FIELD TESTING OF ABRASIVE DELIVERY SYSTEMS IN WINTER MAINTENANCE

By

Wilfrid A. Nixon

Funded by the Iowa Highway Research Board
Project TR 458

FINAL REPORT

IIHR Technical Report # 471

IIHR—Hydroscience & Engineering
College of Engineering
The University of Iowa
Iowa City, IA 52242

May 2009

ACKNOWLEDGEMENTS

This project was made possible by funding from the Iowa Highway Research Board, Project Number TR 458. This support is gratefully acknowledged, as is the assistance of Mr. Mark Dunn in bringing this project to completion. The assistance of Iowa DOT personnel was invaluable, as was the support of Dennis Burkheimer of the DOT.

The support of the Directors of IIHR Hydroscience and Engineering during the execution of this project, Dr. V.C. Patel and Dr. L.J. Weber, enabled this study to proceed. Shop assistance from Mr. Darian DeJong and Mr. Steve Laszczak was invaluable.

ABSTRACT

The key goals in winter maintenance operations are preserving the safety and mobility of the traveling public. To do this, it is in general necessary to try to increase the friction of the road surface above the typical friction levels found on a snow or ice covered roadway.

Because of prior work on the performance of abrasives (discussed in greater detail in chapter 2) a key concern when using abrasives has become how to ensure the greatest increase in pavement friction when using abrasives for the longest period of time. There are a number of ways in which the usage of abrasives can be optimized, and these methods are discussed and compared in this report. In addition, results of an Iowa DOT test of zero-velocity spreaders are presented.

Additionally in this study the results of field studies conducted in Johnson County Iowa on the road surface friction of pavements treated with abrasive applications using different modes of delivery are presented. The experiments were not able to determine any significant difference in material placement performance between a standard delivery system and a chute based delivery system.

The report makes a number of recommendations based upon the reviews and the experiments.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The key goals in winter maintenance operations are preserving the safety and mobility of the traveling public. To do this, it is in general necessary to try to increase the friction of the road surface above the typical friction levels found on a snow or ice covered roadway. In general, this improvement in surface friction is best achieved by a pro-active use of chemicals (Ketcham et al., 1996; Al Qadi et al., 2004). However, under certain circumstances, the use of chemicals may not be recommended or may not be possible. In such circumstances, abrasives have frequently been used to improve the friction level of the snow or ice covered roadway (albeit temporarily).

Because of prior work on the performance of abrasives (discussed in greater detail in chapter 2) a key concern when using abrasives has become how to ensure the greatest increase in pavement friction when using abrasives for the longest period of time. There are a number of ways in which the usage of abrasives can be optimized, and these methods will be discussed and compared in this report.

Additionally in this study the results of field studies conducted in Johnson County Iowa on the road surface friction of pavements treated with abrasive applications using different modes of delivery will be presented. The implications of these results will be discussed. On the basis of these results and of prior work on the use of abrasives, a series of recommendations will be made for the optimal methods of abrasive usage under a variety of conditions.

2. PREVIOUS STUDIES AND CURRENT STATE OF UNDERSTANDING

The previous work on the use of abrasives can be considered in a number of ways. In this report, the general performance of abrasives will first be examined. It is clear from the studies cited in this part of the review that a significant challenge when using abrasives is ensuring that they remain on the pavement for as long as possible, and thus provide friction enhancement for as long as possible. The next three parts of the review will look at three ways in which abrasives (and other solid materials) can remain longer on the pavement surface: pre-wetting, using zero velocity spreaders, and using thermal methods. The final part of the review will examine the method of modifying abrasive delivery to be tested in this study.

2.1. General Abrasive Performance

The use of abrasives in winter maintenance is a well-established practice. Minsk (1999) reports that sand (or other abrasives) constituted the major part of winter maintenance activities (in addition, of course, to plowing) up until the 1970's in the United States. At that time, the use of salt and other de-icing chemicals became more widespread. The sand or other abrasive is intended to increase friction between vehicles and the (often snow or ice covered) pavement. The sand may be applied "straight," it may be pre-wet with liquid brine (at the spinner or in the box during loading as discussed below), or it may be delivered mixed with salt (with mixtures ranging from 1:1 sand: salt up to 4:1 sand: salt).

However, only limited information exists on the value of sanding as a winter maintenance procedure. Studies from the late 1950's suggest that at highway speeds sand is swept off the roads by relatively few (8 to 12) vehicle passes. More recent studies suggest that friction gains from sanding (when sand remains on the road) are minimal.

2.1.1. Traffic Effects

While the practice of sanding as part of a winter maintenance program is widespread, the few studies that have been done on this do not indicate that this practice is particularly valuable. Gray and Male (1981) note that even in the 1950's studies in Germany indicated that sand was swept from snow-covered highway surfaces after only ten to twelve vehicle passages (at highway speeds). More recently, a study conducted by the Ontario Ministry of Transportation (Comfort and Dinovitzer, 1997) showed that at low temperatures (below –15º C) the friction gains due to application of abrasives were substantially reduced by the passage of relatively light traffic (5 to 10 vehicles and 3 to 5 logging trucks).

This Ontario study also showed that substantial application rates had to be used to obtain substantial gains in friction. In one series of tests on hard packed snow under cold (below –15º C) conditions, the friction factor of the untreated roadway was measured as 0.18. After application of 300 kg per lane kilometer (kg/lkm), which corresponds to about 1,000 lbs/lane mile, the friction factor increased to 0.40. After light traffic, this value reduced to 0.23. Table 1 shows the stopping distance for a passenger vehicle with an initial velocity of 40 kilometers per hour (kph) for these friction values.

Table 2.1. Stopping distances after abrasive treatment (from Comfort and Dinovitzer, 1997)

Road Condition	Friction Factor	Stopping Distance (m)
Hard packed snow cover (below –15° C)	0.18	35.0
Abrasives freshly applied (300 kg/lkm)	0.40	15.7
Same surface after light traffic	0.23	29.5

Comfort and Dinovitzer did find some circumstances in which traffic did not reduce the effectiveness of abrasives to the extent indicated in table 2.1. At warmer temperatures on a snow-pack covered road, the abrasives were less likely to be swept off the road by vehicle passage, although friction still decreased with traffic. In addition, on a warmer ice covered road, traffic appeared to increase friction. This latter effect was attributed to two factors – strong sunlight during the test that melted the sand into the ice; and mechanical action by the traffic that roughened the road surface.

2.1.2. Other Effects

Other studies have been conducted on the usage of sand as a friction enhancer. Borland and Blaisdell (1993) examined five different ice types. They found that coarse sand gave more friction enhancement at low temperatures, while find sand was better close to the melting point of ice. They also found that friction enhancement was a strong function of application rates. They applied at rates up to 580 kg/lkm. They found that abrasives could provide gains in friction factor from about 0.10 (for bare ice) up to 0.31.

Hossain et al. (1997) conducted a study for New York Department of Transportation in which three different sand types were tested over a range of temperatures and application rates. The sand was also applied with salt and salt-brine mixtures. They found that sand alone gave little benefit in friction factor, while best results appeared to be obtained with a 2:1 sand – brine mix (using a 25% brine solution) at warmer temperatures.

2.2. Effect of Pre-Wetting on Material Usage

Pre-wetting involves adding liquid to the material being placed on the road. The liquid can be added at a number of different points in the material handling process: in the stockpile; while loading the back of the truck; and as the material is being delivered to the spinner[1]. The purpose of pre-wetting is generally considered to be twofold. First, when used with salt or other solid chemicals, the pre-wetting liquid is intended to "jump start" the melting process of the solid chemical. This is particularly important when using salt (sodium chloride) since it is not particularly deliquescent and thus if placed dry on an ice surface that is also dry, salt will take a long time to go into solution. Adding a liquid to the solid salt avoids this initial slowness to solution.

Second, pre-wetting is considered (for reasons discussed below) to stop material from bouncing off the road when initially applied. Clearly any material that is swept off the road, either when initially placed or under the subsequent action of traffic, is lost material and thus it is important to limit this loss as much as possible. Studies indicate (although not without some contradictory results) that pre-wetting is extremely effective at minimizing loss due to bounce and scatter of material.

Typical pre-wetting rates have been about 8 gallons (about 32 liters) of liquid per ton of solid material. Recently there has been considerable interest in using much higher rates (as much as 50 gallons of liquid per ton of solid material) of pre-wetting (reflecting practices in Europe), creating what might be termed a slurry rather than a solid material application. While this technique is still very much experimental initial anecdotal reports suggests this may have some future promise.

2.2.1. Michigan DOT Report

In the 1970's the Michigan Department of Transportation conducted a study on the effectiveness of pre-wetting in winter maintenance material delivery. This report, (Lemon, 1975) presents four sets of results, the first three being brief summaries of (presumably) previous reports. The first set is from a summer study conducted in 1972. The second, third, and fourth sets of results come from field testing (or "testing under

---

[1] Up until recently, liquid added at the spinner was almost always added as the solid material hit the spinner. However, there are now a number of material delivery systems that add liquid as the solid material leaves the auger or chain typically 2 to 5 feet above the spinner.

adverse conditions" as it is described in the report) during the winters of 1972-73, 1973-74, and 1974-75 respectively.

First Result Set: Summer 1972

These results, given simply as a bar graph, show the effect of pre-wetting on the dispersal of material on the road. The bar graphs represent 21 different tests conducted over four days. No data are given in this report as to the exact rate of pre-wetting, but it seems reasonable (see below for why) to assume that pre-wetting in this series of tests was at a similar rate to that in the 1974-75 winter study, namely two gallons per mile of liquid applied to a material delivered at 400 lbs per mile (or 10 gallons per ton of material)

The bar graph (recreated in Figure 2.1) shows the significant benefits of using pre-wetting when applying any material to the roadway. Significantly, when applied to a 24 foot wide road, 96% of the pre-wet material remains on that 24 foot width, in contrast with only 70% of material applied dry. Considered another way, dry material losses are 30%, while a pre-wet material will lose only 4% due to scatter off the road.

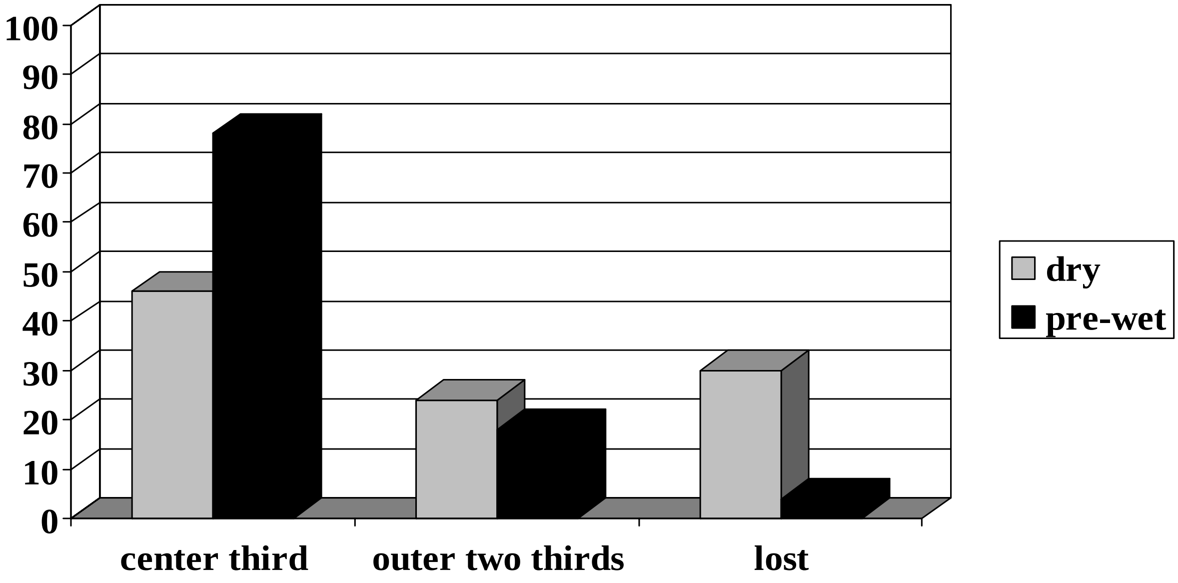

Figure 2.1. Results from Michigan DOT Study on Pre-wetting (Lemon, 1975)

Again, no information is given here as to the speed of the vehicles when applying materials. Later in the report, reference is made to two different types of application mechanism (auger and spinner) and no indication is given in this report as to which mechanism was used in this series of tests. Nonetheless, the 1972 summer tests indicate the potential for significant reduction in wastage of materials when pre-wetting is used.

Second Result Set: Winter 1972-73

This represents the first testing under field conditions of pre-wetting as part of the overall study. Eight units (trucks) were equipped with pre-wetting capabilities, and assigned to eight specific routes at various locations around Michigan. Three conclusions were reached as a result of this winter's testing, namely:

1: The pre-wet salt did not appear to melt snow faster than untreated salt above 27°F (-2.8°C).

2: Conversely, below 20°F (-6.7°C), the pre-wet salt did melt snow and ice more rapidly than untreated salt.

3: More pre-wetted salt stayed on the pavement than untreated salt.

Third Result Set: Winter 1973-74

The aim of this second season of field trials was to bring all the units equipped for pre-wetting to one location (the Williamston Garage) and to upgrade all other units at that location to be able to apply pre-wet salt also. Thus one complete garage would be equipped to pre-wet. The expectation was that a variety of operational issues could thus be explored, including what level of pre-wet salt should be applied to the road to achieve a certain level of service.

Unfortunately, there were a series of delays and interruptions so a true evaluation of material savings was not possible. The winter season was not, however, totally wasted. They were able to show that they could reduce salt applications (if the salt was pre-wet) and not reduce the level of service. They were also able to develop a locking system for their spreading equipment that limited the maximum application rate. Further, the season of tests indicated the importance of three things. Equipment must be properly calibrated. Operators must know what their equipment can do. And supervisors must be involved to ensure reduction in quantities of materials used.

