Multiple-Blade Snowplow Project Final Report

Prepared by

CTC & Associates LLC
Madison, Wisconsin

December 30, 2010

Table of Contents

Executive Summary

For more than 50 years, front-mounted snowplows have followed a fairly standard design—a single rigid cutting edge of steel or carbide that removes snow from the roadway. Led by Iowa DOT, a five-state consortium of Clear Roads member states—Indiana, Iowa, Minnesota, Ohio and Wisconsin—issued a request for proposal in April 2008 to assess interest in the private sector in the development of a prototype snowplow that moves snowplow design beyond the single rigid cutting edge.

The group envisioned a prototype plow that would use a series of blades to attack the varying conditions operators face when fighting winter storms—a flexible cutting edge placed in front that adjusts to the contours of the roadway, a blade that cuts into hardpack and ice (a scarifying blade) and a blade that removes excess liquids and solids the other blades miss (a rubber slush or squeegee blade). The scarifying and squeegee blades would be operated independently—engaged only when needed—and would be expected to leave the roadway cleaner with a single pass.

A competitive evaluation of responses to the RFP led to the selection of four vendors. The table below identifies the vendor/state associations for developing and testing prototypes and the type of multiple-blade plow tested.

State	Vendor	Prototype Multiple-Blade Plow
Indiana	Henke Manufacturing	Flexible cutting edge, scarifier, squeegee
Iowa	Flink Company	Flexible cutting edge, squeegee
Minnesota	Henderson Products Inc.	Flexible cutting edge, squeegee
Ohio	Henke Manufacturing	Flexible cutting edge, scarifier, squeegee
Wisconsin	Monroe Truck Equipment	Flexible cutting edge, scarifier, squeegee, with adjustable moldboard

Three of the four participating vendors—Flink Company, Henderson Products Inc. and Monroe Truck Equipment—chose an off-the-shelf solution for the prototypes' flexible cutting edges (the Flink and Henderson prototypes used the PolarFlex flexible cutting edge; Monroe selected the Active Blade Adapter System). Henke Manufacturing opted to develop its own flexible-edge blade system.

The Project Plan

The project plan called for participating states to test the prototypes over two winters. Three states—Indiana, Iowa and Minnesota—began testing the prototypes during the 2008-2009 winter season. Later deliveries delayed testing in Ohio and Wisconsin until the 2009-2010 winter. Indiana and Ohio DOTs field-tested prototypes on Interstate highways, Iowa DOT and the Brown County (Wisconsin) Highway Department ran the prototype plows on two-lane highways, and Mn/DOT plowed a two-lane city route with its prototype.

Installation

All vendors opted for air rather than hydraulics to operate the multiple blades. While Monroe used air in its retrofit installation, Monroe representatives noted that this decision was made to expedite a cheaper retrofit and was not based on performance. Other participating vendors considered air to be the better choice given the cost-effectiveness of tapping into existing air lines. Participating states noted air's flexibility in applying varying amounts of down pressure to completely clear the roadway or leave some salt brine on the road.

Field Tests

Universally, the states field-testing the prototypes reported interest in the multiple-blade concept, but conveyed differing experiences—and degrees of success—in their testing.

Of the three blade types—flexible-blade cutting edge, squeegee and scarifier—the squeegee blade met with the greatest success in this project's field testing. While Iowa DOT found that the flexible blades conformed to the roadway, lasted longer and allowed for better cleaning of the roadway, other participating states expressed some concern about blade wear and loosened fasteners. All participating states with an opportunity to test it reported positively on use of the squeegee blade. The squeegee was effective in removing the snow and slush the front cutting blade missed, with operators reporting that the squeegee was most effective in warmer weather, when the roadway was wet. The scarifying blade included on the prototypes tested in Indiana, Ohio and Wisconsin received a less enthusiastic response from operators, who conveyed concerns about blade wear and a preference for underbody scrapers in removing hardpack.

What's Next

All four vendors participating in the project currently offer some form of a multiple-blade plow, and all reported interest in the product within the winter maintenance community. Some vendors use flexible blade systems on the multiple-blade plows they currently market, while others are not actively promoting the flexible blade.

Indiana, Iowa, Minnesota and Wisconsin plan continued use of the prototypes during the 2010-2011 winter. While interested in the concept, none of the five participating states plan to purchase additional multiple-blade plows at this time. Cost is an issue, though at least one participant expects costs to come down as more vendors enter the multiple-blade plow market and designs are standardized.

Conclusion

Clear Roads undertook this project to spur interest in the vendor and winter maintenance communities in moving snowplow design beyond the single rigid cutting edge. The multiple-blade plow was conceived as a way for operators to apply the most appropriate blade based on roadway conditions—snowy, slushy, ice-covered or hardpack—to clear the roadway with a single pass, without swapping out blades or plows.

Through the project's limited course of field-testing, participating states discovered that factors such as climactic conditions and the capabilities of existing winter maintenance fleets will affect how a multiple-blade plow is used. For example, states with winter maintenance fleets equipped with underbody scrapers, or areas that are not prone to hardpack, may not have the need for a scarifying blade. Areas with milder temperatures that receive wet, heavy snow will likely make more frequent use of a squeegee blade. As some of the participating states concluded, a two-blade rather than a three-blade solution may be best suited to an agency’s winter maintenance fleet and the winter conditions it faces.

Researching new technologies such as the multiple-blade plow requires time in the field to test the concept and make design modifications that take into account real-world experience with the prototype. This project succeeded in completing those first critical steps in moving a new idea from concept to production. While further testing and modifications are likely, this project brought the multiple-blade plow out of test mode and into general use, with vendors now making multiple-blade plows part of their standard product offerings. The lessons learned from this project’s field testing are expected to influence future snowplow design and encourage others in the winter maintenance community to consider alternatives to the traditional front-mounted single-blade snowplow.

1. Introduction

While there have been advances in snow and ice control practices over the years, generally speaking, the same type of snowplow has been used for the last half-century—a single rigid cutting edge of steel or carbide that removes snow from the roadway. Rigid blades do not conform to the road, and snow and ice that are missed by the blade remain in the traveled portion of the roadway. The remaining snow can affect traffic safety and limit the effectiveness of deicing chemicals.

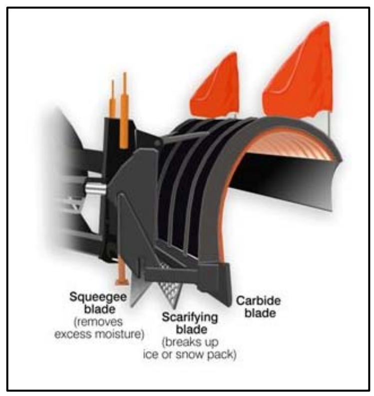
Improving snowplow design was at the heart of a 2006 Clear Roads pooled fund research project to develop a concept highway maintenance vehicle. Clear Roads is an ongoing research program with 20 member states pooling resources to fund practical, usable winter maintenance research.

In April 2006, a Clear Roads project team met to discuss the desired capabilities of a concept snow removal device that improves snow and ice control performance and the feasibility of assembling such a prototype. The group considered both front-mounted, underbody and rear-mounted prototype plows that could be designed to address the goals of the project—clear the roadway in a single pass, reduce snow residue behind the plow, provide an alternative to the rigid cutting blade, and increase plow speed to more closely approximate traffic speed. These discussions laid the groundwork for further consideration of the next generation of snowplows, but actual development of prototypes did not proceed under this project. A report of the minutes from the April 2006 project team meeting is included as Appendix A.

With funding remaining from the Clear Roads concept highway maintenance vehicle project, and the matter of a redesigned plow unresolved, the Clear Roads member states, led by Iowa DOT, moved forward with a follow-on project to encourage investment in the next generation of snowplows. States participating in the field testing included Indiana, Iowa, Minnesota, Ohio and Wisconsin.

Developing the Request for Proposal

The group issued a request for proposal in April 2008 to assess interest in the private sector in the development of a prototype snowplow that moves beyond the single rigid cutting edge. The prototype plow envisioned by the group would use a series of blades to attack the varying conditions operators face when fighting winter storms—a flexible cutting edge placed in front that adjusts to the contours of the roadway, a blade that cuts into hardpack and ice (a scarifying blade) and a blade that remove excess liquids and solids the other blades miss (a rubber slush, or squeegee, blade). The scarifying and squeegee blades would be operated independently—engaged only when needed—and would be expected to leave the roadway cleaner with a single pass.



Participating states envisioned a three-blade solution to tackle a wide range of winter road conditions in a single pass.

Development of the RFP was informed by work conducted by Iowa DOT to develop and test multiple-blade plowing systems. Using sandblasting sand to replicate snow on flat and wheel-rutted roadway surfaces, side-by-side tests pitted four multiple-blade plows with flexible-edge cutting systems and scarifying and squeegee blades against Iowa DOT's standard 11-foot snowplow.

Researchers found:

- On a flat surface, the multiple-blade test plows showed a 68 percent improvement in removing material from the roadway over the standard snowplow.
- The multiple-blade test plows performed even better on a wheel-rutted surface, with a 70 percent to 92 percent improvement in performance over the standard snowplow.

See Appendix B for the report describing results of Iowa DOT's field tests of multiple-blade plowing systems.

Participating states recognized that designing an underbody multiple-blade plow would require an entirely new plow designed around axles to address clearance problems. Participants favored a front-mounted option to encourage development of new plowing systems without requiring a substantial investment in research and development. The RFP included 14 performance specifications to guide vendors in developing front-mounted prototypes that would test the concept of a multiple-blade plow:

- Remove snow at high speed to reduce speed differential
- Remove as much snow and ice as possible with each pass
- Conform to the road surface
- Keep snow off the front of the truck and windshield
- Put snow where you want it
- Plow must be as light as possible, but still effective at removing snow and ice
- Able to remove all types of winter precipitation efficiently
- Minimal maintenance
- Attach and detach easily
- Use minimal truck resources (hydraulic/air systems)
- Minimize plow cost
- Reduce vibration
- Reduce noise in cab
- Option to attach other blades

Selecting the Vendors

A competitive evaluation used a 100-point scale to score vendor proposals on the following:

- Creativity—Ability to remove snow, slush and ice.
- Durability—Materials used in construction and weight of overall plow.
- Options for different types of blades and how they are attached.
- Ease of blade installation and overall maintenance.
- Cost of the prototype plow (not including research and development costs).

