as compared with the costs of the standard V-Box spreader due to its more precise spreading capability and even application rate. The more precise spreading of abrasives is also expected to improve traction, which increases traveler safety.

The 25% reduction in material usage is calculated to reduce the cost of materials by $110,000 over a 10-year life time, well over the cost of the Epoke. In areas such as the Lake Tahoe Basin, where the sand must be collected after storms, the more efficient application of material will further reduce costs. Additional savings are expected due to the anticipated lower maintenance costs of the Epoke system.

Based on this research, it appears the Epoke's applied technology is fully developed and its integrated mechanical and control systems are robust. The combination of a unique delivery system that is fully integrated with a closed loop control system allows for the precise control of spreader rate. While there has been inadequate long-term usage by Caltrans to draw conclusions about reliability, the spreader has proven to be very reliable in Nevada's operations despite the sophistication of the automated system. Since all the mechanical and control system components are defined by the manufacturer, warranty and technical support is provided by a single vendor.

Based on discussions with Caltrans operators and AHMCT researchers' observations about the two Epokes tested, material is saved because of the following features:

- The Epoke's spread pattern is easily adjusted to change width and direction.
- The Epoke precisely meters the spread material due to its unique material feed system and closed loop control system that continually and automatically adjusts for changes in system hydraulic pressure, truck speed, and operator defined settings.
- The Epoke allows for directing material asymmetrically on the cleared path behind both the front plow and the wing plow.

Also, the Epoke has an integrated brine system that facilitates a wide combination of brine and pre-wet operations.

8.2 Recommendations for Future Work

The Epokes should be operated and monitored during upcoming winters to continue to establish their value in snowfighting operations on freeways and, if possible, secondary roads.

The brining capability should be tested further in anti-icing and deicing operations. Given a more typical winter, the deicing capabilities, along with the multi-lane spreading functions, may prove to be of particular value when spot-treating the roadway in between the storms. In order to support this effort, it is recommended that the DM&T data loggers remain activated to collect operational data.

The operation of the Epokes should be monitored to document the long-term maintenance costs of the machines and to obtain operator feedback on potential operational issues, such as the jamming of wet sand experienced in Kingvale and the potential need for the simplification of the controller interface.

If the multi-lane spreading function proves useful to Caltrans, it will be important to establish the required maximum spread widths, application rates, and operating speeds. The Caltrans' Epoke can treat a three-lane-wide road with pre-wet or dry material. In order to apply brine across more than two lanes, a different model with a larger pump is required.

The Epoke can be configured as a pre-wet only spreader with a lower liquid and a higher dry material capacity than the machines tested. The industry has established that pre-wetting reduces the waste of salt by minimizing the bounce and scatter effect. It is recommended that Caltrans confirms that pre-wetting provides expected savings in their operations, which use large quantities of sand instead of salt.

It is important to quantify the potential value of an Epoke due to the savings in materials and other cost factors based on Caltrans' unique operations. In spite of higher initial equipment costs, systems like the Epoke can provide significant savings. It is important to assess the potential value to operations in all the varied snowfighting operations of California.

To obtain valid spread mapping data, tests should be done using a sampling area at least twice as long, and the samples should be taken using a 1 m by 1 m (3.3 x 3.3 ft) grid to describe the pattern in both longitudinal and lateral directions. The configurations most similar to Caltrans' operations would be the testing of spreaders in one- and two-lane spread width configurations at 56 km/h (35 mi/h). Supervisors confirmed that the maximum spread width relevant to their operations would be two lanes wide.

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APPENDIX A:
TEST RESULTS

This appendix includes the results from 8 tests run to define the spread pattern of the Epoke spreader compared to a standard V-Box spreader. The tests were run in October 2013 using the Epoke spreader on Caltrans truck 0530506 and a V-Box spreader on Caltrans truck 0537255. The spreader material was collected on a test section representing a two-lane road, as described in Figure A.1.

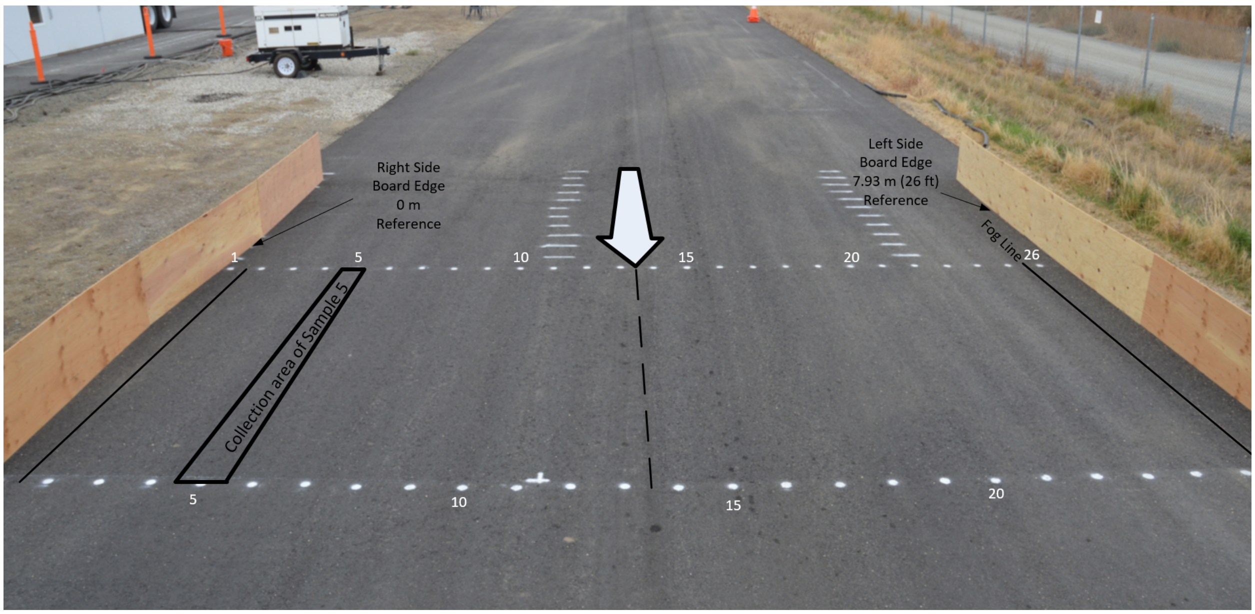


Figure A.1: Description of Test Section Layout used for Spreader Tests

Tests #1 through 4 were run using a 7 m spread, which is equivalent to almost two lanes. Tests #5 through 8 were run using a spread width of 5 m. The spreaders were driven down the middle of the test section as represented by the arrow except in Tests #7 and #8, which tested the Epoke symmetry function that directs the spread left or right of the center line.

In Tests #1 through 4, waste was defined as the material collected in sample areas 1 and 26, which represent areas beyond the fog line. In Tests #5 through 8, the waste area was defined as the sample areas 1-5 and 22-26, which represent the area beyond the 5 m spread pattern.

Data are presented as follows:

Tables A.1 through A.8 list the weights of each of 26 samples collected for each of the 8 tests. Each sample has a weight for all particles and a weight for small and large particles separated by sieving. Each sample was collected within a 0.305 m by 3.658 m (1ft by 12 ft) area.