Final Result Set: Winter 1974-75

In the final season of this study (which forms the bulk of the Michigan DOT report) the test program was expanded to five garages, each of which was given storage capacity for the pre-wetting liquid. In each garage, all trucks were modified to allow them to apply pre-wetted salt, which a maximum application rate of 400 lbs per mile. In total 40 units (trucks) were equipped with pre-wetting capability.

From the five garages, 200 observations were collected, using a standardized form for data collection. The summary results of these observations indicated that 75% of the time, pre-wetted salt was spread in the center one third of the road. Further, 95% of the observations indicated that pre-wet salt performed better than dry salt below 20°F (-6.7°C), while 76% felt that the pre-wet salt performed better above 20°F (-6.7°C).

One observation that caused some concern was that roads treated with pre-wet salt took longer to dry than roads treated with dry salt. However, of the 200 observations made, only 18% indicated that pre-wet salt caused a longer road drying time. The conclusion appeared to be that drying time was not a significant concern.

Visual observations of pattern control conducted in the 1974-75 winter season suggested that pre-wetting keeps the salt away from the highway shoulders very effectively. This observation was based on the fact that in areas where pre-wet salt was applied, road shoulders remained snow covered, whereas in areas where dry salt was applied, the shoulders became slushy or wet.

The foreman from each garage in the study was asked to record their overall observations. One of the more common observations was that level of service could be maintained using pre-wet salt at 400 lbs per mile application rate, as opposed to 500 lbs per mile with dry salt.

Among the summary results noted in this section of the report was a comparison of salt usage at the Kalkaska garage. Even though the 1974-75 season had 26% more snow and 35% more storms than the 1973-74 season, use of pre-wet salt meant that total salt usage was 12% less in the 1974-75 season than in the previous year.

Another interesting comparison was made between the Williamston garage which used pre-wet salt, and five surrounding garages which used dry salt. The average total salt usage for the five garages over the 1974-75 season was 24.35 tons per “E” mile (“E” probably implies “equivalent” – it is not specified in the report). The Williamston garage used 20.75 tons per “E” mile, or about 15% less than the five garages using dry salt. This savings value (a reduction of 15% in salt usage) was used in their subsequent cost benefit analysis.

At this point in the report, they make explicit reference to their rate of pre-wetting. Pre-wetting was done using a 30% Calcium Chloride brine, applied at a rate of 10 gallons of liquid chloride for every ton of dry salt (or 2 gallons for every 400 lbs, thus 2 gallons per lane mile). Costs quoted for Calcium Chloride brine in the report (about 9 cents a gallon) are of course not relevant today.

One saving alluded to in the report but not apparently considered in the analysis was the extended range of each truck because of a lower salt application rate. If application rates are reduced from 500 to 400 lbs per mile, then a truck with a capacity of 10 tons (~20,000 lbs) would have a range of 50 miles instead of 40 miles. This would result in a saving of re-load time between trips and might also result in a much more effective system of routes, thus also contributing to improved levels of service.

The study concludes with clear recommendations to implement pre-wetting throughout Michigan DOT. A cost analysis shows that by the fifth year the program would have saved more than it cost, with ongoing annual savings in excess of $100,000. Some caveats were identified, specifically the need for training and the need to ensure that application rates are actually reduced when pre-wetting is used.

Summary Comments on Michigan DOT Report

It is apparent that Michigan DOT conducted a very thorough, multi-year investigation into the benefits of using pre-wetting with their salt application. From tests in the field and also under somewhat controlled conditions (during the summer of 1972) they found significant reductions in the amount of salt required to be used without any reduction in the level of service.

2.3. Use of Zero-Velocity Spreaders

It is a reasonable assumption that one reason why so much material is lost from a truck when it is placed on the road in a dry condition is that the material simply bounces and scatters because of the forward velocity imparted to it by the truck from which it is being delivered. One way in which this drawback could be minimized is if the material is ejected from the truck with a velocity in the rearward direction equal in magnitude but opposite in direction to the velocity of the truck itself. This is the idea behind the zero-velocity spreader unit.

2.3.1. Iowa DOT Zero Velocity Tests

In 2003 (specifically, on November 7, 2003) on new and unopened stretch of US 20 south of Iowa Falls, a series of tests were conducted to determine whether zero-velocity spreaders were better than regular spreaders at placing material within the targeted lane at a variety of spreading speeds. Five different types of delivery system were tested, of which three were zero-velocity units, one was a regular spinner unit, and one was a regular unit but with a chute rather than a spinner at the rear of the truck. Figures 2.2 through 2.6 show the five delivery systems. Each was mounted on its own truck.

Figure 2.2. Truck A - standard truck with traditional tailgate spreader that would be typical of the department's fleet. Spreader was mounted on the left hand side of the truck, approximately 18 inches from the roadway surface.

Figure 2.3. Truck B - standard truck outfitted with a shop made stainless steel chute system. The chute is designed to place material in a narrow windrow when the chute is engaged or bypass the chute and distribute material to a traditional spreader for broader distribution, depending on the needs. The system is hydraulically controlled from the cab. For purposes of this test, the chute was fully engaged for a narrow distribution.

The testing area was a one-mile stretch of new, heavily tined, concrete pavement on relatively level terrain. The day was sunny but the winds increased throughout the day with recorded speeds ranging from19-27 mph with gusts of 20-35 mph during the comparison period. The charts (see below) showing distribution of materials for each truck show the influence winds had on the project. Though the winds influenced the final results, they also are representative of a typical winter storm event.

Figure 2.4. Truck C - Monroe Accuspread zero velocity system. The truck is a standard truck from the fleet equipped with a prototype Accuspread unit modified by the Bedford shop.

Figure 2.5. Truck D - standard truck from the Oakdale shop that was equipped with a Swenson Positive Placement System (PPS) zero velocity unit.

Figure 2.6. Truck E - standard truck from the Des Moines West shop equipped with one of the original Tyler zero velocity systems purchased in 1997.

2.3.2. Iowa DOT Zero Velocity Test Method

On the day of testing (November 7, 2003) all five trucks had their spreader units calibrated, and were loaded with straight road salt at the Iowa Falls maintenance garage salt dome. The test area had been prepared some days prior to the day of testing, by pre-marking the concrete into 3 foot by 3 foot segments with yellow painted borders, as indicated in Figure 2.7. A catch box was placed at each shoulder to stop material distribution beyond the edge of the shoulder. Each of the segments was numbered as shown in Figure 2.7 (for use in data collection and management).

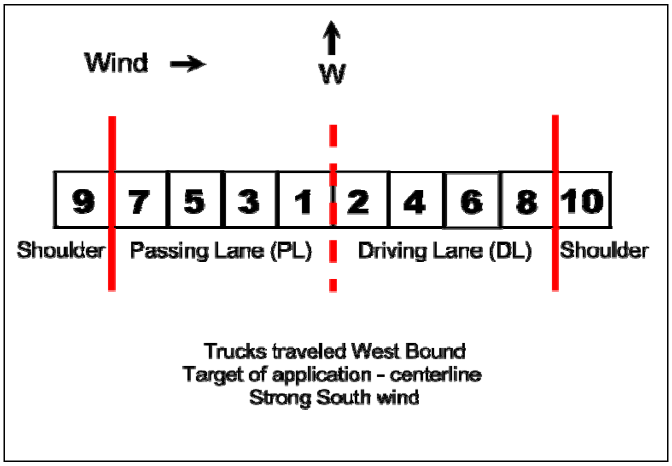

Figure 2.7. Roadway section numbering sequence

An additional 3 foot long by 24 foot wide area, located close to the test collection area, was painted black and provided an easy way to observe visually the pattern of material placement for each run.

Prior to any data collection, each truck conducted a test run to ensure that operators were comfortable with the test procedure, the equipment, and the road. In all cases, trucks started every test run approximately one mile away from the test area, to ensure sufficient distance to achieve the desired test speeds. Every truck was trailed by a camera vehicle that both recorded the operation of the spreader, and ensured that the spreader was working properly prior to entering the test area. If any problems occurred, the run could be cancelled and re-run after appropriate adjustments were made.

All trucks conducted tests at three speeds (25, 35, and 45 mph) and at two application rates (150 and 250 lbs per lane mile) resulting in six test runs for each truck (not including the initial test run). All of the five trucks were able to conduct all six of the test runs allow for full comparison across the test matrix. Truck speeds were determined using a radar gun. If the speed of any truck through the testing area was not within 10% of the required speed for that test, then that test would be re-run.

After each test run, an industrial vacuum cleaner was used to vacuum all the materials form each individual 3 foot by 3 foot segment. The material was then carried to the collection station. At that location, it was poured through a funnel into a plastic collection bag. Collection bags were numbered with a letter (A through E) indicating the truck, followed by two numbers. The first number was the run number (1 through 6) and the second number (1 through 10) was the segment from which the sample was collected. Thus B-3-7 would indicate the sample collected for truck B on run 3 from the segment labeled 7.

After collection, bagging, marking and storing of the material from any given test run was completed, the test segments were blown clear of any remnant materials with air compressors. A 50 foot long area in the approach to the test area was also blown clear to avoid carrying any materials in that area into the test area by the trucks. More than 300 samples were collected during the testing and were transported to the Materials Laboratory at Iowa DOT headquarters for weighing. All measurements were done in metric and are presented as grams of material per square yard of road surface.

2.3.3. Iowa DOT Zero Velocity Test Results

The first concern with the test results was to determine to what extent the calibrated application rates were confirmed by the testing. As noted above, the two application rates tested were 150 and 250 lbs per lane mile. These rates translate to 9.66 and 16.11 grams per square yard. If all the material delivered by each truck for each run landed in the ten test segments (for that three foot long stretch of road) then the total amount of material collected for each test run would be 96.6 grams and 161.1 grams for the two application rates respectively. However, this did not prove to be the case. Table 2.2 shows the collected weights for the runs conducted by Truck A. It is clear that the collected material was substantially different from the expected amounts, as indicated by the fourth column of the table, which normalizes the quantity of material collected with respect to the expected amounts for the given application rates.

Table 2.2. Collected Material in Test Section for Truck A.

Application Rate (lbs per lane mile)	Speed (mph)	Material Collected (grams per sq. yard)	Normalized Material collected
150	24.9	72.4	0.75
150	33.9	78.4	0.81
150	44.2	109.4	1.13
250	24.7	71.2	0.44
250	33.9	98.3	0.61
250	42.0	65.0	0.40
150	23.9	39.0	0.40
150	33.4	34.1	0.35

Clearly, for this truck, the quantity of material was significantly less than that expected and also varied significantly from run to run, even when all conditions were nominally the same (see in Table 2.2 the second and the eighth runs, both at application rates of 150 lbs per lane mile, both at target speeds of 35 mph yet the material collected varied from 81% to 35% of the expected amount). This is in itself worrying (see below). It also means that in order to compare results between different delivery systems it was necessary not to report absolute values, but rather to present the results as a percentage of the total material collected for a given test run. It should be noted that some of the variation in amounts delivered may be due to variations in wind speed at the time of the run. However, wind speed values were not collected for each run. Equivalent results to those presented in Table 2.2 are presented in Tables 2.3 through 2.6 for the other four delivery systems. Table 2.7 reprises which truck had which delivery system.

Table 2.3. Collected Material in Test Section for Truck B.

Application Rate (lbs per lane mile)	Speed (mph)	Material Collected (grams per sq. yard)	Normalized Material collected
150	23.9	70	0.72
150	33.5	57.7	0.60
150	43.5	53.3	0.55
250	24.9	49.5	0.31
250	33	82.8	0.51
250	42.9	90.4	0.56

Table 2.4: Collected Material in Test Section for Truck C.

Application Rate (lbs per lane mile)	Speed (mph)	Material Collected (grams per sq. yard)	Normalized Material collected
150	25	49.6	0.51
150	34.2	35.6	0.37
150	45	46.2	0.48
250	25.7	76.8	0.48
250	35.2	84.6	0.53
250	43.9	89.2	0.55

Table 2.5. Collected Material in Test Section for Truck D.

Application Rate (lbs per lane mile)	Speed (mph)	Material Collected (grams per sq. yard)	Normalized Material collected
150	25.2	57.8	0.60
150	36	42.8	0.44
150	45.6	58.6	0.61
250	25.8	65.8	0.41
250	37	87.3	0.54
250	45.8	82.7	0.51

Table 2.6. Collected Material in Test Section for Truck E.