After review and evaluation of the five proposals received in response to the RFP, participating states selected four vendors to participate in the project:

- Flink Company
- Henderson Products Inc.
- Henke Manufacturing
- Monroe Truck Equipment

Vendors were asked to develop and deliver prototypes that could be tested by participating states during the 2008-2009 winter.

2. Overview of the Technology Tested

All prototypes developed by participating vendors included a flexible cutting edge and at least one additional blade—a slush or squeegee blade. Two vendor prototypes also included scarifying blades.

2.1 Flexible Cutting Edges

Rather than the continuous single blade mounted on a traditional front-mounted snowplow, a flexible cutting edge uses a segmented blade system that mounts individual blades to the plow. Vendors marketing segmented blade systems cite such benefits as allowing the cutting edge to conform to the surface of the road, thereby allowing for better cleaning of the roadway, and reduced vibration and chatter than can lead to longer blade life, less plow maintenance and reduced operator fatigue.

Three of the four participating vendors—Flink Company, Henderson Products Inc. and Monroe Truck Equipment—used an off-the-shelf solution for the prototypes' flexible cutting edges. Henke Manufacturing opted to develop its own flexible-edge blade system.

Flink Company's two-blade prototype included a PolarFlex flexible cutting edge and a rubber squeegee blade.

The Flink and Henderson prototypes used the PolarFlex flexible cutting edge from Valley Blades Limited (see http://www.valleyblades.com/products/pdf/polarflex_10208.pdf). The PolarFlex mounts individual 12-inch carbide-tipped steel segments using a patented system of reusable synthetic rubber flexible elements. Monroe Truck Equipment opted for the Active Blade Adapter System, a segmented blade system Valley Blades Limited marketed prior to the PolarFlex. The ABAS system uses rubber-mounted active adapters and three- and four-foot carbide blades that move independently.

Henke's custom-built flexible cutting blade is composed of four two-foot and one three-foot blade sections, for a front cutting blade of 11 feet. The system, built into the bottom of the moldboard, incorporates steel holders to which the blades are bolted and rubber cushions to absorb the shock load. (The moldboard is the angled plate at the front of a snowplow designed to push aside snow.)

The protoype developed by Henderson Products Inc. included two blades: a PolarFlex cutting blade and rubber squeegee blade.

2.2 Scarifying Blade

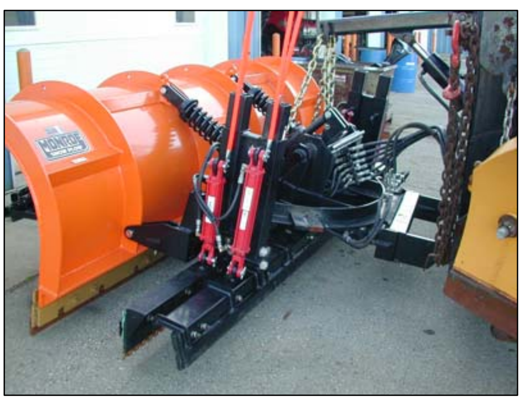
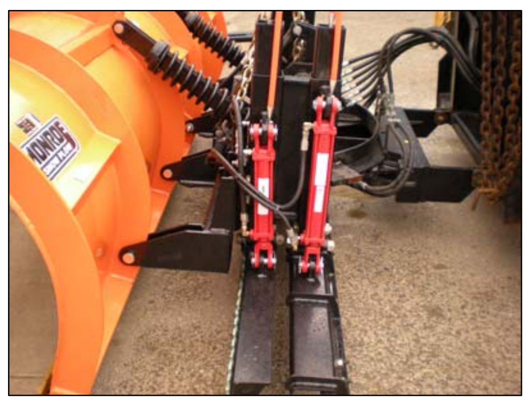
A scarifying blade is used to scrape and loosen hard-packed snow left by the traditional cutting blade. Scarifying blades cut grooves into an even surface of compacted snow and ice and allow salt and sand to take hold, helping to accelerate the deicing process. Some have touted the scarifying blade as a replacement for the underbody scrapers used in many winter maintenance fleets. An underbody scraper is a blade apparatus mounted to the undercarriage of a truck between the front and rear axles.

Both vendors providing a scarifying blade in their prototypes—Henke and Monroe—used the Olofsfors P300 blade (see http://www.olofsfors.se/default.aspx?id=3077&refid=&ptid=4750). The Olofsfors blade is marketed as self-sharpening and less damaging to the road surface than cemented carbide-tipped blades.


The Henke Manufacturing prototype featured a custom-built flexible cutting edge, an Olofsfors scarifying blade and a squeegee blade.

2.3 Rubber Slush or Squeegee Blade

All four vendor prototypes included a slush or squeegee blade. Able to better follow the contours of the road than the traditional rigid cutting blade, squeegee blades are designed to remove from the roadway the excess liquids and snow left behind by the front cutting edge. Less snow and/or liquids on the roadway means less deicing material is needed and operators can more quickly return roadways to normal driving conditions.

Three blades are used on Monroe Truck Equipment's prototype: the ABAS flexible blade system, an Olofsfors scarifying blade and a squeegee blade.

2.4 Other Special Features

The prototype provided by Monroe included a feature not found on the other prototypes—a rotating moldboard. The rotating moldboard allows for differences in the attack angle of the cutting blade, which can be helpful in peeling up hardpack. Adjustments are available up to 25 to 30 degrees that move the cutting blade left and right and forward and back. The operator hydraulically activates the cutting edge attack angle by tilting the moldboard. While Monroe is not the first vendor to offer the tilting moldboard, it was the only vendor to apply this functionality to the prototypes developed for this project.

2.5 Matching Vendors with Participating States

The table below identifies the vendor/state associations for developing and testing prototypes and the type of multiple-blade plow tested.

State	Vendor	Prototype Multiple-Blade Plow
Indiana	Henke Manufacturing	Flexible cutting edge, scarifier, squeegee
Iowa	Flink Company	Flexible cutting edge, squeegee
Minnesota	Henderson Products Inc.	Flexible cutting edge, squeegee
Ohio	Henke Manufacturing	Flexible cutting edge, scarifier, squeegee
Wisconsin	Monroe Truck Equipment	Flexible cutting edge, scarifier, squeegee, with adjustable moldboard

Contact information for representatives from the states and vendors participating in this project appears in Appendix C.

2.6 Costs

Costs for purchase of each prototype and vendor research and development are summarized in the table below. Additional costs were incurred for spare blades and additional parts.

Vendor	Plow Cost	R&D Cost	Total Cost
Flink	$15,990	$6,250	$22,240
Henderson	$15,307	$8,000	$23,307
Henke (Indiana)	$8,950	$5,000	$13,950
Henke (Ohio)	$8,950	$5,000	$13,950
Monroe	$22,711	$5,000	$27,211

3. Field Tests

3.1 Background

The project plan called for participating states to test the prototypes over two winters. Three states—Indiana, Iowa and Minnesota—began testing the prototypes during the 2008-2009 winter season. Later deliveries delayed testing in Ohio and Wisconsin until the 2009-2010 winter.

Each state was provided with cameras and mobile recorders to obtain video footage of the prototype plows operating in actual winter storm conditions. The system included four color cameras that could be mounted in various locations on the plow and vehicle. The cameras were equipped with an internal microphone and were capable of reversing the image when mounted on the rear of the vehicle.

Also included in the system was a color monitor for mounting on the dash of the cab with the capability to display views from the four cameras at once or an individual camera. A mobile digital video recorder mounted in the truck created video files in common formats that could be downloaded and displayed on a laptop computer with no additional software requirements.

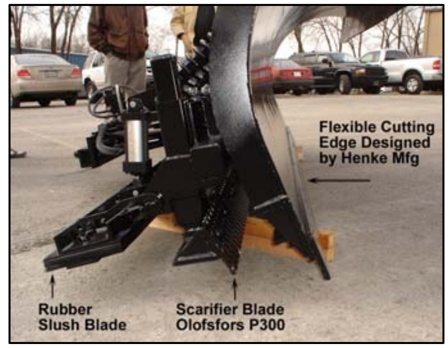
See the Clear Roads Web site (http://www.clearroads.org/multiple-blade-plow-prototypes.html) for videos of the prototype plows in action in Indiana, Minnesota and Wisconsin.

In the sections below we provide a summary of field tests conducted by participating states, presenting information in the following categories:

- Plow/blade configuration and installation
- Evaluation
- Future plans
- Vendor perspective

3.2 Indiana

Indiana was one of two participating states that tested the Henke Manufacturing prototype plow (Ohio DOT tested the same Henke prototype). The plow was tested over the 2008-2009 and 2009-2010 winter seasons on Interstate 65 in INDOT's Amity unit in southcentral Indiana.



3.2.1 Plow/Blade Configuration and Installation

The Henke prototype included three blades:

- Flexible front blade designed by Henke
- Olofsfors P300 scarifier blade
- Rubber slush, or squeegee, blade

The prototype plow was mounted to a 2007 International multipurpose dump truck. Approximate total weight of the prototype plow is 2,750 lbs.

The custom-designed flexible front blade had five independently moving sections—four two-foot and one three-foot blade sections—that made up an 11-foot flexible cutting blade. Using a full moldboard trip, Henke's flexible-edge system was built into the bottom of an 11-foot steel moldboard approximately 41 inches tall, with a steel integral shield and rubber flap to prevent blowback of snow. The plow included steel holders to which the blades are bolted and rubber cushions to absorb shock load. An extended moldboard curl was designed to keep snow off the front of the truck.

The scarifying and squeegee blades could be operated with hydraulic or air cylinders. For the Indiana DOT prototype, two air circuits were used to operate the additional blades—one to control the squeegee blade, and one to control the scarifying blade. No additional capacity was required for the truck's air system to operate the added air cylinders.

3.2.2 Evaluation

Operators' experience with the prototype was mixed. The most positive feedback was associated with the squeegee blade. Use of the squeegee was so well received that operators reported a preference to outfit all existing plows with such a blade.

Operators also reported the following:

- The bolts used to mount the segmented blades to the steel moldboard came loose, prompting repairs to the angle iron or installation of new brackets.
- Only one of the six operators using the prototype liked the separate controls used to operate the three blades. Most operators preferred simplicity and did not like having to independently raise and lower the blades.

- With the weight of the multiple blades, installation of the prototype was difficult in cold weather, and air lines had to warm up before use.
- The scarifying blade wore more quickly than expected.