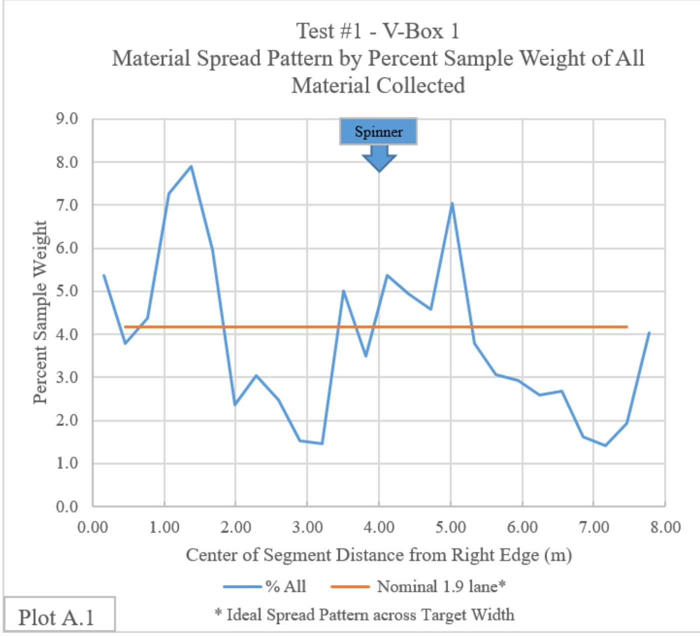
- Column 1: Sample identification per Figure A.1.
- Column 2: Position of center of sample starting at 0.152 m (6 in) and increments of 0.305 m (12 in) collected.
- Columns 3: Weight of all particles collected

- Columns 4 and 5: Weight of small and large particles separated after screened with mesh approximating a # 14 sieve (Opening size 1.4 mm by 1.4 mm. [.055 in x .055 in]).
- Columns 6, 7, and 8: Values from Columns 3, 4 and 5 are represented as percentages of the total within each category.
- Column 9: Ratio of large particles to small particles.
- Column 10: The ideal nominal distribution of material within the area represented by the corresponding sample. It represents an ideal pattern with no waste and equal distribution within the spread pattern. For Tests #1-4, it is the middle 24 sample areas, with a width of 7.32 m (24 ft). For Tests #5-8 it is the middle 16 samples areas, with a width of 4.88 m (16 ft).
- A normalized plot of the spread distribution is included.

Table A.9 through A.12 are tabulations and plots of the test results.

TABLE A.1: Test #1 V-Box 1 Data: Spread width 7 m. Application rate 60 kg/ln-km. Samples not retained for sieve analysis.

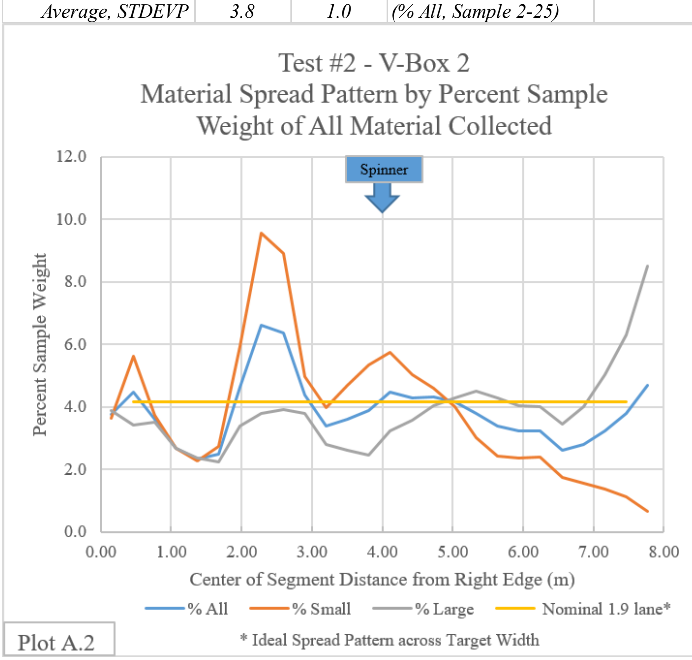
Test #1 - V-Box 1				
Sample	Position, m	All, g	% All	Nominal 1.9 lane
1	0.15	57.5	5.4	
2	0.46	40.6	3.8	4.2
3	0.76	46.9	4.4	4.2
4	1.07	77.7	7.3	4.2
5	1.37	84.6	7.9	4.2
6	1.68	63.8	6.0	4.2
7	1.98	25.3	2.4	4.2
8	2.29	32.6	3.0	4.2
9	2.59	26.5	2.5	4.2
10	2.90	16.4	1.5	4.2
11	3.20	15.6	1.5	4.2
12	3.51	53.7	5.0	4.2
13	3.81	37.5	3.5	4.2
14	4.11	57.4	5.4	4.2
15	4.42	52.9	4.9	4.2
16	4.72	48.9	4.6	4.2
17	5.03	75.5	7.1	4.2
18	5.33	40.6	3.8	4.2
19	5.64	32.8	3.1	4.2
20	5.94	31.4	2.9	4.2
21	6.25	27.7	2.6	4.2
22	6.55	28.7	2.7	4.2
23	6.86	17.3	1.6	4.2
24	7.16	15.2	1.4	4.2
25	7.47	20.6	1.9	4.2
26	7.77	43.1	4.0	
	Totals	*1070.7*	*100.0*	*100.0*
	Waste	*100.6*	*(Sample 1,26)*	
Average, STDEVP		*3.8*	*1.9*	*(% All, Sample 2-25)*



Plot A.1

TABLE A.2: Test #2 V-Box 2 Data: Spread width 7 m. Application rate 120 kg/ln-km.

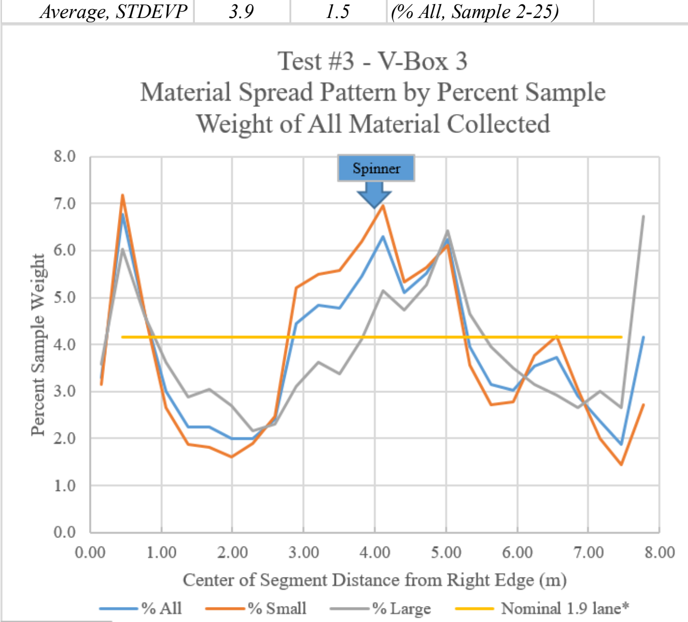
Test #2 - V-Box 2									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.9 lane
1	0.15	28.0	13.2	14.8	3.8	3.6	3.9	1.1	
2	0.46	33.4	20.4	13.0	4.5	5.6	3.4	0.6	4.2
3	0.76	26.9	13.5	13.4	3.6	3.7	3.5	1.0	4.2
4	1.07	19.9	9.7	10.2	2.7	2.7	2.7	1.1	4.2
5	1.37	17.3	8 3	9.0	2.3	2.3	2.4	1.1	4.2
6	1.68	18.4	9 9	8 5	2.5	2.7	2.2	0.9	4.2
7	1.98	34.5	21.6	12.9	4.6	5.9	3.4	0.6	4.2
8	2.29	49.2	34.8	14.4	6.6	9.6	3.8	0.4	4.2
9	2.59	47.3	32.4	14.9	6.3	8.9	3.9	0.5	4.2
10	2.90	32.5	18.1	14.4	4.4	5.0	3.8	0.8	4.2
11	3.20	25.1	14.5	10.6	3.4	4.0	2.8	0.7	4.2
12	3.51	26.9	17.0	9 9	3.6	4.7	2.6	0.6	4.2
13	3.81	28.8	19.4	9.4	3.9	5.3	2.5	0.5	4.2
14	4.11	33.2	20.9	12.3	4.5	5.7	3.2	0.6	4.2
15	4.42	31.9	18.3	13.6	4.3	5.0	3.6	0.7	4.2
16	4.72	32.1	16.7	15.4	4.3	4.6	4.0	0.9	4.2
17	5.03	30.9	14.6	16.3	4.1	4.0	4.3	1.1	4.2
18	5.33	28.2	11.0	17.2	3.8	3.0	4.5	1.6	4.2
19	5.64	25.1	8.8	16.3	3.4	2.4	4.3	1.9	4.2
20	5.94	24.0	8.6	15.4	3.2	2.4	4.0	1.8	4.2
21	6.25	24.0	8.7	15.3	3.2	2.4	4.0	1.8	4.2
22	6.55	19.4	6 3	13.1	2.6	1.7	3.4	2.1	4.2
23	6.86	20.9	5.6	15.3	2.8	1.5	4.0	2.7	4.2
24	7.16	24.1	5.0	19.1	3.2	1.4	5.0	3.8	4.2
25	7.47	28.1	4 1	24.0	3.8	1.1	6.3	5.9	4.2
26	7.77	34.8	2.4	32.4	4.7	0.7	8.5	13 5	
	Totals	*744.9*	*363.8*	*381.1*	*100*	*100.0*	*100.0*		*100.0*
	Waste	*62.8*	*15.6*	*47.2*	*(Sample 1,26)*				
Average, STDEVP		*3.8*	*1.0*	*(% All, Sample 2-25)*					