Application Rate (lbs per lane mile)	Speed (mph)	Material Collected (grams per sq. yard)	Normalized Material collected
150	25.2	66.4	0.69
150	33.7	41.2	0.43
150	43	76.3	0.79
250	24.3	171.4	1.06
250	34.2	158.4	0.98
250	43.7	145	0.90

Table 2.7. Truck and Delivery System Data

Truck Identifier	Truck Type	Spreader Type
A	A 29231	Standard Spreader
B	A 29231	Chute
C	A28463	Monroe ZV
D	A30830	Swenson ZV
E	A28079	Tyler

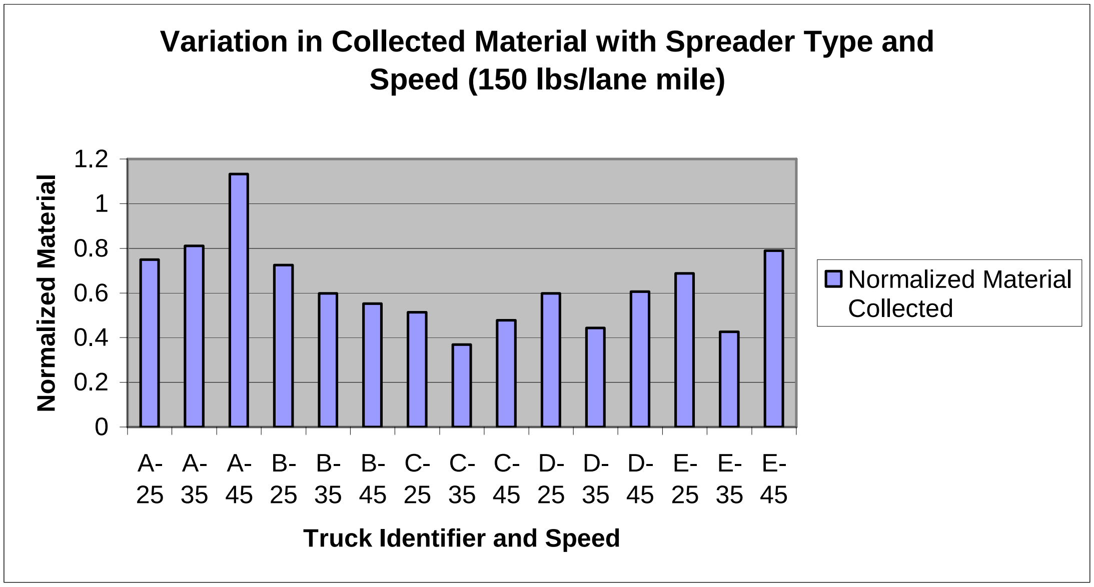

Figure 2.8. Variation of material collected with truck and speed (150 lbs/lane mile)

Figures 2.8 and 2.9 show how the amount of material that was collected varied from the expected amount for the different spreader types and at the different speeds. Figure 2.8 shows the variation for a nominal application rate of 150 lbs/lane mile (i.e. a value of 1 for the normalized material would indicate an equivalent of 150 lbs per lane mile was deposited in the ten sample areas in the test section), while figure 2.9 shows the variation for a nominal application rate of 250 lbs/lane mile.

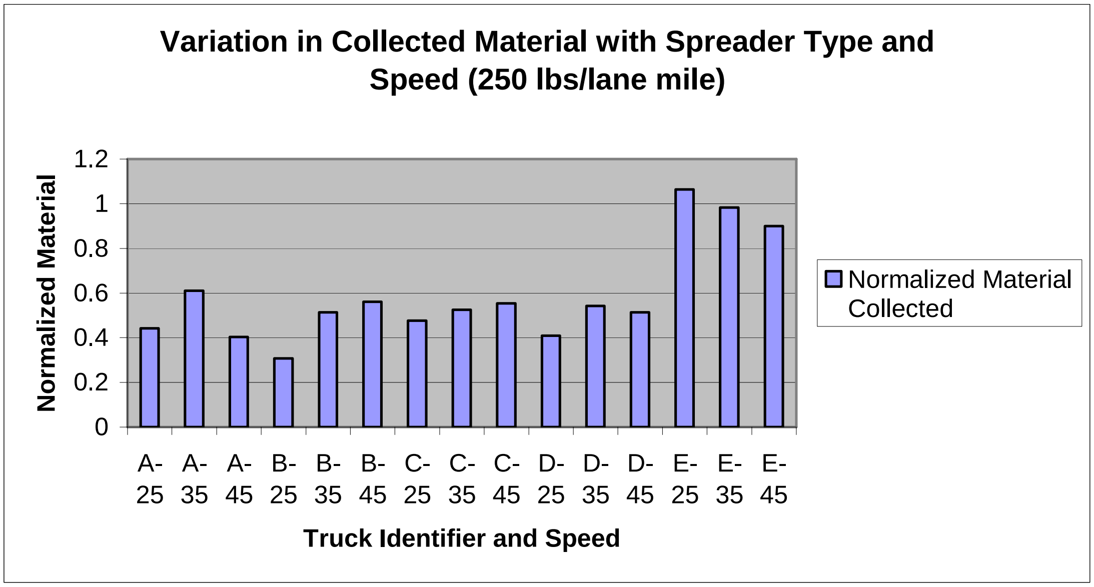

Figure 2.9. Variation of material collected with truck and speed (250 lbs/lane mile)

There are few clear trends evident from these two figures. At the higher application rate, spreader type E appears to deliver closest to the specified application rate, while at the lower rate, it would appear that spreader type A does so. Spreader type C appears to offer the smallest variation with speed at both application rates.

However, perhaps the most notable result that is evident from figures 2.8 and 2.9 is that most of the spreaders, under most of the conditions of testing, delivered significantly less material in the testing segment than would be expected from their (very recently calibrated) settings. For only two conditions (truck A, 45 mph, 150 lbs per lane mile; truck E, 25 mph, 250 lbs per lane mile) was the amount of material collected more than expected based on the selected application rate (13% and 6% more, respectively). Spreaders typically do not deliver a uniform stream of material, so it is not unexpected that the material collected differs from the amount (supposedly) delivered. But if the explanation for this variance was due to non-uniform delivery, then it would be reasonable to assume that about half the runs would show less material, and half would show more. That is not found in these results. Rather, most of the runs showed less material, and approximately one third of the runs showed less than half the selected material quantity that would be expected. At present, there is no explanation for this, especially since the delivery systems were all calibrated that day prior to testing. This issue requires further study, since it strongly suggests that delivery systems actually deliver less material than their calibrations and settings would seem to suggest.

In examining the distribution of materials across the test segments, results are shown (as noted above) in terms of the percentage of the total collected material found in a single box or segment of the test area. Figure 2.10 shows the distribution across the test section for truck A at a delivery rate of 150 lbs per lane mile.

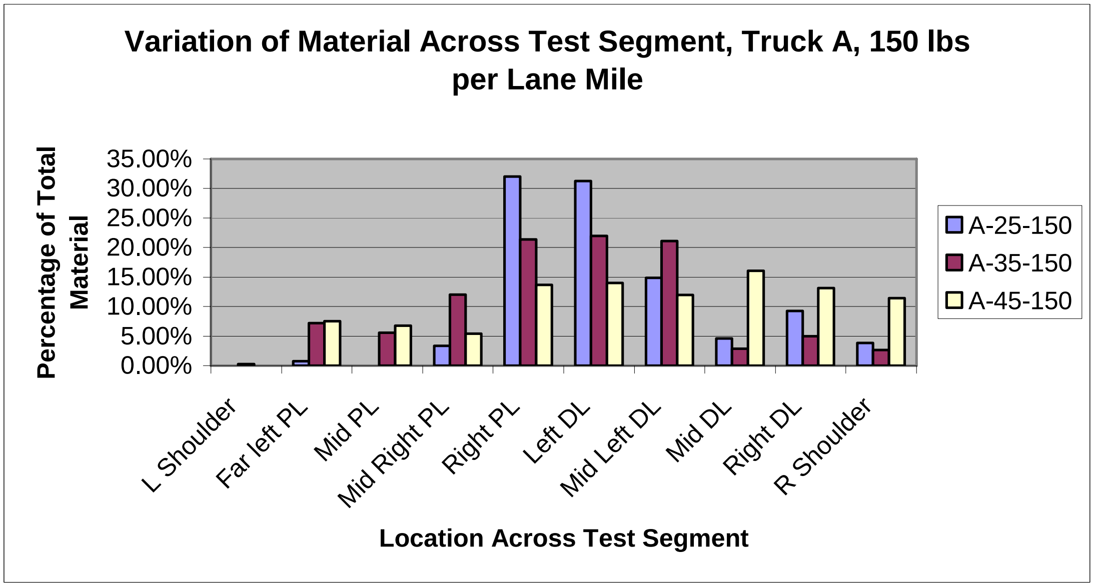

Figure 2.10. Material distribution, Truck A, 150 lbs per lane mile (PL = Passing Lane, DL = Driving Lane)

Figures 2.11 through 2.19 show equivalent results for the remaining 9 truck and application rate configurations.