INDOT added another multiple-blade plow to its winter maintenance fleet at the time the Henke prototype was being tested. Unlike the prototypes developed for this project, which required the operator to engage the blades when needed, all three blades on INDOT's commercially available plow touched the ground at the same time with the same amount of down pressure. The scarifying blade was mounted in front of the main cutting blade; behind the main cutting blade is the squeegee. The plow used standard blades and changed pitch to keep the truck from becoming covered in debris or snow.

3.2.3 Future Plans

The Henke prototype will be back in operation in INDOT's Amity unit during the 2010-2011 winter season. INDOT has no formal plans to purchase additional multiple-blade plows, though winter maintenance managers remain interested in proven strategies for safe and more effective clearing of winter roadways.

3.2.4 Vendor Perspective

Henke representatives noted that the multiple-blade plow allows for more material to be removed from the roadway in a single pass.

The flexible blade system can be more effective than the standard cutting blade in getting down into crevices and adapting to road conditions, and the scarifying blade is effective in removing hard-packed ice. With an effective front-mounted scarifying blade, winter maintenance managers can remove underbody scrapers for long-term savings. The squeegee blade works well in certain situations to remove the material left behind by the front cutting blade, clearing moisture off the road and preventing the roadway from refreezing. Operators have reported that more snow and slush removed from the roadway means less salt is needed to clear the roadway.

The flexible-edge system developed for this project was strictly a prototype, and Henke has no plans to develop that portion of its multiple-blade plow for production use. Henke uses standard PolarFlex blades as the front blade system on the multiple-blade plows the company is currently selling nationally and in North America. Henke reports that several cities, counties and states are interested in the idea of a multiple-blade plow, and a number have begun using the plow with positive results.

3.3 Iowa

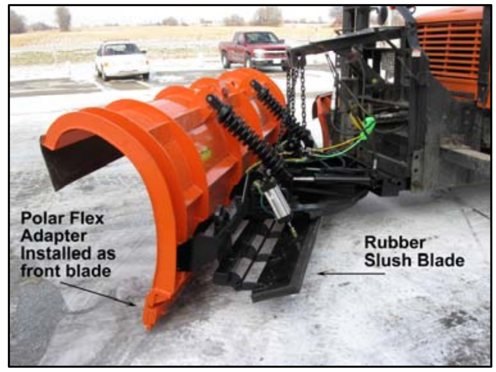
Iowa DOT used the Flink Company prototype for every winter storm over the 2008-2009 and 2009-2010 winter seasons. The plow was used on U.S. Highway 65—a rough two-lane highway in northcentral Iowa—during the two test winter seasons (U.S. 65 was rebuilt after the testing period concluded). The prototype is now used on Interstate 35, also in northcentral Iowa.

3.3.1 Plow/Blade Configuration and Installation

The Flink prototype included two blades:

- PolarFlex flexible-edge cutting blade
- Rubber slush, or squeegee, blade

A scarifying blade was fabricated by Flink but not tested.

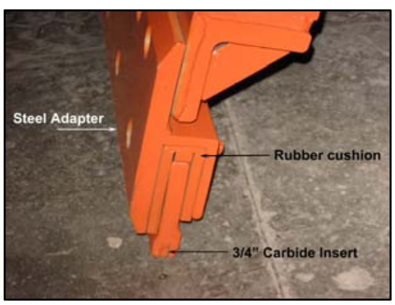


The prototype plow was mounted to a 2001 International 4900 tandem truck. Approximate total weight of the prototype plow was 2,600 to 2,700 lbs.

Flink designed the prototype with a six-hinge-point push table and blades bolted to the moldboard. The PolarFlex cutting blade had 11 one-foot sections encased in rubber. When mounted, the sections move independently of one another. Behind the cutting edge was the squeegee, which pivoted up and down and was controlled by an air cylinder.

Air lines were run to the front of the truck to control the squeegee, and Iowa DOT installed electronic switches and relay valves. Consideration was given to how high to mount the plow and placement of the holes to attach it.

3.3.2 Evaluation



With the prototype in use during every winter storm during the two-year testing period, Iowa DOT had ample opportunity to test the plow and reported positive results. Operators found that the one-foot blade sections conformed to the road and cleaned wheel tracks. The flexible cutting blade was a little more expensive than a traditional cutting blade, but Iowa DOT found that it lasted twice as long. Blades mounted in rubber were very quiet and produced little vibration, which increased the life of the truck and plow components.

Use of the squeegee blade was dependent on conditions, and Iowa DOT used it most often during cleanup operations. Iowa DOT estimated that the squeegee was engaged 20 percent of the time the prototype plow was in operation.

Operators reported optimal use of the squeegee blade when the roadway was too wet and the front cutting blade could not clear the snow and slush from the roadway. The cameras proved to be helpful in showing the operator how much the squeegee cleared of the snow and slush the cutting blade missed. The squeegee worked well when it was just warm enough for wheel tracks to form in the roadway. In general, operators reported that the squeegee blade cleared the road better than the single cutting blade, requiring less deicer to achieve bare pavement. The squeegee blade was not as effective in colder temperatures, when the cutting edge removed most of the snow from the roadway.

3.3.3 Future Plans

Iowa DOT reports no immediate plans to purchase additional multiple-blade plows, but is very interested in still pursuing the concept. Multiple-blade plows are more expensive than the typical single-blade plow, though Iowa DOT expects costs to come down as more manufacturers develop and standardize multiple-blade options to meet the needs of a yet-to-be-tapped market. Iowa DOT has purchased 12 slush blade kits for mounting on existing snowplows that will be tested during the 2010-2011 winter season.

3.3.4 Vendor Perspective

For Flink, the biggest challenge in developing the prototype was making sure that the multiple blades could operate in an enclosed space, and ensuring that parts of the plow did not interfere with the front of the truck.

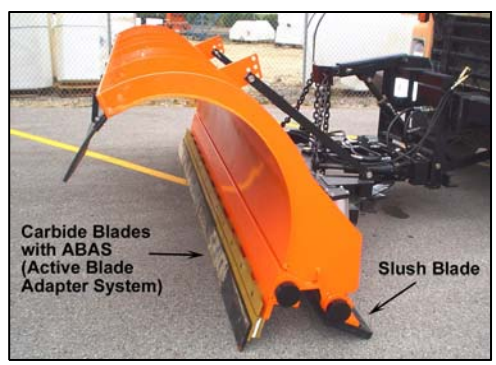
Air rather than hydraulics were used to operate Flink's multiple blades. With air, the operator could adjust the pressure setting, modifying the down pressure coming from the cylinder holding the blade on the pavement surface. This adjustment is harder to make with hydraulics. Flink representatives commented that a retrofit was made easier by tapping into air lines already present on the truck, which has air compressors for air brakes and air suspension.

The multiple-blade plow costs more, but users have been pleased with performance. Flink reports greater interest in a two-blade (main cutting blade plus squeegee blade) rather than a three-blade system (main cutting blade plus scarifying and squeegee blades). Users of the Flink squeegee blade have reported 30 percent to 40 percent better clearing of pavement when activating the squeegee blade after the main cutting blade, with minimal wear to the blade.

Flink is marketing its prototype and reports a recent purchase by a municipality in Indiana. Retrofit packages for the squeegee blade have been sold to Iowa and Illinois DOTs, and interest has been expressed by Illinois municipalities. Flink has also sold multiple versions of the flexible carbide blade system.

3.4 Minnesota

Henderson Products Inc. provided the Mn/DOT prototype. Operators used the prototype during the 2008-2009 and 2009-2010 winter seasons on a city route in St. Cloud with two traffic lanes and up to two turn lanes. St. Cloud is in central Minnesota.



3.4.1 Plow/Blade Configuration and Installation

The Henderson prototype included two blades:

- Flexible front cutting blade (originally the ABAS; transitioned to PolarFlex)
- Rubber slush, or squeegee, blade

The prototype plow was mounted to a 2004 Sterling single-axle truck. The squeegee blade added approximately 450 lbs. to the prototype, bringing the total weight of the prototype plow to approximately 2,600 lbs. Since development of the prototype for the Clear Roads field test, Henderson has constructed other versions of a multiple-blade plow that weigh considerably less.

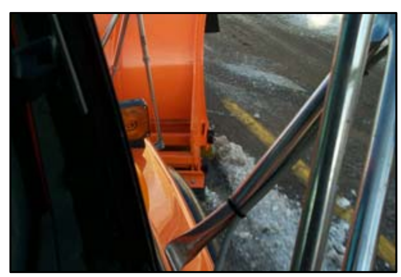
With both the ABAS and PolarFlex flexible-blade systems, blades were bolted to the Henderson prototype's moldboard and mounted on a reversible plow, which shifted the cutting edge to the left or right. Added curl to the shape of the moldboard improved driver visibility, directing snow back down to the road.

The front blade was a fixed, though flexible, "peeling" blade. A second rubber-edged, retractable blade was mounted to the moldboard—not the push frame—and was operated with air by a simple control that allowed the operator to move the blade up or down with adjustable pressure from the driver's seat. The rubber slush, or squeegee, blade was placed behind the cutting blade in a dragging orientation, angled backward.

Henderson's plow system used air from the truck to operate the additional blade, eliminating the need to add a hydraulic circuit to the valve body of the truck. Controls for the squeegee blade were included with the plow. The operator uncoupled two additional hoses for the air lines operating the squeegee blade when removing the plow from the truck.

3.4.2 Evaluation

Preliminary tests in a parking lot showed that the plow could follow uneven contours, and the squeegee cleaned the area down to the blacktop, leaving the pavement in wet condition with no snow residue. While the prototype has showed promise in Mn/DOT testing, maintenance staff encountered a series of obstacles in getting—and keeping—the plow in the field.



Clearing snow in a St. Cloud, Minn., parking lot.

With the initial installation, operators found that the standard lift arm could not lift the plow off the ground. Henderson built a new plow frame and lightened the plow, but the plow could still not be lifted high enough in the angled position to get it off the ground. A Mn/DOT modification lengthened the lift arm so that the plow could be lifted high enough for use, but this modification blocked the truck's headlights. A new push frame built by the vendor changed the push points to address the lifting problem.

Operators found that using the plow on a city route caused significant wear to the squeegee blade. Turning the cutting blade at an angle exposed the secondary squeegee blade, which wore down from repeated contact with the curb; this required rebuilding of the squeegee blade and mountings. When the plow was used again after the rebuild, operators found that the plow chattered and hopped so much that the cutting edge fasteners came loose and maintenance staff could not keep them sufficiently tight.