Plot A.2

TABLE A.3: Test #3 V-Box 3 Data: Spread width 7 m. Application rate 120 kg/ln-km.

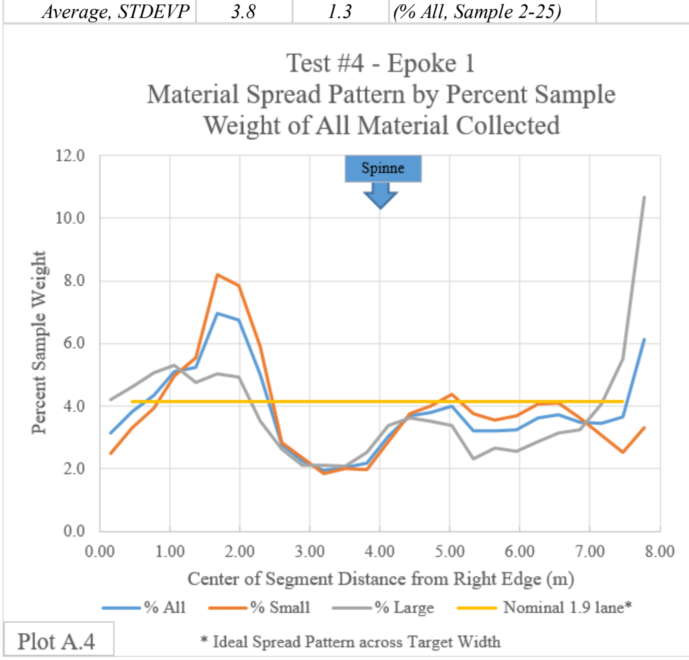
Test #3 - V-Box 3									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.9 lane
1	0.15	20.8	12.7	8.1	3.3	3 1	3.6	0.6	
2	0.46	42.6	29.0	13.6	6.8	7 2	6.0	0.5	4.2
3	0.76	29.3	18.9	10.4	4.7	4.7	4.6	0.6	4.2
4	1.07	18.9	10.7	8.2	3.0	2.6	3.6	0.8	4.2
5	1.37	14.1	7.6	6.5	2.2	1 9	2.9	0.9	4.2
6	1.68	14.2	7.3	6.9	2.3	1.8	3.1	0.9	4.2
7	1.98	12.6	6.5	6.1	2.0	1.6	2.7	0.9	4.2
8	2.29	12.6	7.7	4.9	2.0	1 9	2.2	0.6	4.2
9	2.59	15.2	10.0	5.2	2.4	2 5	2.3	0.5	4.2
10	2.90	28.0	21.0	7.0	4.4	5 2	3.1	0.3	4.2
11	3.20	30.4	22.2	8.2	4.8	5 5	3.6	0.4	4.2
12	3.51	30.1	22.5	7.6	4.8	5.6	3.4	0.3	4.2
13	3.81	34.3	25.0	9.3	5.4	6 2	4.1	0.4	4.2
14	4.11	39.7	28.1	11.6	6.3	7.0	5.1	0.4	4.2
15	4.42	32.2	21.5	10.7	5.1	5 3	4.7	0.5	4.2
16	4.72	34.7	22.8	11.9	5.5	5.6	5.3	0.5	4.2
17	5.03	39.2	24.7	14.5	6.2	6 1	6.4	0.6	4.2
18	5.33	24.9	14.4	10.5	4.0	3.6	4.7	0.7	4.2
19	5.64	19.9	11.0	8.9	3.2	2.7	3.9	0.8	4.2
20	5.94	19.1	11.2	7.9	3.0	2.8	3.5	0.7	4.2
21	6.25	22.3	15.2	7.1	3.5	3.8	3.1	0.5	4.2
22	6.55	23.5	16.9	6.6	3.7	4 2	2.9	0.4	4.2
23	6.86	18.3	12.3	6.0	2.9	3.0	2.7	0.5	4.2
24	7.16	14.9	8.1	6.8	2.4	2.0	3.0	0.8	4.2
25	7.47	11.8	5.8	6.0	1.9	1.4	2.7	1.0	4.2
26	7.77	26.2	11.0	15.2	4.2	2.7	6.7	1.4	
	Totals	*629.8*	*404.1*	*225.7*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*47.0*	*23.7*	*23.3*	*(Sample 1,26)*				
Average, STDEVP		*3.9*	*1.5*	*(% All, Sample 2-25)*					



Plot A.3 * Ideal Spread Pattern across Target Width

TABLE A.4: Test #4 Epoke 1 Data: Spread width 7 m. Application rate 110 kg/ln-km.