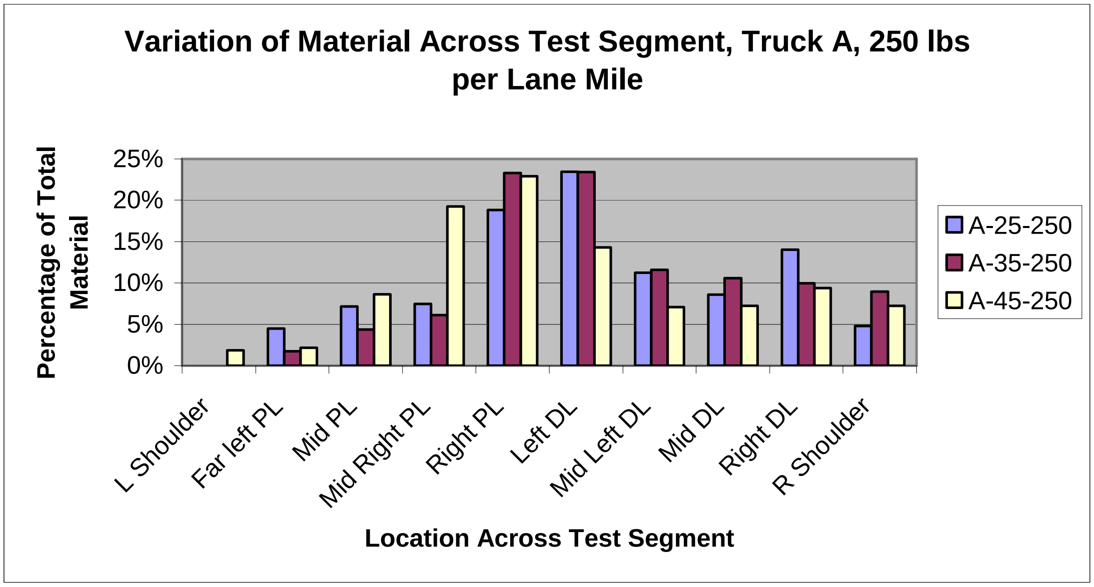

Figure 2.11. Material distribution, Truck A, 250 lbs per lane mile

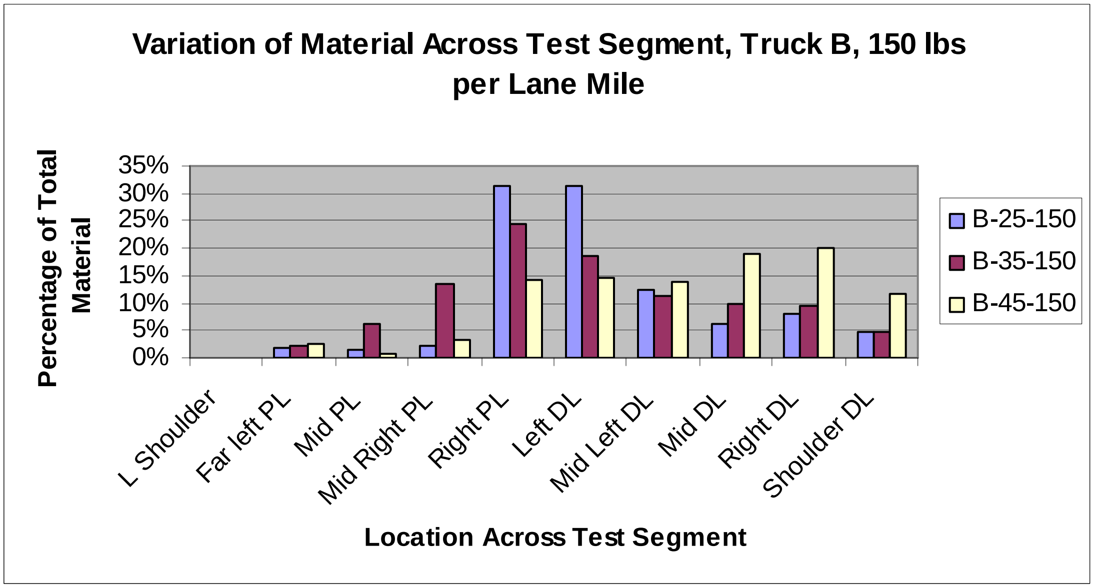

Figure 2.12. Material distribution, Truck B, 150 lbs per lane mile

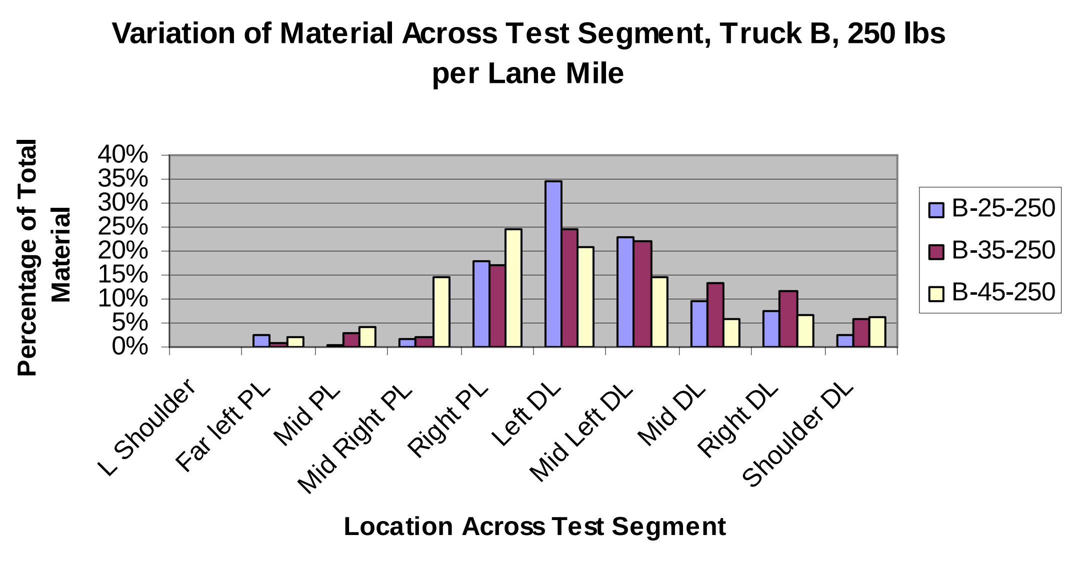

Figure 2.13. Material distribution, Truck B, 250 lbs per lane mile

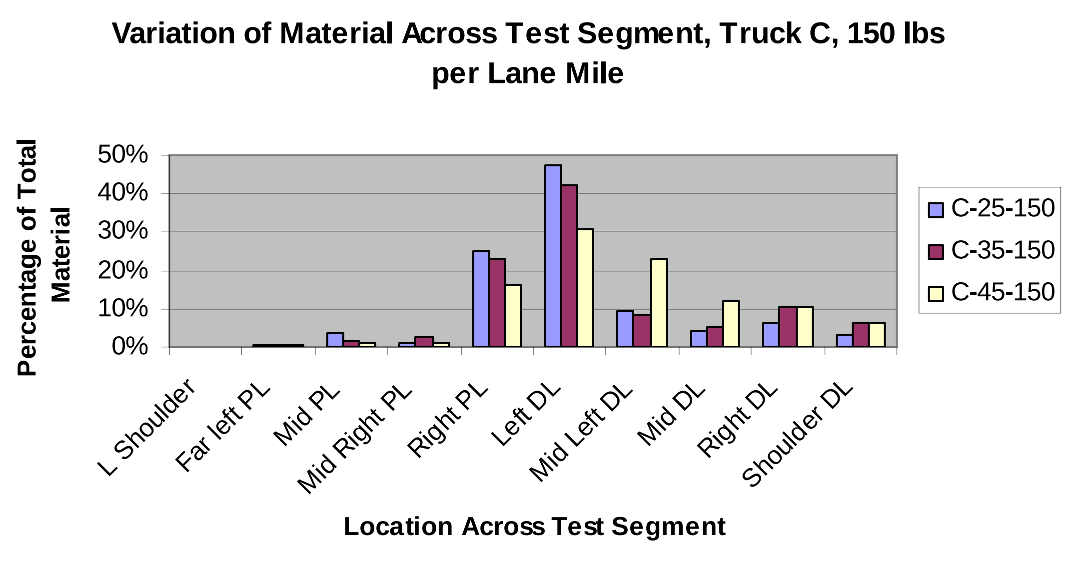

Figure 2.14. Material distribution, Truck C, 150 lbs per lane mile

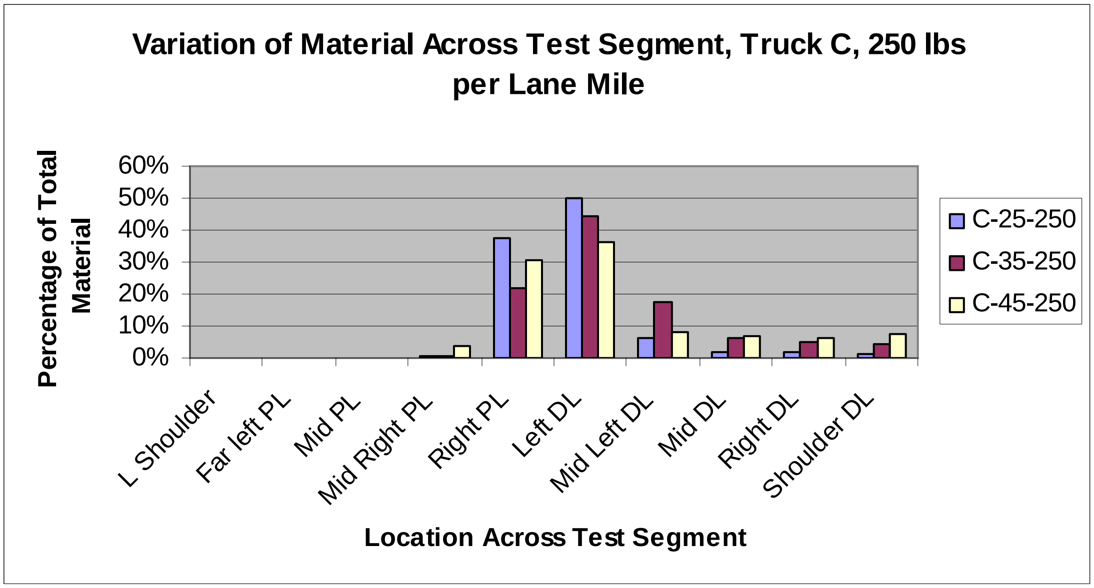

Figure 2.15. Material distribution, Truck C, 250 lbs per lane mile

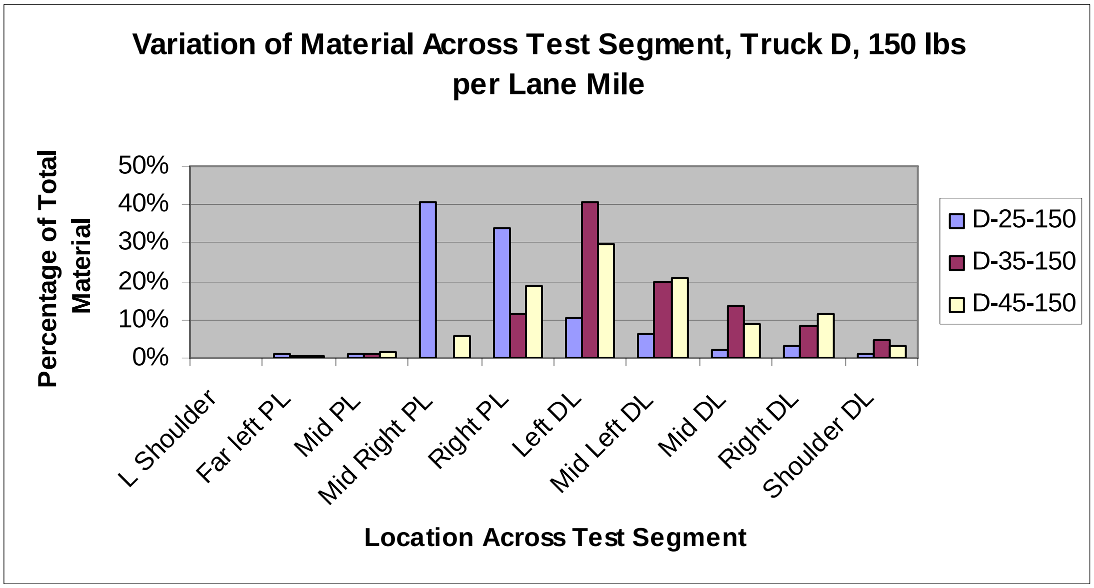

Figure 2.16. Material distribution, Truck D, 150 lbs per lane mile

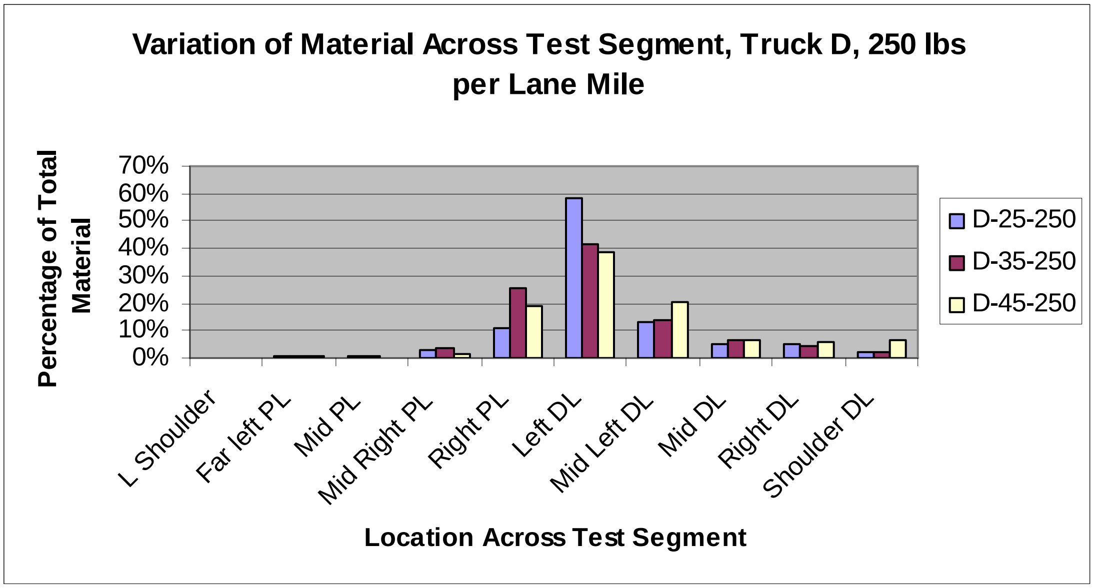

Figure 2.17. Material distribution, Truck D, 250 lbs per lane mile

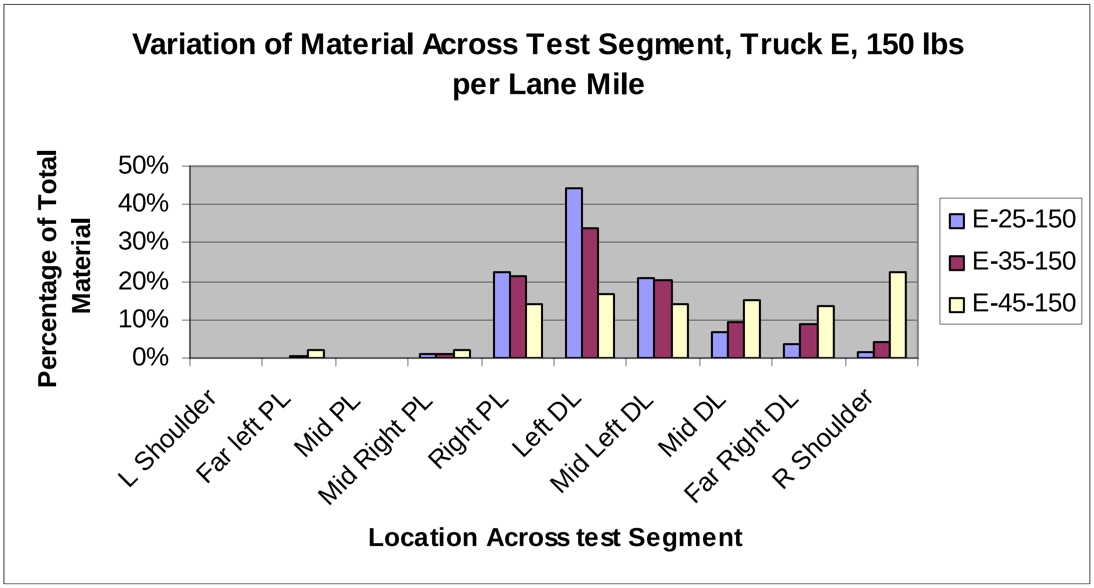

Figure 2.18. Material distribution, Truck E, 150 lbs per lane mile

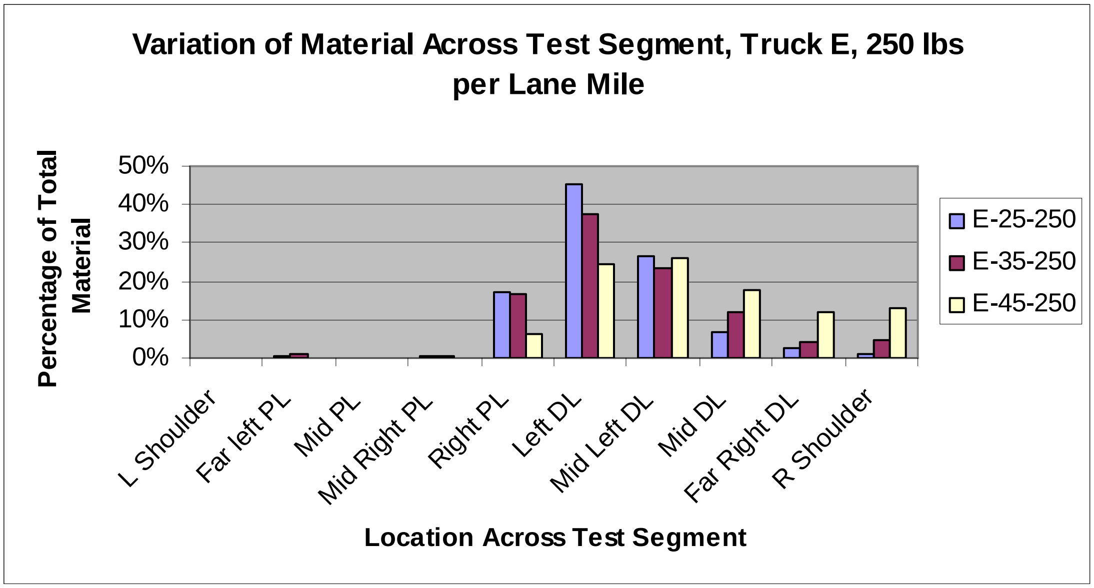

Figure 2.19. Material distribution, Truck E, 250 lbs per lane mile

There are clear differences observable between the various delivery systems, with trucks C, D, and E, for example, showing almost no material in the left four segments, while truck B shows some material in that area, and truck A shows the most material in that location. However, differences between the delivery systems are best seen by way of comparisons. Since the systems were being tested to determine how well they could apply material in a concentrated manner, the ability of each system to deliver material in a six foot, a nine foot, and a twelve foot wide segment (two, three or four segment sections respectively) was determined. In each case, the “best” six, nine, or twelve foot wide segment was chosen. In this context, best was taken to mean that segment in which the most material was collected. These data are shown in figures 2.20 through 2.24 respectively.