In an effort to reduce or eliminate the chatter, the three- and four-foot sections of the ABAS flexible cutting edge were swapped out with the PolarFlex's 11 one-foot sections. Unlike the rubber bonded to steel in the ABAS system, the PolarFlex system uses a bolt-through approach.

Changing to the PolarFlex flexible cutting edge resolved the loosened fastener problem, but the plow then bounced in the air—sometimes up to one to two feet. Operators could not identify a single cause for the bouncing, and stopping the plow was the only way to stop the bouncing. Henderson redesigned a more compact push frame to allow for improved lifting, which should return the plow's cutting edge to an angle that eliminates bounce. Mn/DOT has not yet installed the new push frame, though hopes to have the revamped prototype in operation during the 2010-2011 winter season.

When the prototype was in use, operators found that it cleaned uneven surfaces well, cleaned slushy surfaces, and did a good job of drying out the road. The air-operated squeegee offered the benefit of adjustable air pressure, allowing the operator to lower the pressure to leave a little salt brine on the road, or turn up the pressure for more cleaning.

Mn/DOT's operators recognized the multiple-blade plow's potential, but noted that the prototype they tested was not quite ready to be an off-the-shelf offering. Additional refinement is needed, particularly with a modified push frame. Mn/DOT reported a good working relationship with the vendor, though suggested that having the vendor on-site to examine Mn/DOT's equipment and operating environment earlier in the process might have reduced the number of Mn/DOT shop labor hours—estimated at between 200 and 300—needed for sustained operation of the prototype in the field.

3.4.3 Future Plans

Mn/DOT hopes that staff time will be available to install the revamped prototype, with the new push frame designed by Henderson, for use during the 2010-2011 winter season. Independent testing of the prototype can then continue to assess the plow's performance in Mn/DOT's operating environment.

3.4.4 Vendor Perspective

The front cutting edge in the Henderson prototype was designed to remove solids; the trailing squeegee blade would remove solids and liquids the cutting edge misses; and a third blade—a scarifier not provided on the Henderson prototype—would remove ice. The multiple blades were designed to remove more snow, slush and ice in a single pass, thereby reducing the amount of salt needed to clear roadways.

Use of the squeegee blade was seen as a way to reduce the cost of snow and ice control by limiting salt use and improving placement of material so that more stays on the road, where it is needed. A Henderson representative reported that the squeegee application was more common and often viewed as more necessary than a scarifying blade. Many states, including Minnesota, have trucks with an underbody scraper blade to break up ice and hardpack. In those states where underbody scrapers are uncommon, operators can easily swap out blades, removing the squeegee blade and installing the scarifier as conditions warrant.

Henderson noted several benefits of the multiple-blade plow, including:

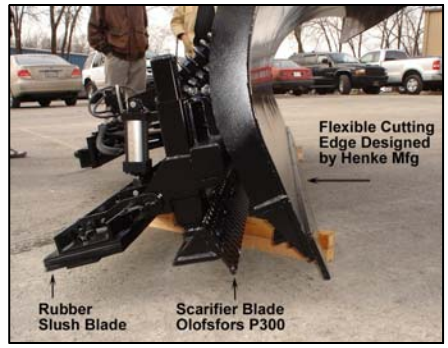
- Using only the steel cutting edge can leave solids and liquids that cars pack down and plows have to remove. With the squeegee blade, operators can get the road to a dry condition without the use of salt or other traction agents.
- Within an hour of using the squeegee blade, which has removed liquid from the road, the road is dry.
- Flexible cutting edges that are rubber-isolated, like the PolarFlex, can more closely follow the contour of the road, leaving less material for the slush blade to remove. Rubber isolation reduces wear, and maintenance staff report getting two seasons out of one set of carbide cutting edges.
- Other benefits of the flexible blade:
    - Reduces operator fatigue. Vibration from traditional steel blades is reflected in the steering wheel and can be jarring to the operator.
    - Eliminates noise.
    - Easier on the truck by not sending shock loads back to the truck.

The Mn/DOT prototype was the first multiple-blade plow built by Henderson; today the vendor offers a variety of multiple-blade plows. To date, Henderson has only built models with two blades (cutting edge and squeegee), though three-blade options (cutting edge, scarifier and squeegee) have been quoted. The Henderson design can be retrofitted to some existing plows depending upon the construction of the plow. After marketing the plows for a couple of years, Henderson reported that the multiple-blade concept is popular, particularly in eastern states, and feedback is positive.

3.5 Ohio

Ohio is the second of two states that tested the Henke Manufacturing prototype plow (Indiana DOT tested the same Henke prototype). The plow was tested during the 2009-2010 winter season on Interstate 30, running east/west near Canton, Ohio, with annual average daily traffic of 50,000 vehicles and 15 to 20 bridges.

3.5.1 Plow/Blade Configuration and Installation



The Henke prototype included three blades:

- Flexible front blade designed by Henke
- Olofsfors P300 scarifier blade
- Rubber slush, or squeegee, blade

The prototype plow was installed on a 10-ton tandem truck with a hopper unit. Approximate total weight of the prototype plow was 2,750 lbs.

The custom-designed flexible front blade had five independently moving sections—four two-foot and one three-foot blade sections—that made up an 11-foot flexible cutting blade. Using a full moldboard trip, Henke's flexible-edge system was built into the bottom of an 11-foot steel moldboard approximately 41 inches tall, with a steel integral shield and rubber flap to prevent blowback of snow. The plow included steel holders to which the blades were bolted and rubber cushions to absorb shock load. An extended moldboard curl was designed to keep snow off the front of the truck.

The scarifying and squeegee blades could be operated with hydraulic or air cylinders. For the Ohio DOT prototype, two air circuits were used to operate the additional blades—one to control the squeegee blade, and one to control the scarifying blade. No additional capacity was required for the truck's air system to operate the added air cylinders.

3.5.2 Evaluation

Ohio DOT's opportunity to test the prototype was more limited than other participating states. A later delivery meant that the plow was only tested during the second of the two winter test periods. Once the plow was in operation, breakdowns further limited the scope of the field test.

Operators ran the prototype as they would any plow in Ohio DOT's winter maintenance fleet, slowing down but not stopping for bridges. In its second use, the prototype hit a bridge and broke down. After conferring with Henke representatives, a local vendor completed repairs to straighten and rebrace the cutting edge. The next time the plow was used in the field, the plow again hit a bridge and broke down.

Ohio DOT suspects that the breakdowns were related to the prototype plow's lack of a trip edge. (A trip edge includes one or more trip plates that are attached to the plow's moldboard with compression springs. The linkages cause the sections of the trip edge to swing up and away from the pavement when a hazard is encountered.) When a plow with a trip edge hits something—like a bridge—the plow will give. Without the trip edge, Ohio DOT surmises that the prototype plow was unable to sustain the hit on the cutting edge when it encountered an obstacle (in this case, a bridge), and the plow broke down.

Operators concluded that they would have to come to an almost complete stop (approximately 5 mph, rather than the 25 mph to 30 mph running speed) when approaching bridges to avoid damaging the plow. After two breakdowns, Ohio DOT opted not to return the prototype plow to its fleet.

During the one storm the prototype was used without incident, the operator used the scarifying blade to remove hardpack and found that it was effective when plowing at 10 mph to 15 mph on a route with low traffic and no bridges. Although hardpack is not a common problem in Ohio—material is used to prevent it—the scarifying blade would be useful on lesser-traveled roads that may have a greater tendency to accumulate hardpack. Ohio DOT's winter maintenance fleet is not outfitted with underbody scrapers.

Ohio DOT noted that the squeegee blade would have been helpful in meeting the level of service required for the route on which the prototype was used—a first-priority road with an LOS guideline that the roadway should be clear and wet 90 percent of the time. The limited availability of the prototype did not give operators an opportunity to test the squeegee blade.

3.5.3 Future Plans

Based on its limited experience with the prototype, Ohio DOT sees an application for a multiple-blade plow on lesser-traveled routes, where the scarifying blade could be used on hardpack or ice. If the prototype is used again on an Interstate at higher speeds, Ohio DOT would direct its operators to slow down or almost come to a stop when approaching a bridge or other hazard to avoid breakdowns.

Introduction of the new technology experienced a setback with breakdowns of the prototype, and there are no immediate plans to reintroduce a multiple-blade plow to the Ohio DOT winter maintenance fleet. While the prototype plow is not part of its winter maintenance fleet for the 2010-2011 winter, Ohio DOT recognizes the potential benefits of the multiple-blade concept.

3.5.4 Vendor Perspective

Henke representatives note that the multiple-blade plow allows for more material to be removed from the roadway in a single pass.

The flexible blade system can be more effective than the standard cutting blade in getting down into crevices and adapting to road conditions, and the scarifying blade is effective in removing hard-packed ice. With an effective front-mounted scarifying blade, winter maintenance managers can remove underbody scrapers for long-term savings. The squeegee blade works well in certain situations to remove the material left behind by the front cutting blade, clearing moisture off the road and preventing the roadway from refreezing. Operators have reported that more snow and slush removed from the roadway means less salt is needed to clear the roadway.

The flexible-edge system developed for this project was strictly a prototype, and Henke has no plans to develop that portion of the multiple-blade plow for production use. Henke uses standard PolarFlex blades as the front blade system on the multiple-blade plows the company is currently selling nationally and in North America. Henke reported that several cities, counties and states are interested in the idea of a multiple-blade plow, and a number have begun using the plow with positive results.

3.6 Wisconsin

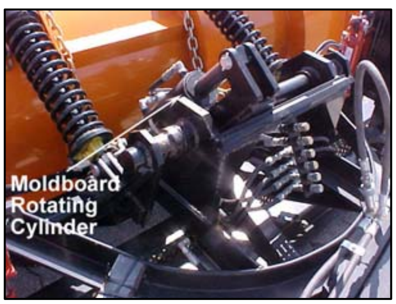
Wisconsin tested a three-blade prototype developed by Monroe Truck Equipment. The plow was field-tested over the 2009-2010 winter season on U.S. Highway 141, a two-lane highway maintained by the Brown County Highway Department. Brown County is in northeastern Wisconsin.

3.6.1 Plow/Blade Configuration and Installation

The Monroe prototype included three blades:

- ABAS flexible cutting blade
- Olofsfors P300 scarifier blade
- Rubber slush, or squeegee, blade

The prototype plow was installed on an International 7600 tri-axle dump truck. The multiple-blade setup added about 500 lbs. to the typical Monroe plow, for a total weight of approximately 3,200 lbs.