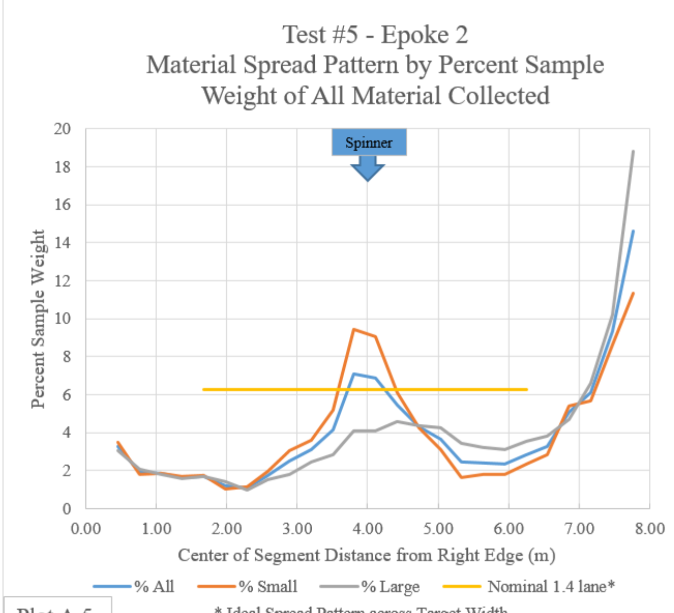
Test #4 - Epoke 1									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.9 lane
1	0.15	47.7	23.3	24.4	3.2	2 5	4.2	1.0	
2	0.46	57.9	31.0	26.9	3.8	3 3	4.6	0.9	4.2
3	0.76	66	36.7	29.3	4.4	3 9	5.1	0.8	4.2
4	1.07	77.2	46.5	30.7	5.1	5.0	5.3	0.7	4.2
5	1.37	79.6	51.9	27.7	5.3	5.6	4.8	0.5	4.2
6	1.68	105.6	76.5	29.1	7.0	8 2	5.0	0.4	4.2
7	1.98	102	73.4	28.6	6.7	7 9	4.9	0.4	4.2
8	2.29	75.7	55.2	20.5	5.0	5 9	3.5	0.4	4.2
9	2.59	41.7	26.4	15.3	2.8	2.8	2.6	0.6	4.2
10	2.90	34.2	21.9	12.3	2.3	2 3	2.1	0.6	4.2
11	3.20	29.7	17.4	12.3	2.0	1 9	2.1	0.7	4.2
12	3.51	31.1	18.9	12.2	2.1	2.0	2.1	0.6	4.2
13	3.81	33	18.4	14.6	2.2	2.0	2.5	0.8	4.2
14	4.11	46.3	26.7	19.6	3.1	2 9	3.4	0.7	4.2
15	4.42	56.2	35.2	21.0	3.7	3.8	3.6	0.6	4.2
16	4.72	57.8	37.3	20.5	3.8	4.0	3.5	0.5	4.2
17	5.03	60.6	40.9	19.7	4.0	4.4	3.4	0.5	4.2
18	5.33	48.5	35.1	13.4	3.2	3.8	2.3	0.4	4.2
19	5.64	48.6	33.2	15.4	3.2	3.6	2.7	0.5	4.2
20	5.94	49.4	34.5	14.9	3.3	3.7	2.6	0.4	4.2
21	6.25	54.7	38.0	16.7	3.6	4 1	2.9	0.4	4.2
22	6.55	56.5	38.3	18.2	3.7	4 1	3.1	0.5	4.2
23	6.86	52.9	34.0	18.9	3.5	3.6	3.3	0.6	4.2
24	7.16	52.5	28.9	23.6	3.5	3 1	4.1	0.8	4.2
25	7.47	55.5	23.5	32.0	3.7	2 5	5.5	1.4	4.2
26	7.77	92.9	31.1	61.8	6.1	3 3	10.7	2.0	
	Totals	*1513.8*	*934.2*	*579.6*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*140.6*	*54.4*	*86.2*	*(Sample 1,26)*				
Average, STDEVP		*3.8*	*1.3*	*(% All, Sample 2-25)*					



Plot A.4

TABLE A.5: Test #5 Epoke 2 Data: Spread width 5 m. Application rate 110 kg/ln-km. Sample #1 is lost.

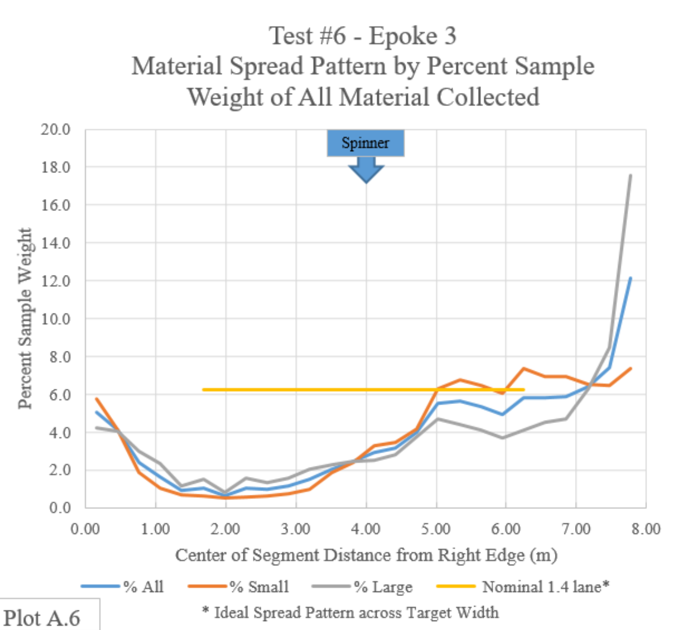
Test#5 - Epoke 2									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.4 lane
1	0.15								
2	0.46	30.2	17.9	12.3	3.3	3 5	3.1	0.7	
3	0.76	17.7	9.3	8.4	1.9	1.8	2.1	0.9	
4	1.07	16.9	9.7	7.2	1.8	1 9	1.8	0.7	
5	1.37	15.1	8.8	6.3	1.6	1.7	1.6	0.7	
6	1.68	15.8	9.0	6.8	1.7	1.7	1.7	0.8	6.3
7	1.98	11.0	5.3	5.7	1.2	1.0	1.4	1.1	6.3
8	2.29	9.8	5.8	4.0	1.1	1 1	1.0	0.7	6.3
9	2.59	16.3	10.1	6.2	1.8	2.0	1.5	0.6	6.3
10	2.90	23.0	15.8	7.2	2.5	3 1	1.8	0.5	6.3
11	3.20	28.4	18.5	9.9	3.1	3.6	2.5	0.5	6.3
12	3.51	38.3	26.8	11.5	4.2	5 2	2.9	0.4	6.3
13	3.81	65.1	48.7	16.4	7.1	9.4	4.1	0.3	6.3
14	4.11	63.2	46.7	16.5	6.9	9.0	4.1	0.4	6.3
15	4.42	50.1	31.6	18.5	5.5	6 1	4.6	0.6	6.3
16	4.72	39.6	22.0	17.6	4.3	4 3	4.4	0.8	6.3
17	5.03	33.4	16.2	17.2	3.6	3 1	4.3	1.1	6.3
18	5.33	22.5	8.6	13.9	2.4	1.7	3.4	1.6	6.3
19	5.64	22.1	9.2	12.9	2.4	1.8	3.2	1.4	6.3
20	5.94	21.7	9.2	12.5	2.4	1.8	3.1	1.4	6.3
21	6.25	26.3	12.1	14.2	2.9	2 3	3.5	1.2	6.3
22	6.55	29.9	14.6	15.3	3.3	2.8	3.8	1.0	
23	6.86	46.7	27.8	18.9	5.1	5.4	4.7	0.7	
24	7.16	56.0	29.4	26.6	6.1	5.7	6.6	0.9	
25	7.47	85.7	44.6	41.1	9.3	8.6	10.2	0.9	
26	7.77	134 3	58.4	75.9	14.6	11.3	18.8	1.3	
	Totals	*919.1*	*516.1*	*403.0*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*432.5*	*220.5*	*212.0*	*(Sample 1-5, 22-26)*				
Average, STDEVP		*3.6*	*2.1*	*(% All, Sample 2-25)*					



Plot A.5

TABLE A.6: Test #6 Epoke 3 Data: Spread width 5 m. Application rate 77 kg/ln-km with 30% pre-wet. (Epoke controller set to 110 kg/ln-km and reduces material automatically.)