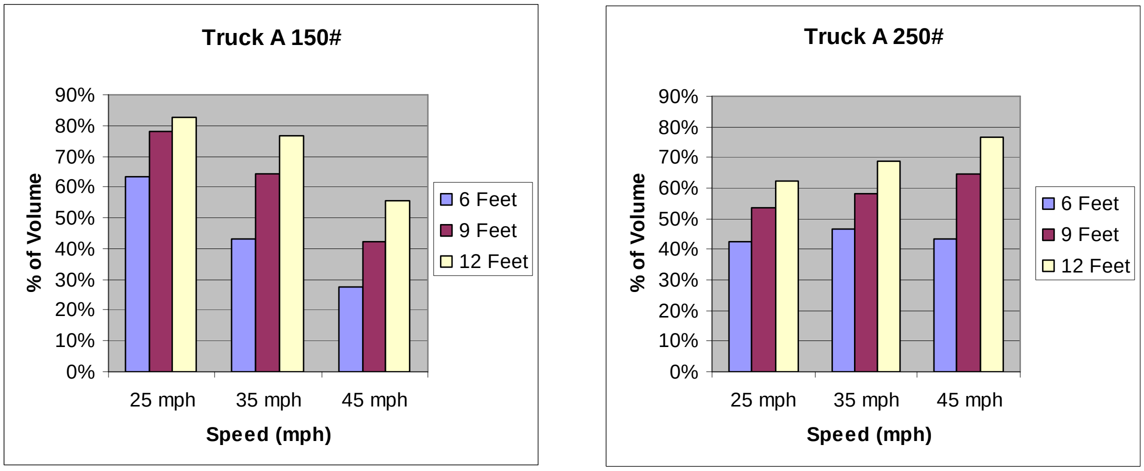

Figure 2.20. Material concentration for Truck A

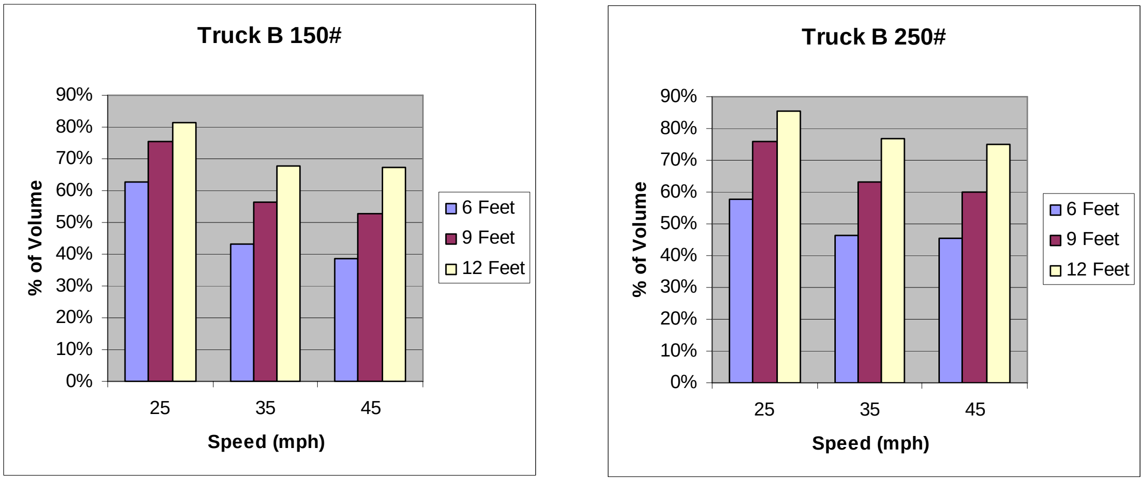

Figure 2.21. Material concentration for Truck B

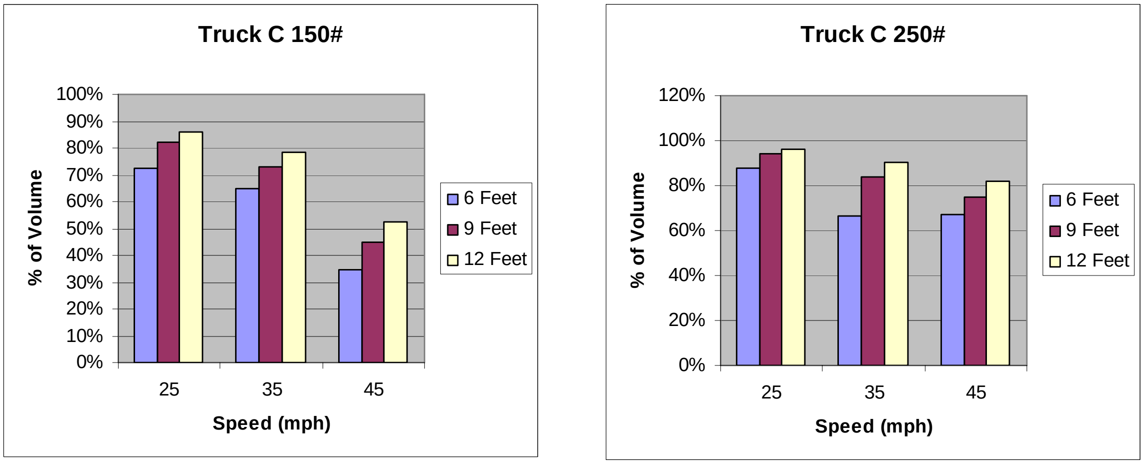

Figure 2.22. Material concentration for Truck C

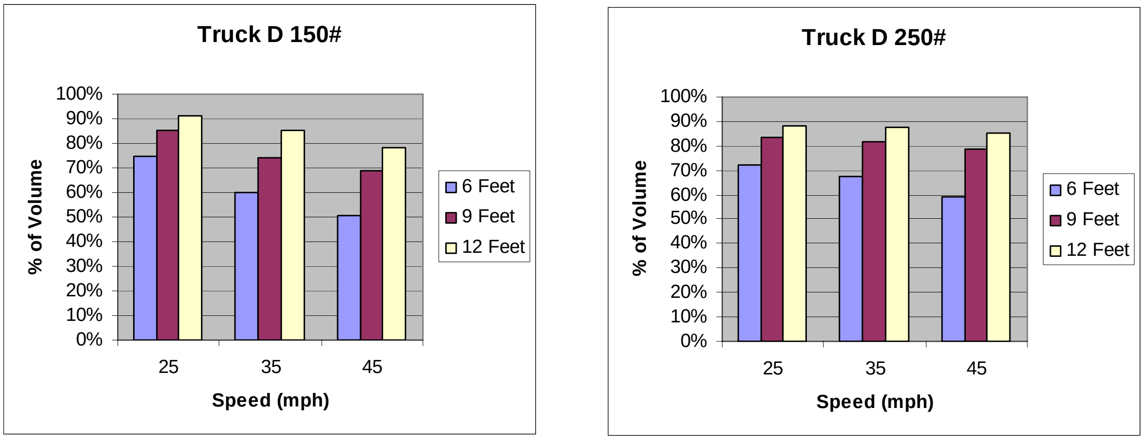

Figure 2.23. Material concentration for Truck D

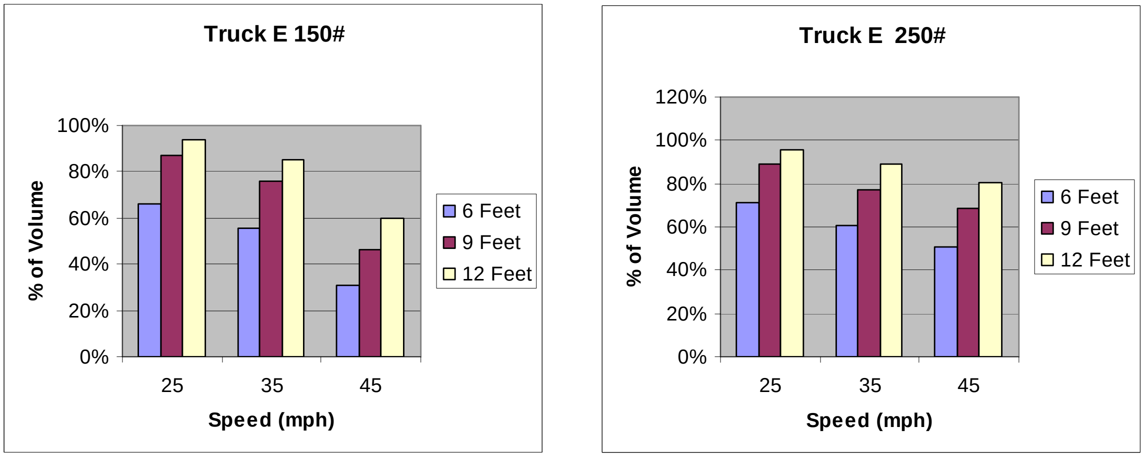

Figure 2.24. Material concentration for Truck E

The general trends from figures 2.20 through 2.24 are that the higher the speed, the less material is maintained in the central area of the highway. The exception to this trend is Truck A at the higher application rate of 250 lbs per lane mile. Additionally, the general trends do not appear to change substantially depending on the width over which the material retention is considered. Thus, the material retained in a six foot width is essentially proportional to that retained in a twelve foot width. Therefore, in any consideration of comparative behavior between the different delivery systems, it is sufficient to consider only one of the three widths.

Figures 2.25 and 2.26 show the five different delivery systems' performance in terms of how much of the total material was retained in the best six foot width.

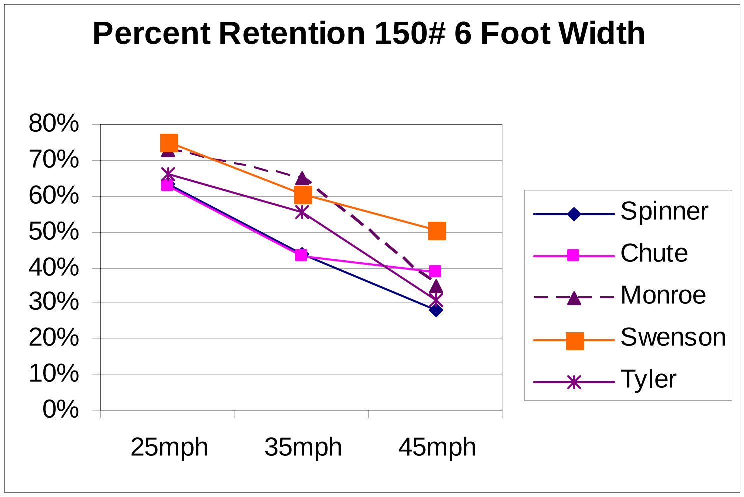

Figure 2.25. Material retained in six foot width for all delivery systems, 150 lbs/LM

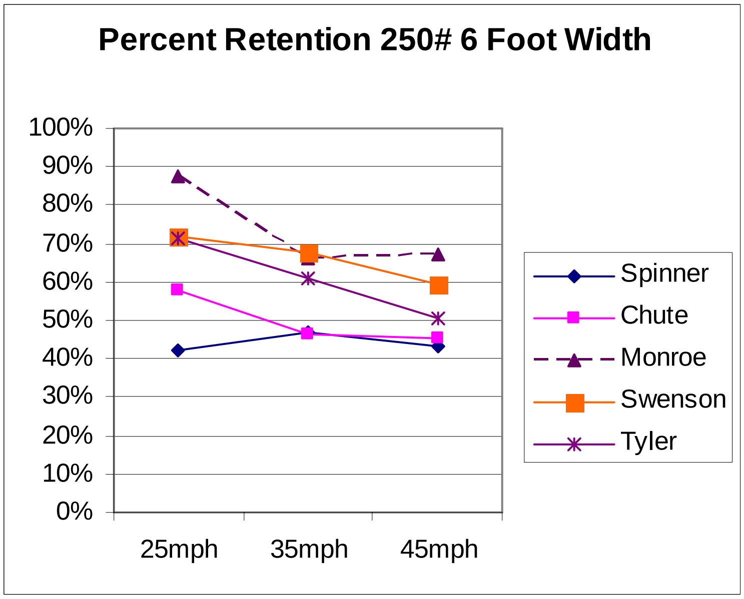

Figure 2.26. Material retained in six foot width for all delivery systems, 250 lbs/LM

From these figures it is apparent that in general the three zero-velocity systems retain more material within a narrow section than the two traditional delivery systems. At the lower application rate, it is clear that the higher the speed of application, the less material is retained within the narrow area, for all five delivery systems. The degree of reduction in retained material is somewhat similar for all five systems, although it appears there is less drop-off with the Swenson system than with the other two zero-velocity spreaders. At the higher application rate, the reduction of retention with increasing speed is less uniform and also smaller. On the basis of these tests, it would appear that using one of the zero-velocity systems tested in this study provides superior performance, in terms of material retention, to the two standard delivery systems tested in this study.

All the data collected by the Iowa DOT during these tests is included, for the sake of completeness, in the Appendix of this report.

2.4. Thermal Methods Used in Abrasive Delivery

A study conducted in Sweden addressed exactly this issue (Hallberg and Henrysson, 1999). In this study, four different applications of materials were made. The most traditional was a sand/salt mixture, which consisted of about sand (0 to 8 mm in diameter) with about 25 kg/m^3 of salt (Sodium Chloride) added to prevent caking. The second traditional material applied was cold aggregate chippings (2 to 5 mm in diameter). In addition, two novel applications were made. One, termed Hottstone®, applied the aggregate chippings (2 to 5 mm in diameter) at high temperature (>180º C), using diesel burners to heat the aggregate just prior to placing it on the road. The second novel method (termed the Friction Maker^{TM}) applied the (0 to 8 mm) sand with hot (90º C) water. The aim of both novel methods was to encourage the sand to stick to the snow or ice covered road surface. All mixtures were applied at rates of 350 kg/lkm per application.

Both novel methods were able to maintain their friction increase for several days. This should be contrasted with the two standard methods, which were not able to provide any lasting friction benefit. As noted by Hallberg and Henrysson (1999): “As early as a couple of hours after having applied conventional methods, there was no longer any friction effect left.” These tests were conducted on a road with AADT of 500.

What the Swedish study shows is that abrasives can be applied in such a way as to provide a lasting friction benefit, but that this requires distinctly non-standard methods.

This method has also been applied with success in Norway. Vaa (2004) reported on the successful use of this approach. More recently (Vaa and Sivertsen, 2008) this method has been tested on one of the major highways in Norway (National Road E6, in the Lillehammer region of Norway) and the results indicated that when use of abrasives was appropriate, the use of this "warm, wet sand" method gave significant friction increases (and enhanced safety) when applied only four times a day. Clearly this method works, but to the author's knowledge, it has not been used in the US or Canada to date.