The ABAS flexible-edge system uses three- and four-foot blade sections. Unique among the project's prototypes, the Monroe multiple-blade plow included a rotating moldboard that allowed for differences in the attack angle of the cutting blade, which was helpful in peeling up hardpack. Adjustments were available up to 25 to 30 degrees that move the cutting blade left and right and forward and back. The operator hydraulically activated the cutting edge attack angle by tilting the moldboard.

Monroe and Brown County representatives agree that hydraulics—pressure transmitted through a cylinder by a liquid such as water or oil—was superior to air when it came to operating the blade tilt and engaging the squeegee and scarifying blades. The down pressure provided by air was not as effective, condensation can freeze up air lines, and cylinders are susceptible to corrosion. A misunderstanding with regard to installation led to Monroe's decision to retrofit the Brown County plow with hydraulic cylinders operated with air, which Monroe described as a cheaper, but less effective, retrofit. Eight hoses were attached when mounting the prototype—two for power reverse, two for blade tilt, two to engage the scarifying blade, and two for the squeegee blade.

3.6.2 Evaluation

Brown County's winter maintenance fleet is equipped with underbody scrapers with right-wing and double-wing plows to catch what comes off the scraper. Operators compared results of the underbody scraper with the prototype's scarifying blade, noting the difference in the degree to which hardpack or ice is removed—the scarifying blade made grooves in the hardpack as opposed to the total scrape done by an underbody scraper.

The county's common practice is to scrape the pavement before applying salt to limit the amount of salt used. Operators found that the scarifying blade had to be replaced frequently, and underbody scrapers did a better job of scraping the pavement with a single carbide blade that took a lot of wear. The issue of blade wear was significant for Brown County operators. Some operators reported checking wear on the scarifying blade every hour.

Brown County concluded that the scarifying blade may be useful in limited circumstances, such as when hard-packed snow results from a severe snowstorm that limits operators' ability to address every area as quickly as they would like.

The following summarizes operators' observations of the prototype in action:

- Operators saw greater benefit with the use of the squeegee blade than the scarifier.
- The scarifying blade wore down quickly.
- The plow had to be pushed out further than is typical to allow for the blade to swing, and it was difficult to get a good angle with the cutting blade.
- With the flexible blades encased in rubber, operators noted a smoother ride and reduced vibration and noise.
- One of the ABAS blade sections loosened and fell off the plow, but the operator was able to locate and reinstall it.
- More time is needed to assess the durability and longevity of the flexible blades and blade holders. Some rounding of the blade sections has been noted, and the cutting edges appear to be wearing into the blade holders.

3.6.3 Future Plans

As Brown County prepares for the 2010-2011 winter, shop maintenance personnel plan to remove the scarifying blade, move the squeegee blade closer to the main cutting blade, and remove the stops to allow the plow to swing more fully and provide a better angle for the cutting blade. The improved cutting angle is expected to result in better clearing of the roadway.

Brown County maintenance staff will continue independent testing of the prototype without the scarifying blade. There are no plans to purchase additional multiple-blade plows at this time.

3.6.4 Vendor Perspective

Monroe representatives noted that engineering was an issue in developing the prototype. Front-mounted dual wings that could not rotate required a special adapter to push the plow forward and rotate. With the front-mounted wings, placing the multiple blades behind the cutting edge limited the attack angle of the plow. Without the ability to modify the attack angle of the plow, snow does not roll off as well, and the snowplow operates much like bulldozer that simply pushes snow straight ahead.

As Brown County has also noted, Monroe suggested that adjusting the cutting angle of the prototype is easier with two rather than three blades. If one of the two blades is to be removed, Monroe recommended removing the scarifying blade and offered the following in support of that recommendation:

- A scarifying blade does not perform the same function as an underbody scraper. An underbody scraper will peel hardpack, but the scarifier simply puts grooves in hardpack to improve the melting capabilities of salt or other deicing material.
- An underbody scraper, used by many state DOTs, can apply more down pressure and works more effectively than engaging the scarifier, which raises the plow when applying down pressure for the scarifying blade. In some states, underbody scrapers are available on almost all trucks in the winter maintenance fleet, and the plow is used as a secondary activity.
- Consider this difference: The weight of a 2,000- to 2,500-lbs. snowplow has to hold down the scarifier using hydraulic pressure. With an underbody scraper, the operator has the benefit of 8,000 lbs. of down pressure from the truck. After finding ways to work around clearance problems, some state DOT maintenance shops have designed underbody scrapers that work in tandem with squeegees.

User comments on the squeegee blade have been uniformly positive, although Monroe acknowledges that the squeegee blade is not as effective in cold weather. When engaged in appropriate conditions, the squeegee blade cleans uneven road surfaces, and cleans roads more effectively after the initial scrape of the main cutting blade. The best markets for the squeegee blade are those areas where there is a lot of wet, heavy, slushy snow, and the squeegee blade can be used to remove more moisture from the roadway than is possible with the cutting blade.

While the Monroe prototype used a flexible blade system, Monroe representatives noted that flexible blades are not part of its existing plows, having concluded that the flexible blade’s advantages do not offset the additional cost. The scarifying and squeegee blades used on the prototype can be retrofitted to existing plows. McHenry County, Ill., is using a Monroe squeegee-only plow, and Monroe has sold other new plows and retrofits. None of the plows recently purchased employ the rotating moldboard used on the prototype.

4. Concluding Remarks

Clear Roads began this project with an eye to advancing snowplow design. By encouraging vendors and the winter maintenance community to work together to develop and test prototypes, this project gave operators real-world experience with an innovative snowplow designed to meet the varying conditions they face when fighting winter storms.

While individual experiences in this project's field testing varied widely—and participants report differing degrees of success—all participating states expressed continued interest in the concept of the multiple-blade plow. With vendors now making multiple-blade plows part of their standard product offerings, the project succeeded in moving the multiple-blade plow out of test mode and into general use. More multiple-blade plows on the market will mean more users—and more feedback—to encourage vendors to continue developing innovative approaches to snowfighting in the 21st century.

Clear Roads would like to thank the vendors and states participating in this project, and wishes all participants continued success as they continue to work with the concept of using multiple blades on snowplows in the future. Those interested in further information about the availability of multiple-blade plows and the prototypes developed for this project will find contact information for participating states and vendors in Appendix C.

APPENDIX A

Improving Snow Plow Design: Highway Maintenance Concept Vehicle Phase V

Meeting Minutes from the Design Charrette
Held in Des Moines Iowa April 26 & 27, 2006

Prepared for the

Clear Roads Program

Prepared by

ctre
Center for Transportation Research and Education

Iowa State University

2901 S. Loop Drive, Suite 3100

Ames, IA 50010-8634

May 8, 2006

INTRODUCTION

The challenges facing states' departments of transportation (DOT) winter operations are numerous. These challenges include rising fuel costs, material costs, flat budgets, and public expectations for clear roadways. The operators face the perils of winter as they strive to provide uninterrupted mobility to the road user. Snow and ice control during winter storms includes highly complex tasks and long, stress-filled hours for equipment operators and their supervisors.

This concept highway maintenance vehicle project undertaken by the Clear Roads consortium is designed to develop highway maintenance vehicles so that they may improve snow and ice control performance, and better suit the needs of the traveling public, the operators, and the highway agencies. This report summarizes the activities of the Design Charrette, which involved determining the desired capabilities for a concept highway maintenance vehicle and predicting the feasibility of assembling prototype vehicles.

On April 26 and 27, 2006 the Clear Roads Project Team convened in Des Moines Iowa to the latest version of the Concept Vehicle Project. The charrette brought together operators and researchers from the seven Clear Roads states to discuss these issues.

Those in attendance were:

Name	Organization
Dennis Burkheimer	Iowa DOT
Jim Dowd	Iowa DOT
Brad Osborne	Iowa DOT
Will Zitterich	Iowa DOT
Jim Bane	Iowa DOT
Bill Schuler	Iowa DOT
Rex Evans	Iowa DOT
Lee Wilkinson	Iowa DOT
Milo Nelson	Iowa DOT
Leland Smithson	AASHTO
Jeffrey Tjaden	Iowa DOT
Dave Budd	Michigan DOT
John Scharfbillig	Minnesota DOT
Mike Sproul	Wisconsin DOT
Greg Shell	Indiana DOT
Bob Lannert	Missouri DOT
Doug Burke	Ohio DOT
Steve Andrle	CTRE-Iowa State University
Dennis Kroeger	CTRE-Iowa State University
Dr. Greg Luecke	Iowa State University

The participants met to define the desired capabilities of a new snow removal device that will meet the goals of the Clear Roads research project. The stated goals of the project are:

- Clear roadway in one pass
- Reduce snow residue behind the plow
- Develop a contour-following blade or alternative to a blade
- Plow speed that is within ten mph of traffic speed—about 40-45 mph

The meeting was conducted in a design charrette style discussion. The participants were brought together to discuss, dissect, design, and assemble two prototype designs that could be built, deployed and tested by next winter. All methods of snow and ice removal were on the table for discussion. Participants were encouraged to bring unconventional ideas to the discussion so as to push the envelope in developing the snow removal device. Once the plans are prepared, one device will be tested in Iowa and one in Indiana.

1. DEFINITIONS

The charrette participants defined the challenges and problems for snow removal as the following.

- Clear 12' lane in one pass
- Target speed should be 60 mph on urban interstates
- Seek travel speed of plow to within 10 mph of traffic speed
- Goal: keep cloud down with down deflection.
- 42" height on moldboard is optimum
- 20" height on experimental plow in Missouri. Take snow perpendicular to the right. Wyoming did some research in this area. Load sensors on plow. Measured horsepower consumption. Moved tilt angle back. Colored top of snow to test. Skew angle will move snow more rapidly to the right.
- 90° angle is the worst for launching snow. Just pushes snow ahead of plow.

1.2 PARAMETERS

- 102" width limit roadways

- If air blowers or brushes are used to clear snow, we can't pull more than 50 hp off the engine. Huge issue. Decreased hp means decreased performance of truck. For example, at 125 cu ft. per min. 65 hp is required to run 4-5 jack hammers. Airports are running 350 hp on compressors

- Focus on interstate condition. ½" max rut. Concrete or hot mix.

- Rock shoulders. How does air and brush work on gravel? Issue in many states. Currently, shoulder plowing uses shoes or hydraulics to keep plow off the rocks

- Cost: we can be in the 5x range on the plow unit. If resources are reduced or increase production capacity we can add some cost. If increased speed and efficiency are gained, agency can absorb some capital cost.