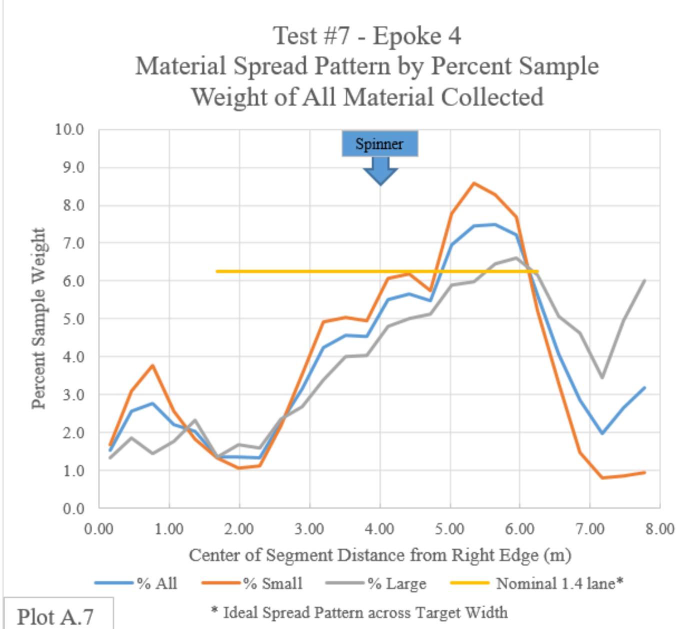
Test #6 - Epoke 3									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.4 lane
1	0.15	38.7	23.4	15.3	5.0	5.8	4.2	0.7	
2	0.46	31.5	16.7	14.8	4.1	4 1	4.1	0.9	
3	0.76	18.4	7.5	10.9	2.4	1 9	3.0	1.5	
4	1.07	12.6	4.1	8.5	1.6	1.0	2.3	2.1	
5	1.37	7.0	2.9	4.1	0.9	0.7	1.1	1.4	
6	1.68	8.0	2.6	5.4	1.0	0.6	1.5	2.1	6.3
7	1.98	5.1	2.2	2.9	0.7	0 5	0.8	1.3	6.3
8	2.29	7.9	2.3	5.6	1.0	0.6	1.5	2.4	6.3
9	2.59	7.4	2.6	4.8	1.0	0.6	1.3	1.8	6.3
10	2.90	8.7	3.1	5.6	1.1	0.8	1.5	1.8	6.3
11	3.20	11.5	4.0	7.5	1.5	1.0	2.1	1.9	6.3
12	3.51	15.8	7.5	8.3	2.1	1 9	2.3	1.1	6.3
13	3.81	18.8	9.8	9.0	2.4	2.4	2.5	0.9	6.3
14	4.11	22.6	13.4	9.2	2.9	3 3	2.5	0.7	6.3
15	4.42	24.3	14.0	10.3	3.2	3 5	2.8	0.7	6.3
16	4.72	30.5	16.9	13.6	4.0	4 2	3.7	0.8	6.3
17	5.03	42.6	25.5	17.1	5.5	6 3	4.7	0.7	6.3
18	5.33	43.3	27.4	15.9	5.6	6.8	4.4	0.6	6.3
19	5.64	41.1	26.1	15.0	5.4	6.4	4.1	0.6	6.3
20	5.94	38.0	24.6	13.4	4.9	6 1	3.7	0.5	6.3
21	6.25	44.7	29.7	15.0	5.8	7 3	4.1	0.5	6.3
22	6.55	44.6	28.1	16.5	5.8	6 9	4.5	0.6	
23	6.86	45.1	28.1	17.0	5.9	6 9	4.7	0.6	
24	7.16	49.3	26.5	22.8	6.4	6 5	6.3	0.9	
25	7.47	56.9	26.1	30.8	7.4	6.4	8.5	1.2	
26	7.77	93.4	29.7	63.7	12.2	7 3	17.5	2.1	
	Totals	*767.8*	*404.8*	*363.0*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*397.5*	*193.1*	*204.4*	*(Sample 1-5, 22-26)*				
Average, STDEVP		*3.4*	*2.1*	*(% All, Sample 6-21)*					



Plot A.6

TABLE A.7: Test #7 Epoke 4 Data: Spread width 5 m. Application rate 110kg/ln-km. Driven on right lane with spread shifted left using symmetry function.

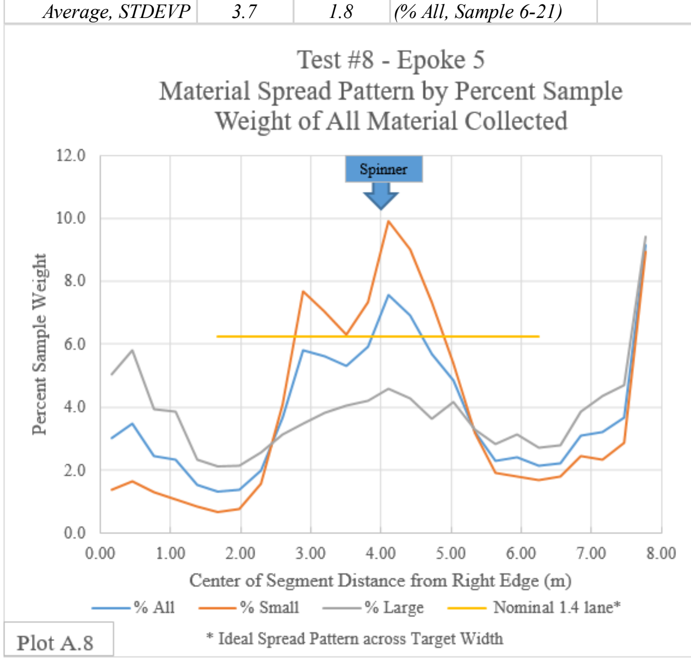
Test #7 - Epoke 4									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.4 lane
1	0.15	16.1	9.9	6.2	1.5	1.7	1.3	0.6	
2	0.46	26.9	18.3	8.6	2.6	3.1	1.9	0.5	
3	0.76	29.0	22.3	6.7	2.8	3.8	1.4	0.3	
4	1.07	23.2	15.1	8.1	2.2	2.6	1.8	0.5	
5	1.37	21.5	10.7	10.8	2.0	1.8	2.3	1.0	
6	1.68	14.2	7.9	6.3	1.3	1.3	1.4	0.8	6.3
7	1.98	14.1	6.3	7.8	1.3	1.1	1.7	1.2	6.3
8	2.29	13.9	6.6	7.3	1.3	1.1	1.6	1.1	6.3
9	2.59	23.8	12.9	10.9	2.3	2.2	2.4	0.8	6.3
10	2.90	33.2	20.8	12.4	3.2	3.5	2.7	0.6	6.3
11	3.20	44.7	29.0	15.7	4.2	4.9	3.4	0.5	6.3
12	3.51	48.2	29.7	18.5	4.6	5.0	4.0	0.6	6.3
13	3.81	47.9	29.2	18.7	4.5	4.9	4.0	0.6	6.3
14	4.11	58.1	35.9	22.2	5.5	6.1	4.8	0.6	6.3
15	4.42	59.7	36.6	23.1	5.7	6.2	5.0	0.6	6.3
16	4.72	57.7	34.0	23.7	5.5	5.8	5.1	0.7	6.3
17	5.03	73.2	45.9	27.3	7.0	7.8	5.9	0.6	6.3
18	5.33	78.4	50.8	27.6	7.4	8.6	6.0	0.5	6.3
19	5.64	78.9	49.0	29.9	7.5	8.3	6.5	0.6	6.3
20	5.94	76.0	45.4	30.6	7.2	7.7	6.6	0.7	6.3
21	6.25	59.3	30.8	28.5	5.6	5.2	6.2	0.9	6.3
22	6.55	42.9	19.5	23.4	4.1	3.3	5.1	1.2	
23	6.86	30.1	8.7	21.4	2.9	1.5	4.6	2.5	
24	7.16	20.8	4.8	16.0	2.0	0.8	3.5	3.3	
25	7.47	28.0	5.1	22.9	2.7	0.9	5.0	4.5	
26	7.77	33.4	5.6	27.8	3.2	0.9	6.0	5.0	
	Totals	*1053.2*	*590.8*	*462.4*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*271.9*	*120.0*	*151.9*	*(Sample 1-5, 22-26)*				
Average, STDEVP		*4.0*	*2.0*	*(% All, Sample 6-21)*					