2.5. Use of Modified Spinner Geometries

The purpose of using a spinner to place material on the road has been to spread the material evenly across the road surface. However, it is far from clear that such a uniform application is desirable. The argument can be made that in certain circumstances it is better to windrow the material into a relatively small strip on the road surface, thus providing a much higher local concentration of material in a limited location on the road surface.

When using chemicals in a de-icing mode, this windrowing has a significant advantage. Specifically, it allows for a high chemical concentration in one location, thus allowing the material applied to melt through the snow or ice cover to the road surface as quickly as possible. Once the material reaches the road surface, it can melt the interface between the road and the snow or ice, spreading out horizontally as it does so. This is an efficient way of applying chemicals in a de-icing mode.

It is less clear whether windrowing abrasives would provide a beneficial effect. One can envisage how this might happen. The high concentration of abrasives in the wheel path on a snow or ice covered roadway would require more time to be dispersed by traffic to the point at which it ceased to be effective in increasing friction. Thus the primary beneficial effect of such a windrow type application of abrasives would be to increase the length of time over which an application of abrasives would provide an increase in friction.

The purpose of the experiments undertaken in this project was to determine whether two different spinner geometries could provide different friction levels when used to apply sand on a snow covered pavement. The two geometries are shown in figures 2.27 and 2.28. The special chute, developed at the Ames DOT garage, is designed to place the abrasive material directly in the wheel path.

Figure 2.27. Sander chute in operation mode

Figure 2.28. Sander chute in by-pass mode

The chute has a “trapdoor” in it. When the trapdoor is closed, the material is deposited in a windrow. When the trapdoor is open, the material drops down onto the spinner and is deposited in a broadcast manner.

3. EXPERIMENTAL PROCEDURES

The method used in this project was to treat a specific section of road (140th Street, West of Highway 1 in Johnson County, shown in Figure 3.1, through to Ely Road) with different methods of abrasive delivery, and then measure the friction on the road, using a deceleration device. The two different methods of abrasive delivery to be tested were described in section 2.5 and can be classified as “windrow” or “broadcast.”

The stretch of road selected for this experiment is about 2.65 miles long. Four locations were selected on the road (shown in figures 3.2 through 3.5) for friction testing.

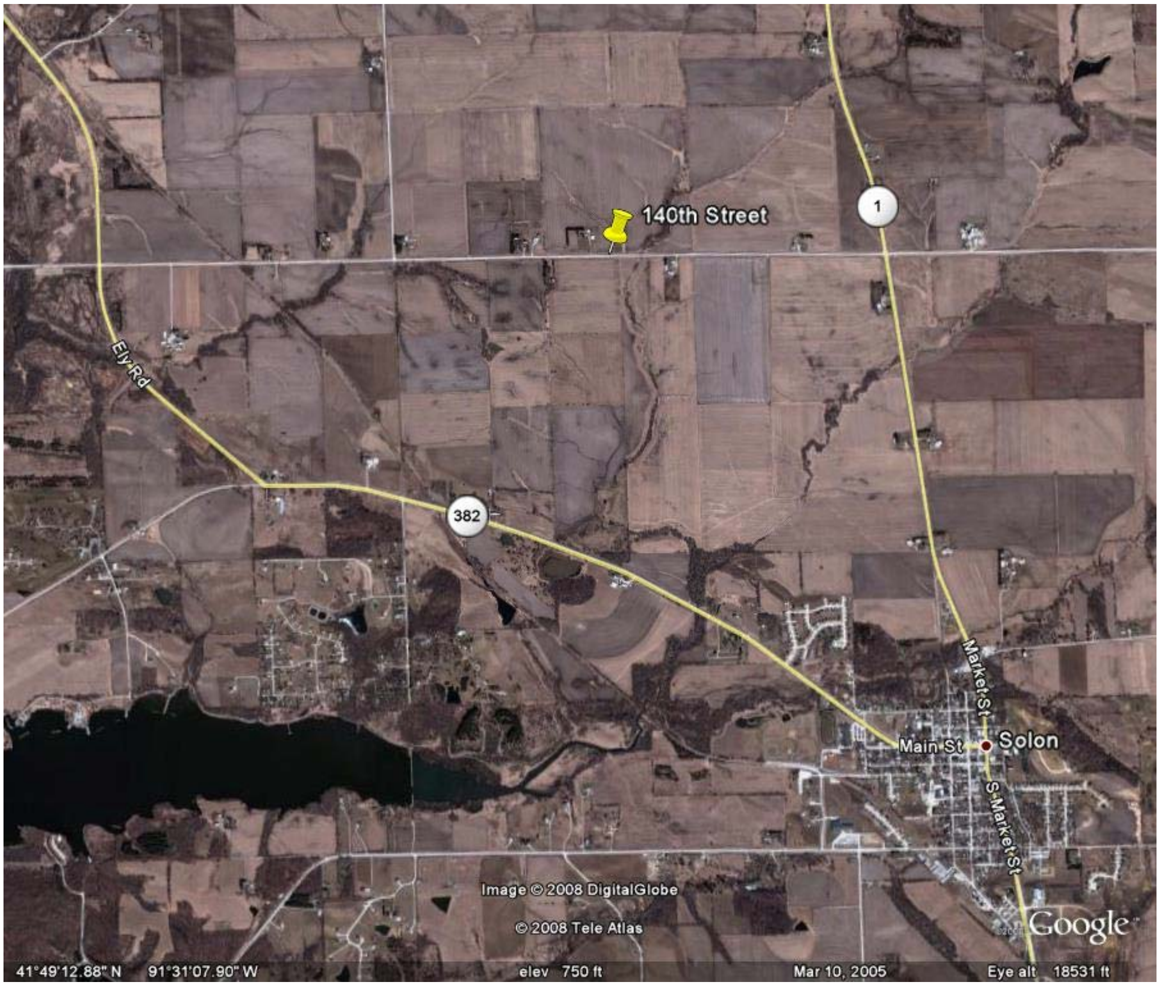

Figure 3.1. 140th Street in Johnson County, west of Highway 1 and north of Solon

Figure 3.2. First test location, about 0.5 miles west of Highway 1

Figure 3.3. Second test location, about 1.0 mile west of Highway 1

Figure 3.4. Third test location, about 1.5 miles west of Highway 1

Figure 3.5. Fourth test location, about 2.0 miles west of Highway 1

Testing was conducted using a friction measuring device (a Coralba meter) mounted in a University of Iowa vehicle (a Chrysler minivan). The Coralba meter worked by measuring the deceleration of the test vehicle. To measure friction effectively, the vehicle had to undergo severe breaking from a speed of 35 mph to zero. Thus, particular care was needed in the testing to ensure that no vehicles were following the test vehicle when friction testing was being conducted. This is one reason for the selection of 140th Street as a test location – it is relatively lightly traveled. AADT in 2006 was 620 and in 2002 was 470[2].

The goal of the measurement process was to obtain a friction measurement after the storm had started but before the plow had treated the road. Then, the plow would come by, using the standard spreader for half the length of 140th street, and the chute variation for the other half. Ideally, the use of chute and standard delivery methods would alternate each time the plow went by (thus, if on the first passage, the chute delivery method was used for the first half of the road, on the second passage the standard delivery method would be used for the first half of the road, and vice-versa). After the plow had treated the road, a second set of friction readings would be taken as soon as was safely possible. Thereafter, friction readings would be taken every 30 minutes, until the next time the plow came round, at which point the process would start again. Initially, the goal had been to take friction readings after a certain number of vehicles had passed over the road, but tracking this proved difficult and it was decided it was unnecessarily complex. It was planned that traffic counts would be conducted simultaneously with the testing, but this proved to be infeasible also.

Thus, for any given storm, a series of passes down the road, from east to west, would be made, with four friction readings being taken on each pass. The time of each pass start was noted, along with the four friction readings. After the storm, information as to which delivery method was used when was collected from the truck operator. These data, along with weather data subsequently collected from National Weather Service sites (see below) constitute the data set for these experiments.

---

[2] AADT data were obtained from the Iowa DOT Transportation Data Files available on the Internet at : http://www.iowadotmaps.com/msp/traffic/aadtpdf.html accessed on 12/11/2008.

4. EXPERIMENTAL RESULTS

Tests were conducted during the 2003-04 winter season. In this chapter, the storms during which testing could be conducted are described first, then the experimental results are presented.

4.1. Weather Conditions in the 2003-04 Winter Season

From a practical viewpoint, the winter season may be considered to run from November through March. Data from the National Climatic Data Center (NCDC) are summarized in table 4.1. Days with snow include those days when only a trace of snow was recorded. Note that February 2004 had 29 days.

Table 4.1. Summary of Weather Data for Winter 2003-04.

Month	Days with Snow	Total Snow Amount	Days with low 32° or below	Days with high 32° or below
November 2003	3	Trace	18	2
December 2003	10	6.9”	28	8
January 2004	8	7.8”	31	20
February 2004	11	9.9”	26	14
March 2004	6	7.8”	19	0

Table 4.1 indicates that snowfall occurred on 38 days during the winter. However, a surprisingly high number of these snowfall events involved only a trace of snow or small amounts of less than 2 inches in depth. Table 4.2 lists those days on which snowfall of 2 inches or more occurred. This quantity was selected because it is a typical level at which plowing is required. Note that the high and low temperatures presented in Table 4.2 are for those days, while high and low temperatures during the storms are discussed in section 4.2 below. The storm on 12.5.03 was marginal on that day, and in fact no data were collected during that storm. For the other four storms listed, data were collected, and are presented in section 4.2 below.

Table 4.2. Snow Storms during the 2003-04 Winter Season

Date	Depth of Snow (inches)	Low Temperature (°F)	High Temperature (°F)
12.5.03	2.0	27	39
1.3-5.04	5.1	-4	39
2.2.04	4.0	20	32
2.5.04	5.2	20	27
3.15-16.04	6.5	26	33

4.2. Test Results

Results are presented for each storm during which readings were taken. The data presented are friction readings expressed as a friction value between 0 and 1. The four sites at which data are collected are identified in Chapter 3 above as sites 1 through 4.

4.2.1. January 3, 2004

This storm began on Saturday, January 3 between 8 and 9 p.m. Light snow continued from then until some time between 1 and 2 a.m. on Sunday January 4. Light snow started falling again at about 6:30 a.m. on Sunday January 4, and continued until about 7 a.m. on Monday January 5, with very little snow falling between 1 a.m. and 5 a.m. on January 5. Temperatures ranged between 25° and 10.9° F, being in the range of 25° to 20° F through until the evening of January 4, at which time the temperature dropped significantly.

Ten runs were completed on Sunday January 4, and data are presented in Table 4.3 below. The times indicated are those on which the test vehicle began to move down 140th Street.

Table 4.3. Friction Data Collected for January 4, 2004 Storm

Time	Location # 1	Location # 2	Location # 3	Location # 4
7:55 a.m. January 4	0.36	0.34	0.34	0.31
8:48 a.m. January 4	0.32	0.31	0.32	0.32
9:44 a.m. January 4	0.29	0.26	0.28	0.29
10:37 a.m. January 4	0.25	0.24	0.28	0.26
11: 35 a.m. January 4	0.26	0.24	0.26	0.25
1:22 p.m. January 4	0.36	0.37	0.34	0.33
2:25 p.m. January 4	0.32	0.31	0.30	0.32
3:28 p.m. January 4	0.29	0.30	0.30	0.28
4:25 p.m. January 4	0.26	0.27	0.26	0.25
5:22 p.m. January 4	0.25	0.23	0.22	0.25

Figure 4.1 shows how the friction varied during this storm.

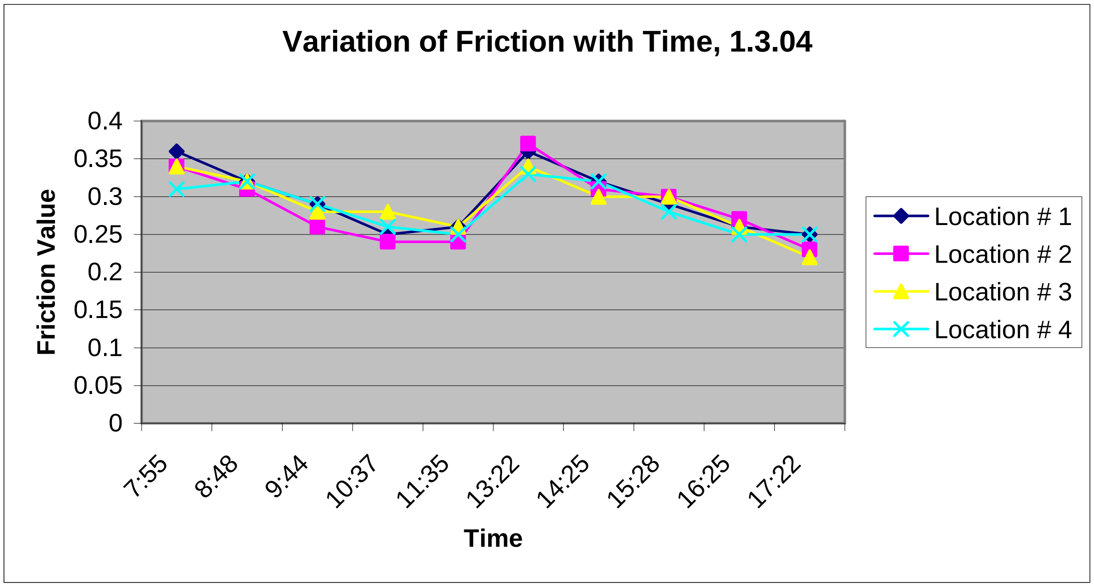

Figure 4.1. Variation of friction with time for storm of 1.3.04

4.2.2. February 2, 2004

This storm began on Monday, February 2 between 2 and 3 a.m. with freezing rain, and temperatures between 30° and 32° F. The rain changed over to snow at about 7 a.m. This snow continued thereafter until about 2 a.m. on Tuesday February 3. For the most part, the precipitation after 7 a.m. on February 2 was characterized as light snow, although there was a period between 1 and 5 p.m. on February 2 when the snow intensified somewhat (corresponding with reports of fog). From 7 a.m. on February 2 through the end of the storm on February 3 temperatures ranged from 31° to 16° F, with the temperature dropping significantly after about 10 p.m. on February 2.