- Spreading material: Operators in some states are spreading 800 pounds /mile so they can see it in their rearview mirrors. Should be doing 200 pounds per mile or less. $5 per lane mile to keep snow from bonding.

- 1/2" of ice takes 70 tons of salt per 2-lane mile to melt at 10 degrees

- On interstate, shoulders are treated to the same standards as mainline.

- The farther back you move the plow the faster you can drive.

- Goal: Reduce residue by 25 %

- Goal: One plow, one truck

1.3 PROBLEMS AND CHALLENGES

Once the group defined the problems that they face they were asked to identify methods to overcome the problems and challenges faced with snow and ice removal.

- Skew angle. Move the plow to negative angle.

- Horsepower. 300 hp is limit without $20K upgrade. Emissions regulations.

- Challenge of removing snow on ice, removing ice, slush and deep snow.

- Dry snow- Hard to avoid cloud. Keep air out of it. Curved underbody plow with cover. Light fluffy snow will pack under truck with underbody blade. Wet snow will come off in a rooster tail.

- Differential blade wear is a problem. We need to control left and right down pressure. Ohio DOT uses a blade balance valve.

- There is a lot of plow chatter on the roadway when using a gravity plow. Plow chatter and blade chatter is a problem causing unnecessary wear and operator fatigue. Missouri DOT uses -5° to -10° attack angle to reduce chatter. This method also carries material to right faster. It is also useful when plowing wet pavement a lot.

- Missouri states that one way to solve some of these issues is to use a negative attack angle with skew and down pressure.

- Underbelly clearance is a problem, for example at railroad crossings. Need to ensure ability to lift underbody blade. High speed underbody plows have been in use in Iowa for 20 years. There is a need to raise drive shaft and fuels tanks. At higher speeds, there may be trouble getting snow to clear out fast enough to avoid packing underbody of truck.

- Must remember that plows are used for more than snow. They must have the ability to do other maintenance work and be versatile. Don't create new problems for other functions.

- Signs: Casting of snow and slush on roadway signs will not be tolerated. New retro-reflective signs need to last 10 years.

1.4 General Issues

Once the problems were stated and defined, the discussion continued with other issues being focused on.

- Blowback and visibility. There is need for more work on aerodynamics in front of the plow. Snow pack can plug radiators and air intakes, which will slow trucks down. Run out of horsepower above 45 mph. Can't maintain the higher speed.

- Another danger is chunks of snow and ice coming off the plow at higher speeds.

- Residue left behind the plow, still need to remove.

- In Ohio, there are raised pavement markers, which can become hazardous to oncoming motorists if plow grabs them and throws them. The device needs to slide over them.

- Weight: front end limits – plows can be made too light or too heavy.

- There are rear end accidents in left lane – for example, semis hit snow plow trucks. Many times this is not a failure to see the plow, but of reaction time. Truck drivers are overdriving for conditions. Issues: Should we clear the passing lane first? This method moves fast traffic to the clearer passing lane. Another method is tandem plowing to prevent rear end crashes.

- Why front end plow? Under body plow can be used for average snowfall removal.

- The standards for snow and ice control are: No snow allowed on interstates.
    - Need for high speed, high production
    - Use all available tools including under body plow and rear wing
    - Secondary roads different standards

1.5 OPERATIONS

Following the discussion of problems and challenges and methods to overcome those problems, the charrette participants were asked about their operations for snow and ice control. The participants were asked to discuss their operations and how a new device may change those operations. They were also asked if there were changes in the operations that could be readily made. Their responses are as follows:

- Any new device will use hydraulics to manage down pressure, and sometimes carry the plow.

- Tilt control will be used. Tilt the blade to adjust to road surface.

- Rotate front plow to adjust attack angle. Combine with squeegee following. Adjust pressure on slush blade.

- Must be simple to operate and maintain. Lots of part-time operators.

- Cost control is a big issue. There is a lot pressure on maintenance agencies to contain costs. Any new device must be productive and keep costs down.

- Training is a big issue. It is hard to get drivers to go out without a front plow. Once they get use to it, they like it because the visibility is better. If no front plow is used on the new device, we will have to gain operator acceptance. This issue can make it a success or failure.

1.6 PRODUCTS: BENEFITS AND SHORTCOMINGS

Following the operations discussion, the participants were asked if there were any existing products available that may be used for the proposed snow removal device. If there are products available, what are the good things about them and what are the bad? The discussion went as follows:

- Joma blades– but their shoes fail and we have to replace the vulcanized rubber each time
    - These blades have been used in Cleveland OH. There costs 3 times regular blades but they lasts 3 times longer. To avoid excessive wear, you have to run 20° forward. The blades need wheels or shoes to keep full weight off rubber blade.

- Active Blade Adapter System (ABAS) – (This is a segmented blade device bolted to existing moldboard. The blades move up and down with the contour of the road surface.)
    - Tried in Cleveland and other Ohio DOT sites
    - In service in Bedford Iowa (Iowa DOT)
    - Too heavy
    - Raises plow 5 inches.
    - According to Bill Schuler of Iowa DOT this system works very well on rough pavements. Runs smoother at 50 mph than a regular plow at 30 mph. We had to drill vertical holes to relieve tension on rubber. Is it possible to pump liquid chemicals through these holes?

- There are two types of active adapters. One works on a tension/compression basis. The other has a shear action on the rubber block.

- Schmidt-Wausau: has poly-moldboard

- In Bedford, Iowa District, we can run the plow at 50 mph with good vision if rotate the c-blade far forward. You need to keep snow out of the top of the plow.

2. NEW IDEAS

Following the product discussion, the participants were asked about any new ideas that they have thought of but for whatever reason hadn't tried. All ideas were to be on the table, regardless of budgets, political issues, other limitations, etc. The goal of this discussion was to get the participants thinking of new methods and concepts that could work for snow and ice removal. Once these ideas were discussed and dissected, then they could be parsed down into practical applications.

- Using multiple blades. First blade placed 2" or so off ground, followed by other blades.
- Michigan DOT runs front plow 2" off ground. Uses underbody plow to clear remainder of snow and ice from the roadway.
- Devices would require down pressure with hydraulics.
- Underbody plow doesn't move truck over when it hits an obstruction at high speed like front end plow.
- Michigan and Ohio have used rubber blade with carbide backing.
- Missouri stated that neoprene blades have been used in St. Louis at low speeds. These blade don't work well at high speeds
- Could brushes be used at high speed? Need to investigate this.
- Poly moldboard that can be tightened up.
- Inject brine up front to hold down plume. Spray the cloud? Spray the roadway in front? May help reduce the blow back in problem. Ohio and Iowa running brine trailers
- Indiana — has outsourced snow plowing.

2.1 CONCLUSIONS

The following conclusions were drawn from the morning's discussion.

- Underbody plow is probably solution to high speed plowing. At higher speeds, there is so much mass truck won't shift.
- Moldboard with trip mechanism is not likely solution to high speed plowing.

- Negative blade angle with skew and down pressure. There is a possibility to investigate here.
- Multiple blades. Shallow plow or plow with cover.
- Alternative. Slush blade in front. Tilt moldboard forward to engage slush blade. Put cylinder on bottom and rotate down whatever blade you need.
- Different than plow discharge. Rooster tail comes off end of plow.
- Two prototypes should be totally different. Wide spectrum of conditions.
- State Maintenance Engineer goals
    - Wider path
    - Plow slower for safety
    - More production, more capacity
    - Reduce costs of snow removal

3.0 WORK PLAN

The discussion continued with participants developing the work plan for a snow removal device. The focus here was to not focus on a plow, but any device that could remove snow and ice from the road surface.

The methods of snow removal are different for urban service and rural service. There may have to be different designs for these operations.

- Interstate urban device
- Rural Device

The participants focused their ideas on efficiency, following the contour of the road surface, and discharge of the snow. Their ideas are as follows:

3.1 Efficiency

- 1300° exhaust temperature on back of moldboard to increase fuel economy.
- Reduce friction. Increases production. Makes plow scour. Reduces horsepower needs. Keeps cloud down.
- Inject brine at bottom. Reduces friction on bottom of plow. The plow then tends to hydroplane.
- Inject brine through the back of the moldboard.

3.2 Clear roadway in one pass. Contour-following

- Rotating multiple cutting blades/squeegees that can adjust the angle of attack.
  - Mounted behind plow
- Air auger 10” cylinder with spiral air flutes. Pulsating air nozzles. Compress fines.
- Air jets with auger
- Brooms: Poly with steel. Paint crew model. Thermo plastic markings may change the cost equation for brooms. Paint crews are grooving in the markings to avoid the plow. How fast can a broom turn?
- Belt with brushes that continually move material to right. Follow up with a squeegee. Will need enough width to move the snow. Doug Burke
- An alternative would be to place in front of the blade. Use the blade if you need it. Follow with squeegee. Probably not feasible
- Broom shaped like an auger
- Put behind plow at any mounting location as a groomer to pick up residual.
  - Power washer effect.
- Carbide-tipped ¼” cables hung like a rake behind the plow. Followed by squeegee. All three work independently. Spring loaded cables or squeegee to apply pressure idea from Bill Schuler. Grooves hard pack so chemicals can work.

3.3 Discharge/Plume reduction

- Curved blade
  - Horizontal curve in front
  - Horizontal curve under truck.
  - 3 blades under, like a railroad switch
  - Pivoting under body blade with curved fenders behind each front wheel. Option: add a belt.
- Deep J blade with rubber to 6” of road. Add belt or auger to move snow down the chute. Sharp skew angle.
- 3-point hitch option with pivoting blade.
- Flexible, composite material with flutes that can be slide shifted from left to right.

- Auger with melter unit

Following the examination of the ideas put forth by the group, the discussion focused on what type of device the group should pursue. With the parameters being kept in mind that the research must be able to be implemented and a prototype device must be available for testing next winter. There will be two prototypes to be tested next winter in Iowa and Indiana.

3.4 PROTOTYPE A

This was the first design discussed.

- Underbody pivot plow design:
    - Test mounting arrangement
    - 13’ clearing path—telescoping?
    - Test curvature of moldboard to move snow off the road
    - 8 way blade control
    - RR switch idea
    - Test multiple edges
    - Test adjustable angle of attack
    - Test left and right design if possible
    - Adaptable for summer shoulder work

Question: what is the wheel base?