Plot A.7

TABLE A.8: Test #8 Epoke 5 Data: Spread width 5 m. Application rate 110kg/ln-km. Driven on left lane with spread shifted right using symmetry function.

Test # 8 - Epoke 5									
Sample	Position, m	All, g	Small, g	Large, g	% All	% Small	% Large	Large:Small	Nominal 1.4 lane
1	0.15	20.5	5.2	15.3	3.0	1.4	5.0	2.9	
2	0.46	23.8	6.2	17.6	3.5	1.6	5.8	2.8	
3	0.76	16.8	4.9	11.9	2.5	1 3	3.9	2.4	
4	1.07	15.8	4.1	11.7	2.3	1 1	3.9	2.9	
5	1.37	10.3	3.2	7.1	1.5	0.8	2.3	2.2	
6	1.68	8.9	2.5	6.4	1.3	0.7	2.1	2.6	6.3
7	1.98	9.4	2.9	6.5	1.4	0.8	2.1	2.2	6.3
8	2.29	13.6	5.9	7.7	2.0	1 5	2.5	1.3	6.3
9	2.59	25.0	15.5	9.5	3.7	4 1	3.1	0.6	6.3
10	2.90	39.8	29.3	10.5	5.8	7.7	3.5	0.4	6.3
11	3.20	38.3	26.7	11.6	5.6	7.0	3.8	0.4	6.3
12	3.51	36.3	24.0	12.3	5.3	6 3	4.1	0.5	6.3
13	3.81	40.6	27.9	12.7	5.9	7 3	4.2	0.5	6.3
14	4.11	51.7	37.8	13.9	7.6	9 9	4.6	0.4	6.3
15	4.42	47.4	34.4	13.0	6.9	9.0	4.3	0.4	6.3
16	4.72	38.9	27.9	11.0	5.7	7 3	3.6	0.4	6.3
17	5.03	33.1	20.5	12.6	4.8	5.4	4.2	0.6	6.3
18	5.33	22.0	12.1	9.9	3.2	3 2	3.3	0.8	6.3
19	5.64	15.7	7.2	8.5	2.3	1 9	2.8	1.2	6.3
20	5.94	16.3	6.8	9.5	2.4	1.8	3.1	1.4	6.3
21	6.25	14.5	6.3	8.2	2.1	1.7	2.7	1.3	6.3
22	6.55	15.2	6.8	8.4	2.2	1.8	2.8	1.2	
23	6.86	21.0	9.3	11.7	3.1	2.4	3.9	1.3	
24	7.16	22.0	8.8	13.2	3.2	2 3	4.3	1.5	
25	7.47	25.1	10.9	14.2	3.7	2 9	4.7	1.3	
26	7.77	62.6	34.0	28.6	9.1	8 9	9.4	0.8	
	Totals	*684.6*	*381.1*	*303.5*	*100.0*	*100.0*	*100.0*		*100.0*
	Waste	*233.1*	*93.4*	*139.7*	*(Sample 1-5, 22-26)*				
Average, STDEVP		*3.7*	*1.8*	*(% All, Sample 6-21)*					



Plot A.8

TABLE A.9: Plots Comparing Tests #1 thru 4 and Tests #5 thru 8.

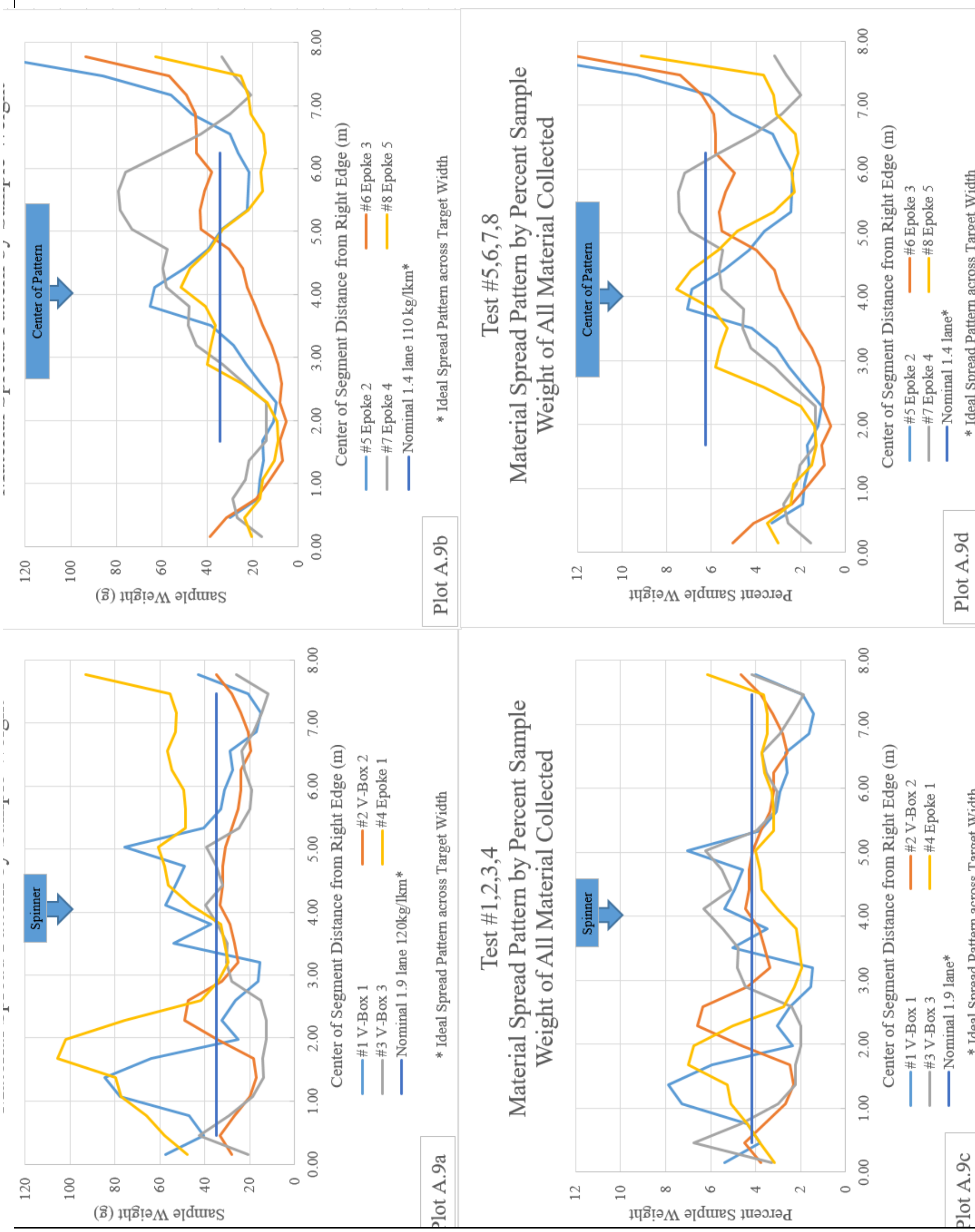
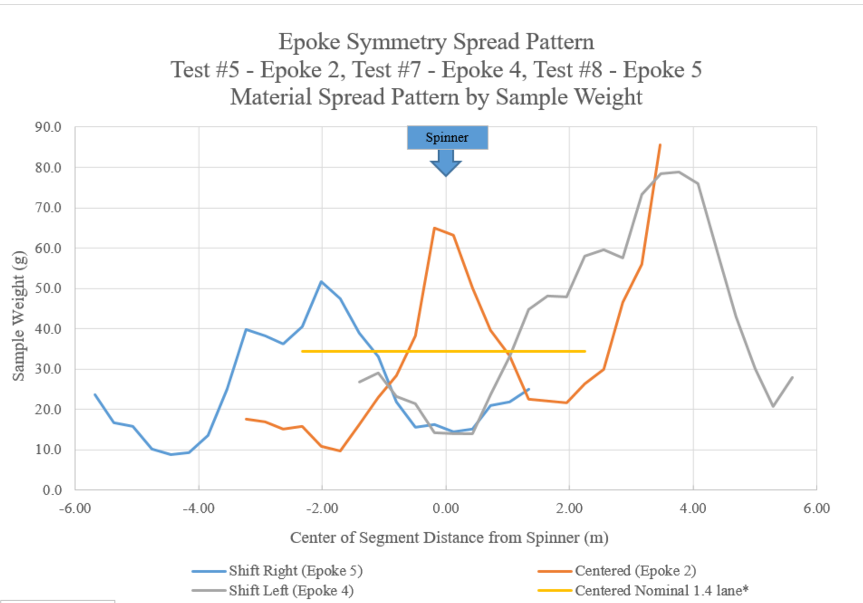