Nine runs were completed on Monday February 2, and data are presented in Table 4.4 below.

Table 4.4. Friction Data Collected for February 2, 2004 Storm

Time	**Location # 1**	**Location # 2**	**Location # 3**	**Location # 4**
8:50 a.m. February 2	0.23	0.22	0.24	0.21
9:48 a.m. February 2	0.21	0.23	0.20	0.22
10:44 a.m. February 2	0.34	0.32	0.33	0.36
11:37 a.m. February 2	0.31	0.30	0.30	0.29
12:45 p.m. February 2	0.32	0.29	0.31	0.27
2:15 p.m. February 2	0.29	0.27	0.28	0.29
3:12 p.m. February 2	0.26	0.25	0.25	0.28
4:10 p.m. February 2	0.24	0.26	0.26	0.25
5:08 p.m. February 2	0.24	0.25	0.26	0.24

Figure 4.2 shows the variation of friction during the course of this storm.

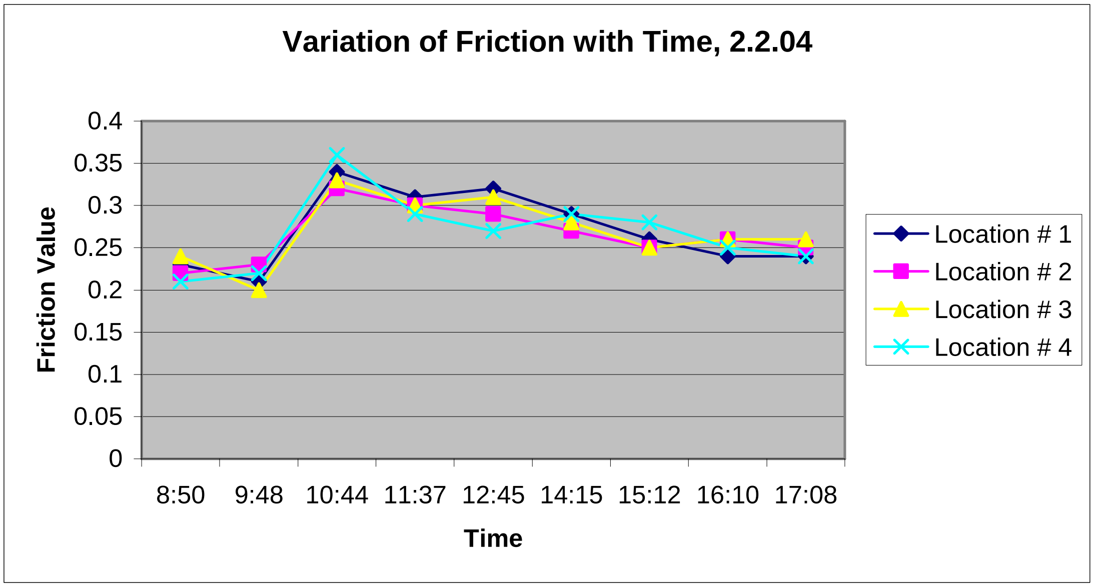

Figure 4.2. Variation of friction with time for storm of 2.2.04

4.2.3. February 5, 2004

This storm began on Thursday February 5 between11 a.m. and Noon. It continued as snow or light snow without interruption through about 2 a.m. on February 6. There was additional light snow from between 5 and 6 p.m. on February 6 through about Noon on February 7, but no friction measurements were made during this second part of the storm. Temperatures during the first part of the storm ranged between 27° and 24° F, while during the second part of the storm (on February 6 and 7) they ranged between 25° and 12° F.

Eight runs were completed during the storm on Thursday February 5. The measurements are shown in Table 4.5.

Table 4.5. Friction Data Collected for February 5, 2004 Storm

Time	Location # 1	Location # 2	Location # 3	Location # 4
1:45 p.m. February 5	0.25	0.27	0.26	0.24
2:43 p.m. February 5	0.24	0.23	0.24	0.26
3:39 p.m. February 5	0.36	0.38	0.39	0.35
4:35 p.m. February 5	0.33	0.34	0.32	0.33
5:32 p.m. February 5	0.31	0.29	0.30	0.29
6:30 p.m. February 5	0.28	0.27	0.29	0.28
7:25 p.m. February 5	0.26	0.25	0.26	0.24
8:20 p.m. February 5	0.25	0.28	0.24	0.27

Figure 4.3 shows how the friction measurements varied during the storm.

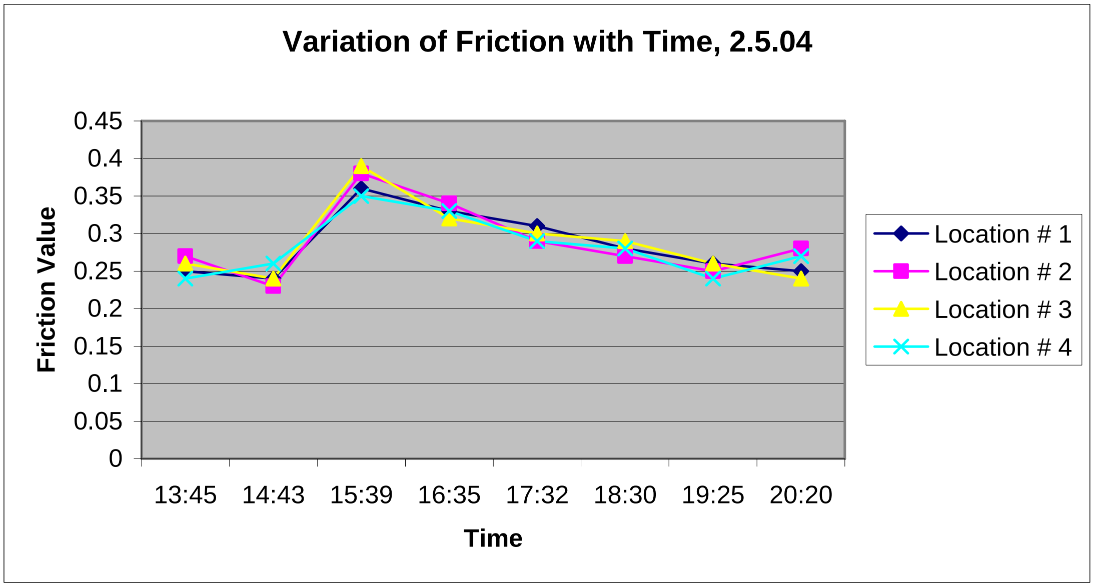

Figure 4.3. Variation of friction with time for storm of 2.5.04

4.2.4. March 15, 2004

The storm on Monday, March 15 began between 10 and 11 a.m., and ended on March 16 at about 5 a.m. For the most part, the snowfall was characterized as light snow, with period s of snow and heavy snow between 11 a.m. and 1 p.m. on March 15. During the storm, temperatures ranged between 32° and 28.4° F. Additional light snow was reported between 9:30 p.m. on March 16 and 2:30 a.m. on March 17.

Seven runs were completed during the storm. The collected data are shown in Table 4.6.

Table 4.6. Friction Data Collected for March 15 2004 Storm.

Time	Location # 1	Location # 2	Location # 3	Location # 4
12.32 p.m. March 15	0.24	0.27	0.22	0.26
1:24 p.m. March 15	0.23	0.23	0.27	0.24
2:17 p.m. March 15	0.31	0.33	0.29	0.34
3:10 p.m. March 15	0.28	0.30	0.29	0.32
4:35 p.m. March 15	0.27	0.31	0.28	0.29
6:45 p.m. March 15	0.24	0.27	0.25	0.27
8:20 p.m. March 15	0.22	0.25	0.26	0.24

Figure 4.4 shows how friction varies during the storm.

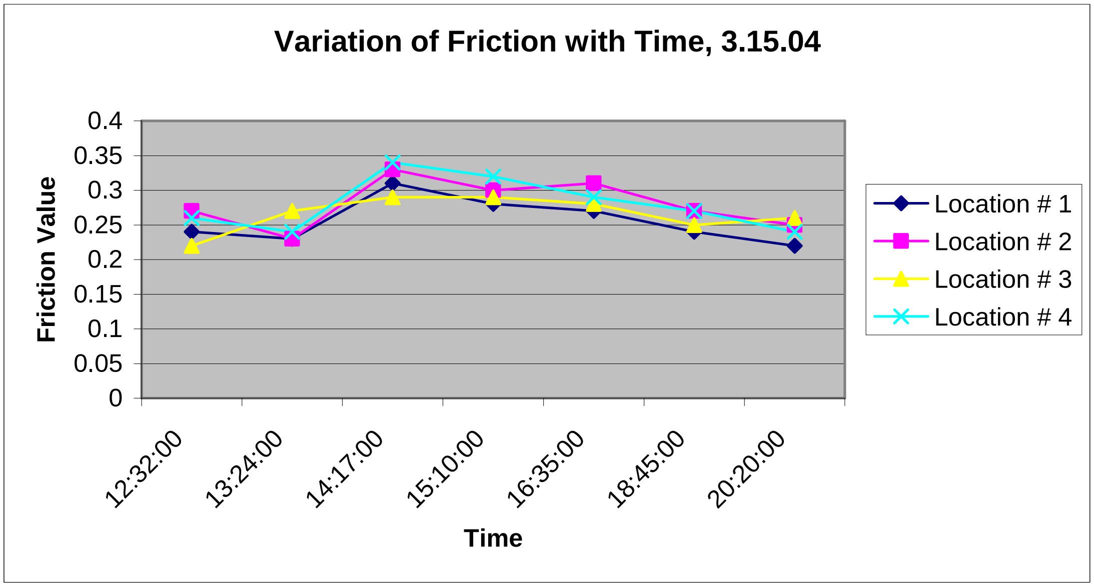

Figure 4.4. Variation of friction with time for storm of 3.15.04

5. DISCUSSION AND RECOMMENDATIONS

5.1. Results from Friction Tests

The data collected during the four storms in the 2003-04 winter season (presented in Chapter 4) were essentially inconclusive insofar as determining whether the spreader or the chute method of material delivery was more effective at creating a higher level of friction on the highway. The passage of the plow truck over the road could be clearly identified from the friction values, and while the truck was not always observed plowing at that time, in all four storms subsequent conversations with the plow operator confirmed that the truck did indeed plow 140th Street between test runs for which friction values increased markedly. It was also confirmed that the truck operator used the standard spreader for the first half of 140th Street and the chute spreader for the second half in all cases.

Examination of the data made clear that there was no significant difference in friction levels between the two locations where materials had been placed with a standard spreader (locations 1 and 2) and with a chute spreader (locations 3 and 4). Thus, for the sort of storms observed, there is no benefit or drawback to using the chute configured spreader versus the standard spreader. This is a somewhat negative result, but it nonetheless shows that either approach can be used for these types of storms with no drawback. Thus on the basis of this study, no recommendation can be made as to whether a chute or standard spreader should be used.

5.2. Recommendations Based on Other Tests

Three other methods of enhancing friction on roads have been discussed in this report: pre-wetting of material, the use of zero-velocity spreaders, and the use of thermal methods when applying the material. For all three methods, there is evidence that the methods can effectively enhance the placement and/or retention of material on the pavement surface.

The thermal methods described in chapter 2 (basically either heating material, or mixing material with near boiling water prior to placing it on the road) have been shown to be effective when used operationally in Scandinavia. However, the use of heating systems on trucks here in the United States present significant safety concerns, and thus, until these safety concerns can be addressed, it is not recommended that these thermal methods be investigated or considered further.

The use of pre-wetting has been shown to be effective at increasing the quantity of material retained on the pavement. It is recommended that, whenever possible, material be placed on the pavement in a pre-wet condition. The best form of pre-wetting appears to be pre-wetting on the truck at rates of 8 gallons per ton. While pre-wetting equipment adds to the expense of a plow truck, this expense can be rapidly recovered by material savings.

The Iowa DOT studies of zero-velocity spreaders showed that such spreaders are more effective than standard application techniques for placing materials upon the highway. However, these systems have not, to the author’s knowledge, been tested “side by side” with pre-wetting systems, so it is unclear whether they perform as well as or better than such systems. It is recommended that such side by side tests be conducted. It can be concluded also that zero-velocity systems are superior to standard delivery systems for material placement.

6. CONCLUSIONS

A series of field experiments have been conducted to determine whether a standard or a chute based delivery system provides better friction when used to deliver abrasives to the road during winter storms. On the basis of these tests, no significant differences can be found between the two systems.

Reviews of other methods of material delivery have been made, together with an extensive report of a series of Iowa DOT tests on zero-velocity spreaders. On the basis of the field testing and the reviews, a number of recommendations with respect to material delivery systems have been made.

REFERENCES

Al Qadi, I. L., Loulizi, A., Flintsch, G. W., Roosevelt, D. S., Decker, R., Wambold, J. C. and Nixon, W. A., “Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility,” Paper No. 04-2751, Proceedings of the 83rd Annual Meeting of the Transportation Research Board, Washington DC January 11-15, 2004.

Borland, S. L. and Blaisdell, G.L., (1993). "Braking Friction on Sanded Ice," Transportation Research Record 1387, pp. 79 - 88.

Comfort, G. and Dinovitzer, A., (1997). "Traction Enhancement Provided by Sand Application on Packed Snow and Bare Ice: Summary Report," Ontario Ministry of Transportation Report no. MAT-97-02.