3.5 PROTOTYPE B

- Front plow design
    - Bill: adjust all parameters because conditions always change.
    - Flexible mold board –
    - Control plume
    - Control casting
    - Adjustable attack angle
    - Adjustable pressure
- 8 way blade
- Front brine injection
- Minimum 3 cutting edges (This is in development by a vendor)
    - Carbide
    - Rake: carbide tipped cable or earth tooth
    - Squeegee
- ABAS-like system makes operator feel more comfortable at higher speeds

3.6 PROTOTYPE C

- Truck-mounted rear plow – slide on like a Truck mounted attenuator (TMA) (probably something similar to underbody)
  - 13' clearing span
  - Safer and meets more of our objectives
  - Flexible mold board –
  - Control plume
  - Control casting
- Adjustable attack angle
- Adjustable pressure
- 8 way blade
- Front brine injection
- Minimum 3 cutting edges (This is in development by a vendor)
  - Carbide
  - Rake: carbide tipped cable or earth tooth
  - Squeegee
- Moldboard may be similar in depth to underbody
- Extend chute for spreader
- Issue: how can we pull a brine trailer?
- Can we put the plow on the tongue of the brine trailer
- Allows for bringing in contract trucks and drivers
- Negative load on hitch. Big issue.
  - Note: Take tripping mechanism out of plow when operating at an angle.
  - Build in a shear-point concept to eliminate a catastrophic event. Shear bolts

3.7 PROTOTYPE D

Philosophy: Front plow that usually runs in non-contact mode
Underbody or trailer unit with the features below

- Trac 3 fusion blade idea
- Develop a 3-blade mechanism
  - Carbide
  - Rake
  - Squeegee
- 13' clearing capability. Extension moldboard
- Shape to obtain optimal cast and plume control
- Not on front: amid ships or trailer

(It was noted that the rake in front of moldboard has not been effective in previous versions.)

3.8 PROTOTYPE E

- Trailer–Test bed to test blades
    - Trailer with truck towing underbody blade
    - Test combinations of blades
    - Provides ability to test various combinations, gets away from under the truck constraints.

A discussion ensued of the merits of all prototype designs. A vote was taken and it was decided that due to the parameters of constructing two prototypes in time to test for next winter and with the limited budget that Prototypes B and C would be constructed and tested. The project will now begin to test a front plow design and a truck mounted rear plow design. Iowa will test the rear mounted plow and Indiana will test the front plow designs.

The Indiana group will test Prototype Device B as follows:

PROTOTYPE B

- 13’ clearing span
- Front plow design
    - Adjustable attack angle
    - Adjustable pressure
- 8 way blade
- Front brine injection
- Multiple (Minimum of 3) cutting edges (This is in development by a vendor)
    - Carbide
    - Rake: carbide tipped cable or earth tooth
    - Squeegee

The Iowa group will test Prototype Device C as follows:

PROTOTYPE C

- Truck-mounted rear plow – slide on like a Truck mounted attenuator (TMA) (probably something similar to underbody)
    - 13' clearing span
    - Safer and meets more of our objectives
- Adjustable attack angle
- Adjustable pressure
- 8 way blade
- brine injection
- Minimum 3 cutting edges (This is in development by a vendor)
    - Carbide
    - Rake: carbide tipped cable or earth tooth
    - Squeegee
- Material chute extension for spreader

The next step for the project team will be to assemble design drawings of the two prototype designs to be constructed. The ISU/CTRE team will begin the design of the prototypes as soon as possible. The group will stay in contact via email and other means, to inform one another on the progress of the project.

Picture 1: Participants examining ABAS system

Picture 2: Examining squeegee blade system

Picture 3: Squeegee blade system

Picture 4: Discussing new approaches

Picture 5: Explaining the ABAS system

Picture 6: Iowa DOT snowplow with squeegee blades

Picture 7: Iowa DOT snowplow with ABAS system

Picture 8: Discussing squeegee blades

Picture 9: Checking out the snowplows

Picture 10: Snowplow with squeegee blades

Picture 11: More group discussions

Picture 12: Checking out the snowplows

Picture 13: More snowplow discussions

Field Test Results of Prototype Plows with Multiple Blades

Office of Maintenance
Iowa Department of Transportation
December 2007

Introduction

The Iowa Department of Transportation has been testing a variety of multiple plow designs to help improve removal of snow and ice from the roadway surface with the ultimate goal of removing all snow and ice from the roadway in one pass. If more snow and ice can be removed from the roadway surface with each pass, less deicing materials should be needed to melt the snow and ice on the roadway, motorists should experience better in-storm pavement conditions and roads should return to normal faster after the end of a winter storm. Observations during plowing operations hint that up to a half inch of snow is often left behind a plow during snow removal operations. Any deicing material dispensed from the truck will then be required to work on the snow and ice left behind the plow in addition to any freshly fallen snow. Removing as much material as possible from the surface in one pass will also remove much of the moisture from the roadway which should increase the evaporation process.

The Iowa DOT has investigated adding different components to the main plow to determine if they can improve the snow removal process. Several different plow configurations have been built over the last three years and tested during winter maintenance operations. The current design incorporates a standard plow with an attached scarifying blade and squeegee blade.

On September 12, 2007 tests were conducted in Bedford, Iowa comparing four test vehicles with different multiple blade configurations to a standard plow representing plows currently in use at the Iowa DOT.

Test Plows

The following is a description of each plow configuration used in the test:

Vehicle 1- (A31373) This is a standard plow that has been modified to add a contour following feature developed by the local shop (Figures 1-2). The flexible edge system is incorporated into the bottom of the moldboard and the blade is then attached to the flexible edge system. The flexible edge system incorporates rubber to allow the blade to adjust easily to differences in the roadway surface. The flexible edge is segmented into 24 and 36 inch segments which allows each segment to flex up to a half inch. This plow is also equipped with a separate squeegee blade that can be activated when needed.


Figure 1 Flexible Edge


Figure 2 Flexible Edge with rebar under blade to show the blades ability to adjust to roadway contours

Vehicle 2 (A30406)- This is a standard plow used by the state that has been equipped with a flexible blade attachment called the Active Adaptor Blade System (AABS)(Figures 3-5). The AABS is attached to the moldboard and then the carbide blade is attached to the AABS. The adapter integrates vulcanized rubber into the design to allow for movement of the carbide blade to keep the blade in contact with the roadway surface. An independently controlled squeegee blade was attached behind the plow to help remove any material left by the main front plow.

Figure 3 Plow with Active Adapter system

Figure 4 Squeegee blade attached to plow frame behind Active Adaptor System

Figure 5 Active Adaptor System with rebar under blades to show ability to adjust to roadway contours

Vehicle 3 (A31156)- This vehicle is a Wausau, 12-foot, down-pressure plow that has been outfitted with an independently controlled scarifying blade and squeegee blade mounted directly behind the main front plow (Figures 6-7). The scarifying blade can be used to remove hard snow/ice pack or can be used in conjunction with the other blades to clean the roadway closer to the surface. The squeegee blade is also used independently or in conjunction with the other blades to remove any snow/ice left by the front plow.

Figure 6 Wausau down pressure plow

Figure 7 Wausau down pressure plow on road test area

Vehicle 4- (A28463) This is a standard snow plow used in the Iowa DOT fleet. Width of the plow is typically 11-feet (Figure 8). This plow was considered as the control plow for this projects since it represents the standard plow used in snow removal operations.

Figure 8 Standard Iowa DOT plow

Vehicle 5 (A29504)- This is an underbody plow from Bloomfield that has a squeegee blade mounted behind the underbody plow to remove any snow/ice left by the front main plow or underbody plow (Figures 9-10). For this test no front plow was mounted on the truck.

Figure 9 Standard Iowa DOT underbody plow with squeegee blade

Figure 10 Squeegee blade in contact with road surface to remove slush and liquids

Testing Procedure

To replicate snow on the roadway surface, sand blasting sand was used. A frame made from pine was constructed to hold a consistent quantity of testing sand. The four corners of the frame were painted on the pavement to make sure the frame could be repositioned in the same location after every test run. The frame was filled with sand and then a worker used a board to strike-off the sand level to make sure each plow started with the same amount of sand for each test run. The frame was removed and each truck moved through the test area with the plow down but each truck was stopped before the front tires encroached into the test area (since vehicle #5 was equipped with only an underbody plow it was allowed to drive through the test area). Each truck went through the test area twice, once with the plow down and the second trip was with the plow and squeegee blade down (vehicle# 5 was only tested in the road test with the underbody plow and squeegee blade down). The sand was vacuumed from the surface after each plow pass and placed in marked plastic bags for later weighing at the Materials Laboratory at Iowa DOT headquarters.

The first tests were conducted near the Bedford garage on a level flat surface to see how the plows would perform on a relatively level roadway surface. Tests were also done on the South-bound lanes of Iowa Highway 148 South of Bedford, IA. The tests on Highway 148 represented a roadway with wheel ruts and uneven roadway surface to see if there was a difference in performance between the plows operating on a level surface and one on an actual roadway surface with some wheel ruts.

The following photos show the steps used in the test on a level surface near the Bedford maintenance garage and also on Iowa Highway 148, South of Bedford:

Figure 11 Frame used to contain sandblast sand

Figure 12 Filling frame with sandblast sand

Figure 13 Striking-off the top of the frame to make sure the same amount of sand was in the test area for each run

Figure 14 Sand ready for run

Figure 15 Test plow runs through sand with squeegee blade activated

Figure 16 Plow and squeegee blade clear sand from test area on second pass

Figure 17 Vehicle stops before encroaching into test area

Figure 18 Collecting sand from frame after plow pass

Figure 19 Capturing sand for weighing

Figure 19 Highway 148, South of Bedford, Ia- Test area

Figure 20 Profile of roadway to show wheel rut

Figure 21 Plow approaching test area on Highway 148 test area

Figure 22 Collecting sand after plow passes through test area

Data Collection results

The vacuumed material collected after every pass was placed in a bag and marked with the vehicle number and pass number. The following are the weights of the sand collected from the frame used in the test at the garage and on Highway 148:

Frame at garage	114.6 pounds
Frame on Highway 148	106.4 pounds

Vehicle results The following tables show the weight of sand left in the test area after each plow run.