TABLE A.10: Plots of Test #5, 7, 8 with aligned spinner location to show shift in the spread pattern, Epoke symmetry function. Samples #7 and #8 are shifted 7 increments equaling 2.13 m. Samples 1 and 26 (grey) not plotted.

Test Reference Sample	Position, m	Test #8 All, g Epoke 5 Shift Right	Test #5 All, g Epoke 2 Centered	Test #7 All, g Epoke 4 Shift Left	Test #8 % All Epoke 5 Shift Right	Test #5 % All Epoke 2 Centered	Test #7 % All Epoke 4 Shift Left	Nominal	Nominal
	-5.98	20.5			3.0				
	-5.68	23.8			3.5				
	-5.37	16.8			2.5				
	-5.07	15.8			2.3				
	-4.76	10.3			1.5				
	-4.46	8.9			1.3				
	-4.15	9.4			1.4				
1	-3.85	13.6			2.0				
2	-3.54	25.0	30.2		3.7	3.3			
3	-3.24	39.8	17.7		5.8	1.9			
4	-2.93	38.3	16.9		5.6	1.8			
5	-2.63	36.3	15.1		5.3	1.6			
6	-2.32	40.6	15.8		5.9	1.7		34.4	6.3
7	-2.02	51.7	11.0		7.6	1.2		34.4	6.3
8	-1.71	47.4	9.8	16.1	6.9	1.1	1.5	34.4	6.3
9	-1.41	38.9	16.3	26.9	5.7	1.8	2.6	34.4	6.3
10	-1.10	33.1	23.0	29.0	4.8	2.5	2.8	34.4	6.3
11	-0.80	22.0	28.4	23.2	3.2	3.1	2.2	34.4	6.3
12	-0.49	15.7	38.3	21.5	2.3	4.2	2.0	34.4	6.3
13	-0.19	16.3	65.1	14.2	2.4	7.1	1.3	34.4	6.3
14	0.11	14.5	63.2	14.1	2.1	6.9	1.3	34.4	6.3
15	0.42	15.2	50.1	13.9	2.2	5.5	1.3	34.4	6.3
16	0.72	21.0	39.6	23.8	3.1	4.3	2.3	34.4	6.3
17	1.03	22.0	33.4	33.2	3.2	3.6	3.2	34.4	6.3
18	1.33	25.1	22.5	44.7	3.7	2.4	4.2	34.4	6.3
19	1.64	62.6	22.1	48.2	9.1	2.4	4.6	34.4	6.3
20	1.94		21.7	47.9		2.4	4.5	34.4	6.3
21	2.25		26.3	58.1		2.9	5.5	34.4	6.3
22	2.55		29.9	59.7		4.2	5.7		
23	2.86		46.7	57.7		4.3	5.5		
24	3.16		56.0	73.2		4.4	7.0		
25	3.47		85.7	78.4		4.5	7.4		
26	3.77		134.3	78.9		4.6	7.5		
	4.08			76.0			7.2		
	4.38			59.3			5.6		
	4.69			42.9			4.1		
	4.99			30.1			2.9		
	5.30			20.8			2.0		
	5.60			28.0			2.7		
	5.91			33.4			3.2		



Plot A.10

TABLE A.11: Material Application Rates Test Results and Waste Calculations.

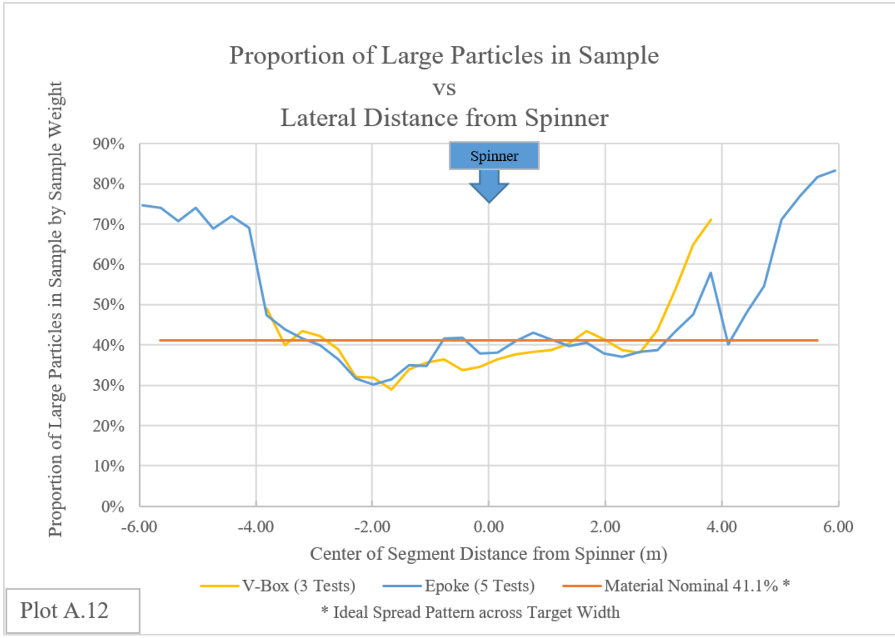
TEST PARAMETERS								TEST RESULTS						
TEST	Application Rate kg/lkm	Application Rate lb/lmi	Spread Width (m)	Spread Width (lane)	Spread Width (ft)	Nominal Weight All (g)	Nominal Ideal Pattern (g)	All (g)	All Waste (g)	Large (g)	Large Waste (g)	Application Rate, Test vs Nominal	All Waste %	Large Waste %
#1 V-Box1	60	214	7	1 9	23 0	420	17 5	1070 7	100 6	na	na	255%	9 4%	na
#2 V-Box2	120	429	7	1 9	23 0	840	35 0	744 9	62 8	381 1	47 2	89%	8 4%	12 4%
#3 V-Box3	120	429	7	1 9	23 0	840	35 0	629 8	47 0	225 7	23 3	75%	7 5%	10 3%
#4 Epoke1	110	393	7	1 9	23 0	770	32 1	1513 8	140 6	579 6	86 2	197%	9 3%	14 9%
#5 Epoke2	110	393	5	1 4	16 4	550	34 4	919 1	432 5	403 0	212 0	167%	47 1%	52 6%
#6 Epoke3	77	275	5	1 4	16 4	385	24 1	767 8	397 5	363 0	204 4	199%	51 8%	56 3%
#7 Epoke4	110	393	5	1 4	16 4	550	34 4	1053 2	271 9	462 4	151 9	191%	25 8%	32 9%
#8 Epoke5	110	393	5	1 4	16 4	550	34 4	684 6	233 1	303 5	139 7	124%	34 0%	46 0%