Gray, D. M., and Male, D. H., (1981). Handbook of Snow: Principles, Processes, Management & Use, Pergamon Press.

Hallberg, S. –E. and Henrysson, G., (1999). "Sanding Tests 1998: Comparison between Conventional Sanding Methods Using Cold Materials and the Friction Maker™ and Hottstone® Hot Material Methods," Technical Report no 2105 of the Swedish National Road Administration (SNRA).

Hossain, M. M., Bajorski, P., and Yang, W.S., (1997). "Frictional Characteristics of Sand and Sand-Deicer Mixtures on Bare Ice," Transportation Research Record 1585, pp. 30 - 38.

Ketcham, S., Minsk, L.D., Blackburn, R., and Fleege, E., “*Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel*,” Report No. FHWA-RD-95-202, Federal Highway Administration, Washington, D.C., June 1996.

H. Lemon (1975). “1974-1975 Prewetted Salt Report,” Methods Unit of the Administrative Services Section of the Maintenance Division, Michigan Department of Transportation.

Minsk, L. D. (1998). Snow and Ice Control Manual for Transportation Facilities, McGraw Hill

Vaa, T. (2004). "Implementation of New Sanding Method in Norway, Transportation Research Circular E-C063," Proceedings of the Sixth International Symposium on Snow Removal and Ice Control Technology, Transportation Research Board of the National Academies, Washington, D.C., pp. 473-486.

Vaa, T. and Sivertsen A., (2008). "Winter Operations in View of Vision Zero, Transportation Research Circular E-C126," Proceedings of the Fourth National Conference of Surface Transportation Weather and the Seventh International Symposium on Snow Removal and Ice Control Technology, Transportation Research Board of the National Academies, Washington, D.C., pp. 16-26.

APPENDIX

This appendix contains the data collected by the Iowa Department of Transportation during their field testing of material delivery systems. The data were collected on November 7, 2002.

Zero Velocity Tests - November 7, 2002 Truck # **A** 7-Nov-02 9:10:00 AM Run 1 2:00 Run 8

Truck "A" Number A 29231 Williams

Zero Velocity Spreader Standard Spreader

Sample Identifier:		
	1st digit	Truck identifier
	2nd digit	Run #
	3rd digit	Test section #

Weight

				Test Sections											
Run #	**Target Speed**	**Actual Speed**	**Appl. Rate**	L Shoulder **9**	Far left PL **7**	Mid PL **5**	Mid Right PL **3**	Right PL **1**		Left DL **2**	Mid Left DL **4**	Mid DL **6**	Far Right DL **8**	R Shoulder **10**	**Total Weight (gm)**
1	25	24.9	150	0	2.1	3.6	5.3	13		15.5	18	6.2	7.4	1.3	72.4
2	35	33.9	150	0.1	4.2	4.7	10.4	15.3		14.2	7.2	5.4	8.2	8.7	78.4
3	45	44.2	150	0	8.2	7.4	5.9	15		15.3	13.1	17.6	14.4	12.5	109.4
4	25	24.7	250	0	3.2	5.1	5.3	13.4		16.7	8	6.1	10	3.4	71.2
5	35	33.9	250	0	1.7	4.3	6	22.9		23	11.4	10.4	9.8	8.8	98.3
6	45	42	250	1.2	1.4	5.6	12.5	14.9		9.3	4.6	4.7	6.1	4.7	65
Re Do															0
8	25	23.9	150	0	0.3	0	1.3	12.5		12.2	5.8	1.8	3.6	1.5	39
9	35	33.4	150	0.1	2.46	1.9	4.1	7.3		7.5	7.2	0.97	1.7	0.9	34.13

Percent

Run #	**Target Speed**	**Actual Speed**	**Appl. Rate**	L Shoulder **9**	Far left PL **7**	Mid PL **5**	Mid Right PL **3**	Right PL **1**		Left DL **2**	Mid Left DL **4**	Mid DL **6**	Right DL **8**	R Shoulder **10**	**Total Weight**
1	25	24.9	150	0%	3%	5%	7%	18%		21%	25%	9%	10%	2%	100%
2	35	33.9	150	0%	5%	6%	13%	20%		18%	9%	7%	10%	11%	100%
3	45	44.2	150	0%	7%	7%	5%	14%		14%	12%	16%	13%	11%	100%
4	25	24.7	250	0%	4%	7%	7%	19%		23%	11%	9%	14%	5%	100%
5	35	33.9	250	0%	2%	4%	6%	23%		23%	12%	11%	10%	9%	100%
6	45	42	250	2%	2%	9%	19%	23%		14%	7%	7%	9%	7%	100%
Re Do For Runs 1 and 2															
8	25	23.9	150	0%	1%	0%	3%	32%		31%	15%	5%	9%	4%	100%
9	35	33.4	150	0%	7%	6%	12%	21%		22%	21%	3%	5%	3%	100%

Zero Velocity Tests - November 7, 2002 Truck # **B** 7-Nov-02 10:25

Truck "B" Number A 29231 Williams

Zero Velocity Spreader Chute

Sample Identifier:		
	1st digit	Truck identifier
	2nd digit	Run #
	3rd digit	Test section #

Weight

				TEST SECTION											
Run #	Target Speed	Actual Speed	Appl. Rate	L Shoulder 9	Far left PL 7	Mid PL 5	Mid Right PL 3	Right PL 1		Left DL 2	Mid Left DL 4	Mid DL 6	Far Right DL 8	R Shoulder 10	Total Weight
1	25	23.9	150	0	1.2	1	1.6	22		22	8.7	4.4	5.7	3.4	70
2	35	33.5	150	0	1.2	3.5	7.7	14.1		10.8	6.5	5.7	5.5	2.7	57.7
3	45	43.5	150	0	1.4	0.4	1.7	7.6		7.8	7.4	10.1	10.6	6.3	53.3
4	25	24.9	250	0	1.2	0.3	0.8	8.9		17.2	11.4	4.7	3.7	1.3	49.5
5	35	33	250	0	0.8	2.4	1.6	14		20.2	18.3	11.1	9.7	4.7	82.8
6	45	42.9	250	0	2	3.8	13.2	22.1		19	13.3	5.2	6	5.8	90.4

Percent

Run #	Target Speed	Actual Speed	Appl. Rate	L Shoulder 9	Far left PL 7	Mid PL 5	Mid Right PL 3	Right PL 1		Left DL 2	Mid Left DL 4	Mid DL 6	Right DL 8	Shoulder DL 10	Total Weight
1	25	23.9	150	0%	2%	1%	2%	31%		31%	12%	6%	8%	5%	100%
2	35	33.5	150	0%	2%	6%	13%	24%		19%	11%	10%	10%	5%	100%
3	45	43.5	150	0%	3%	1%	3%	14%		15%	14%	19%	20%	12%	100%
4	25	24.9	250	0%	2%	1%	2%	18%		35%	23%	9%	7%	3%	100%
5	35	33	250	0%	1%	3%	2%	17%		24%	22%	13%	12%	6%	100%
6	45	42.9	250	0%	2%	4%	15%	24%		21%	15%	6%	7%	6%	100%

Zero Velocity Tests - November 7, 2002 Truck # **C** 7-Nov-02 11:20

Truck "A" Number A28463 Bedford

Zero Velocity Spreader Monroe ZV

Sample Identifier:	1st digit	Truck identifier
	2nd digit	Run #
	3rd digit	Test section #

Weight

				TEST SECTION												
	Target	Actual	Appl.	L Shoulder	Far left PL	Mid PL	Mid Right PL	Right PL		Left DL	Mid Left DL	Mid DL	Far Right DL	R Shoulder	Total
Run #	Speed	Speed	Rate	9	7	5	3	1		2	4	6	8	10	Weight
1	25	25	150	0	0.2	1.7	0.4	12.5		23.5	4.7	2	3.1	1.5	49.6
2	35	34.2	150	0	0.2	0.6	1	8.1		15	2.9	1.9	3.7	2.2	35.6
3	45	45	150	0	0.2	0.4	0.6	7.4		14.1	10.5	5.5	4.7	2.8	46.2
4	25	25.7	250	0	0.1	0.1	0.3	28.8		38.4	5	1.4	1.6	1.1	76.8
5	35	35.2	250	0	0.2	0.2	0.3	18.5		37.6	15	5.1	4.1	3.6	84.6
6	45	43.9	250	0	0.2	0.2	3.1	27.1		32.6	7.1	6.3	5.8	6.8	89.2

Percent

	Target	Actual	Appl.	L Shoulder	Far left PL	Mid PL	Mid Right PL	Right PL		Left DL	Mid Left DL	Mid DL	Right DL	Shoulder DL	Total
Run #	Speed	Speed	Rate	9	7	5	3	1		2	4	6	8	10	Weight
1	25	25	150	0%	0%	3%	1%	25%		47%	9%	4%	6%	3%	100%
2	35	34.2	150	0%	1%	2%	3%	23%		42%	8%	5%	10%	6%	100%
3	45	45	150	0%	0%	1%	1%	16%		31%	23%	12%	10%	6%	100%
4	25	25.7	250	0%	0%	0%	0%	38%		50%	7%	2%	2%	1%	100%
5	35	35.2	250	0%	0%	0%	0%	22%		44%	18%	6%	5%	4%	100%
6	45	43.9	250	0%	0%	0%	3%	30%		37%	8%	7%	7%	8%	100%

Zero Velocity Tests - November 7, 2002 Truck # **D** 7-Nov-02 12:15

Truck "A" Number A30830 Oakdale

Zero Velocity Spreader Swenson ZV

Sample Identifier:	1st digit	Truck identifier
	2nd digit	Run #
	3rd digit	Test section #

Weight

				TEST SECTION											
Run #	**Target** Speed	**Actual** Speed	**Appl.** Rate	L Shoulder	Far left PL	Mid PL	Mid Right PL	Right PL		Left DL	Mid Left DL	Mid DL	Far Right DL	R Shoulder	**Total** Weight
				9	**7**	**5**	**3**	**1**		**2**	**4**	**6**	**8**	**10**	
1	25	25.2	150	0	0.6	0.5	23.6	19.6		6.1	3.5	1.3	1.9	0.7	57.8
2	35	36	150	0	0.2	0.4	0.1	5		17.4	8.4	5.8	3.6	1.9	42.8
3	45	45.6	150	0	0.2	0.9	3.4	11		17.3	12.2	5.2	6.6	1.8	58.6
4	25	25.8	250	0	0.5	0.6	1.9	7.4		38.6	8.8	3.3	3.5	1.2	65.8
5	35	37	250	0.1	0.6	0.7	3.2	22.5		36.6	12	5.5	3.9	2.2	87.3
6	45	45.8	250	0	0.4	0.3	1.4	15.9		32.2	16.8	5.4	5	5.3	82.7

Percent

Run #	**Target** Speed	**Actual** Speed	**Appl.** Rate	L Shoulder	Far left PL	Mid PL	Mid Right PL	Right PL		Left DL	Mid Left DL	Mid DL	Right DL	Shoulder DL	**Total** Weight
				9	**7**	**5**	**3**	**1**		**2**	**4**	**6**	**8**	**10**	
1	25	25	150	0%	1%	1%	41%	34%		11%	6%	2%	3%	1%	100%
2	35	34.2	150	0%	0%	1%	0%	12%		41%	20%	14%	8%	4%	100%
3	45	45	150	0%	0%	2%	6%	19%		30%	21%	9%	11%	3%	100%
4	25	25.7	250	0%	1%	1%	3%	11%		59%	13%	5%	5%	2%	100%
5	35	35.2	250	0%	1%	1%	4%	26%		42%	14%	6%	4%	3%	100%
6	45	43.9	250	0%	0%	0%	2%	19%		39%	20%	7%	6%	6%	100%

Zero Velocity Tests - November 7, 2002 Truck # **E** 7-Nov-02 1:20

Truck "A" Number A28079

Zero Velocity Spreader Tyler

Sample Identifier:		
	1st digit	Truck identifier
	2nd digit	Run #
	3rd digit	Test section #

Weight

				TEST SECTION											
Run #	Target Speed	Actual Speed	Appl. Rate	L Shoulder 9	Far left PL 7	Mid PL 5	Mid Right PL 3	Right PL 1		Left DL 2	Mid Left DL 4	Mid DL 6	Far Right DL 8	R Shoulder 10	Total Weight
1	25	25.2	150	0	0.1	0.1	0.6	14.7		29.3	13.7	4.6	2.4	0.9	66.4
2	35	33.7	150	0	0.2	0	0.5	8.9		14	8.4	3.8	3.6	1.8	41.2
3	45	43	150	0	1.4	0.1	1.5	10.6		12.9	10.9	11.5	10.2	17.2	76.3
4	25	24.3	250	0.1	0.5	0.2	0.5	29.7		77.3	45.3	11.3	4.6	1.9	171.4
5	35	34.2	250	0.1	1.8	0	0.8	26.3		59.2	37.2	18.7	6.8	7.5	158.4
6	45	43.7	250	0	0.2	0	0	9.1		35.3	38	25.7	17.6	19.1	145

Percent

Run #	Target Speed	Actual Speed	Appl. Rate	L Shoulder 9	Far left PL 7	Mid PL 5	Mid Right PL 3	Right PL 1		Left DL 2	Mid Left DL 4	Mid DL 6	Far Right DL 8	R Shoulder 10	Total Weight
1	25	25	150	0%	0%	0%	1%	22%		44%	21%	7%	4%	1%	100%
2	35	34.2	150	0%	0%	0%	1%	22%		34%	20%	9%	9%	4%	100%
3	45	45	150	0%	2%	0%	2%	14%		17%	14%	15%	13%	23%	100%
4	25	25.7	250	0%	0%	0%	0%	17%		45%	26%	7%	3%	1%	100%
5	35	35.2	250	0%	1%	0%	1%	17%		37%	23%	12%	4%	5%	100%
6	45	43.9	250	0%	0%	0%	0%	6%		24%	26%	18%	12%	13%	100%