Notes:
1 Nominal Weight - Rate (kg/lkm) x Spread Width (lane) x Sample length(km)
2 Nominal Ideal pattern across 7 m (1 9 lane) for Tests #1-4 - Nominal Weight / 24 Samples
3 Nominal Ideal pattern across 5 m (1 4 lane) for Tests #5-8 - Nominal Weight / 16 Samples

V-Box % Application Rate	Average	140%	STDEVS	100%
Epoke % Application Rate	Average	176%	STDEVS	31%

TABLE A.12: Proportion of Large Particles vs. Lateral Distance from the Spinner. Samples #7 and #8 are shifted 7 steps, 2.13 m.

10.7	8.2	66.9	49.1	0.73	42.3%	46.5	30.7	9.7	7.2	4.1	8.5			26.7	11.6	87.0	58.0	0.67	40.0%	0.411
7.6	6.5	67.8	43.2	0.64	38.9%	51.9	27.7	8.8	6.3	2.9	4.1			24.0	12.3	87.6	50.4	0.58	36.5%	0.411
7.3	6.9	93.7	44.5	0.47	32.2%	76.5	29.1	9.0	6.8	2.6	5.4			27.9	12.7	116.0	54.0	0.47	31.8%	0.411
6.5	6.1	101.5	47.6	0.47	31.9%	73.4	28.6	5.3	5.7	2.2	2.9			37.8	13.9	118.7	51.1	0.43	30.1%	0.411
7.7	4.9	97.7	39.8	0.41	28.9%	55.2	20.5	5.8	4.0	2.3	5.6	9.9	6.2	34.4	13.0	107.6	49.3	0.46	31.4%	0.411
10.0	5.2	68.8	35.4	0.51	34.0%	26.4	15.3	10.1	6.2	2.6	4.8	18.3	8.6	27.9	11.0	85.3	45.9	0.54	35.0%	0.411
21.0	7.0	61.0	33.7	0.55	35.6%	21.9	12.3	15.8	7.2	3.1	5.6	22.3	6.7	20.5	12.6	83.6	44.4	0.53	34.7%	0.411
22.2	8.2	54.1	31.1	0.57	36.5%	17.4	12.3	18.5	9.9	4.0	7.5	15.1	8.1	12.1	9.9	67.1	47.7	0.71	41.6%	0.411
22.5	7.6	58.4	29.7	0.51	33.7%	18.9	12.2	26.8	11.5	7.5	8.3	10.7	10.8	7.2	8.5	71.1	51.3	0.72	41.9%	0.411
25.0	9.3	62.8	33.3	0.53	34.7%	18.4	14.6	48.7	16.4	9.8	9.0	7.9	6.3	6.8	9.5	91.6	55.8	0.61	37.9%	0.411
28.1	11.6	75.7	43.5	0.57	36.5%	26.7	19.6	46.7	16.5	13.4	9.2	6.3	7.8	6.3	8.2	99.4	61.3	0.62	38.1%	0.411
21.5	10.7	75.0	45.3	0.60	37.7%	35.2	21.0	31.6	18.5	14.0	10.3	6.6	7.3	6.8	8.4	94.2	65.5	0.70	41.0%	0.411
22.8	11.9	76.8	47.8	0.62	38.4%	37.3	20.5	22.0	17.6	16.9	13.6	12.9	10.9	9.3	11.7	98.4	74.3	0.76	43.0%	0.411
24.7	14.5	80.2	50.5	0.63	38.6%	40.9	19.7	16.2	17.2	25.5	17.1	20.8	12.4	8.8	13.2	112.2	79.6	0.71	41.5%	0.411
14.4	10.5	60.5	41.1	0.68	40.5%	35.1	13.4	8.6	13.9	27.4	15.9	29.0	15.7	10.9	14.2	111.0	73.1	0.66	39.7%	0.411
11.0	8.9	53.0	40.6	0.77	43.4%	33.2	15.4	9.2	12.9	26.1	15.0	29.7	18.5	34.0	28.6	132.2	90.4	0.68	40.6%	0.411
11.2	7.9	54.3	38.2	0.70	41.3%	34.5	14.9	9.2	12.5	24.6	13.4	29.2	18.7			97.5	59.5	0.61	37.9%	0.411
15.2	7.1	61.9	39.1	0.63	38.7%	38.0	16.7	12.1	14.2	29.7	15.0	35.9	22.2			115.7	68.1	0.59	37.1%	0.411
16.9	6.6	61.5	37.9	0.62	38.1%	38.3	18.2	14.6	15.3	28.1	16.5	36.6	23.1			117.6	73.1	0.62	38.3%	0.411
12.3	6.0	51.9	40.2	0.77	43.6%	34.0	18.9	27.8	18.9	28.1	17.0	34.0	23.7			123.9	78.5	0.63	38.8%	0.411
8.1	6.8	42.0	49.5	1.18	54.1%	28.9	23.6	29.4	26.6	26.5	22.8	45.9	27.3			130.7	100.3	0.77	43.4%	0.411
5.8	6.0	33.4	62.0	1.86	65.0%	23.5	32.0	44.6	41.1	26.1	30.8	50.8	27.6			145.0	131.5	0.91	47.6%	0.411
11.0	15.2	44.5	109.4	2.46	71.1%	31.1	61.8	58.4	75.9	29.7	63.7	49.0	29.9			168.2	231.3	1.38	57.9%	0.411
												45.4	30.6			45.4	30.6	0.67	40.3%	0.411
												30.8	28.5			30.8	28.5	0.93	48.1%	0.411
												19.5	23.4			19.5	23.4	1.20	54.5%	0.411
												8.7	21.4			8.7	21.4	2.46	71.1%	0.411
												4.8	16.0			4.8	16.0	3.33	76.9%	0.411
												5.1	22.9			5.1	22.9	4.49	81.8%	0.411
												5.6	27.8			5.6	27.8	4.96	83.2%	
V-Box	Totals	1702.1	1186.4											Epoke	Totals	2678.1	1864.4			
	Large:Small	0.697													Large:Smal	0.696				
	Large:Total	41.07%					V-Box & Epoke		Large:Total	41.06%					Large:Total	41.04%				



Plot A.12 of Data from Table A.12