Vehicle # 1- Plow with Flex Edge system and squeegee blade
Truck#- A31373

Run#	Test location	Equipment	Weight (pounds)
1	Garage	Plow only	3.0086
2	Garage	Plow and Squeegee	1.5538
3	Road	Plow only	3.394
4	Road	Plow and Squeegee	2.1685

Vehicle 2- Plow with Active Adaptor system and squeegee blade
Truck#- A30406

Run#	Test location	Equipment	Weight (pounds)
1	Garage	Plow only	2.836
2	Garage	Plow and Squeegee	1.5681
3	Road	Plow only	9.3619
4	Road	Plow and Squeegee	7.6864

Vehicle 3- Wausau 12-foot down pressure plow with squeegee plow
Truck#- A31156

Run#	Test location	Equipment	Weight (pounds)
1	Garage	Plow only	5.8586
2	Garage	Plow and Squeegee	6.0052
3	Road	Plow only	14.224
4	Road	Plow and Squeegee	4.7902

Vehicle 4- Standard Monroe plow that represents most of Iowa DOT fleet (Control plow) Truck#- A28463

Run#	Test location	Equipment	Weight (pounds)
1	Garage	Plow only	4.8828
2	Road	Plow only	25.652

Vehicle 5- Standard Iowa DOT underbody plow with squeegee blade
Truck#- A29504

Run#	Test location	Equipment	Weight (pounds)
1	Garage	Plow only	3.3204
2	Garage	Plow and Squeegee	2.3481
3	Road	Plow only	6.8762

Data Analysis:

The following tables show the number of pounds of sand removed after each vehicle pass compared to the amount of sand that was present in the frame before the plows passed over. The line marked in yellow is the control plow for these tests. All analysis is based on how the other plows performed compared to the control plow.

Garage Test

Vehicle	Blade Only		Blade and Squeegee		Percentage Difference
1	3.0086		1.5538		68.18%
2	2.836		1.5681		1.11%
3	5.8586		6.0052		-0.13%
4	4.8828		N/A		N/A
5	3.3204		2.3481		0.85%

Road Test

Vehicle	Blade	Percent removed	Blade and Squeegee	Percent removed	Percentage Difference
1	3.394		2.1685		1.15%
2	9.3619		7.6864		1.57%
3	14.224		4.7902		8.87%
4	25.652		N/A		N/A
5	Not tested		6.8762		N/A

The following charts show the percentage of sand removed from the roadway surface by each plow compared to the control plow (Vehicle# 4). The first two charts show the results for the tests on a relatively flat surface and the last two represent the tests done on an actual roadway surface. The control plow is given a score of 100% (represented by a dashed red line) and the other plows are rated against that level. A plow with a number higher than 100% means it left more sand behind the plow than the standard Iowa DOT plow. A number less than 100% means the plow left less sand behind the plow then a standard Iowa DOT plow.

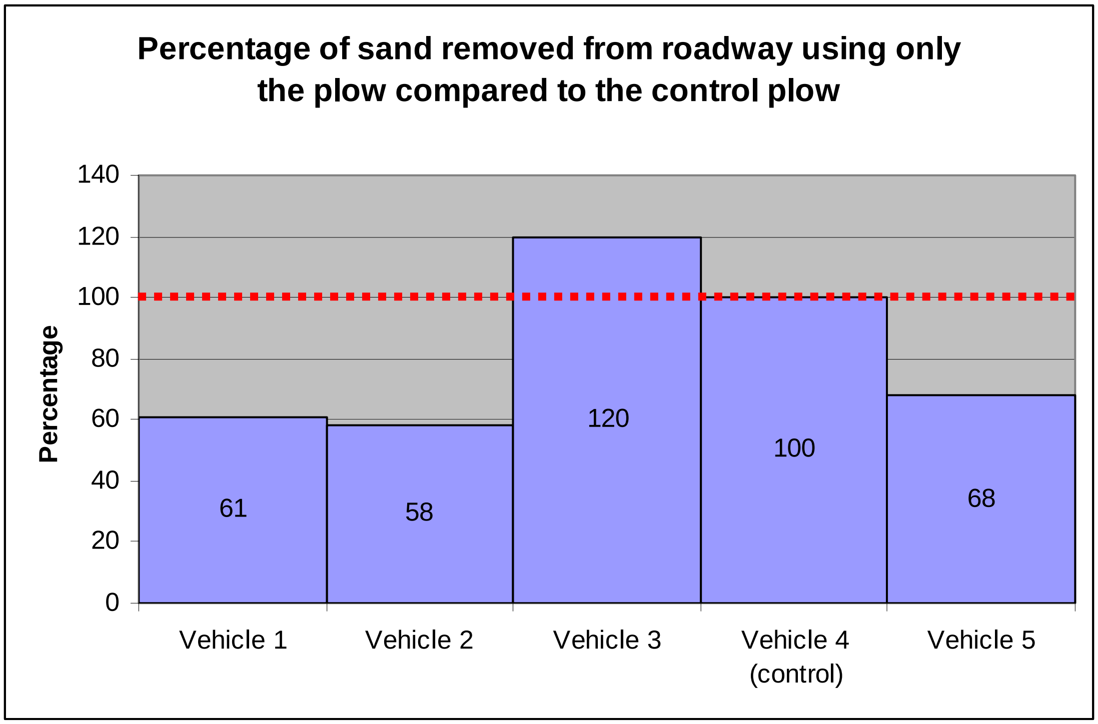


Figure 23. Plow only on even surface

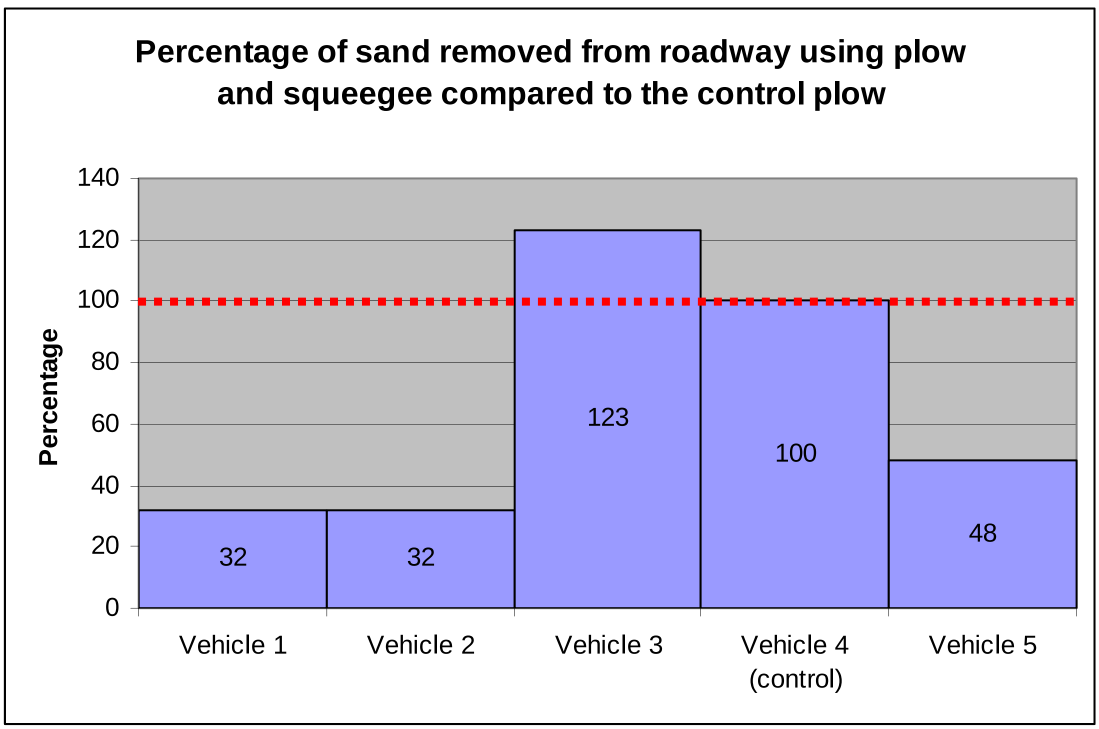


Figure 24 Plow and squeegee on an even surface

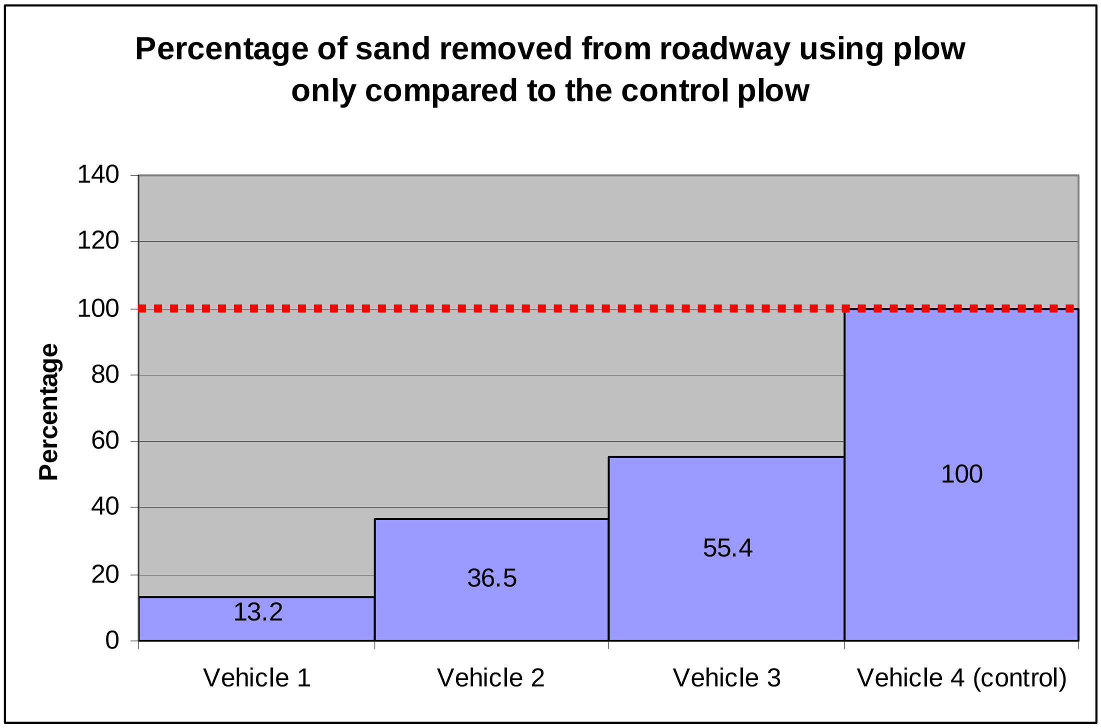


Figure 25 Plow only on actual roadway

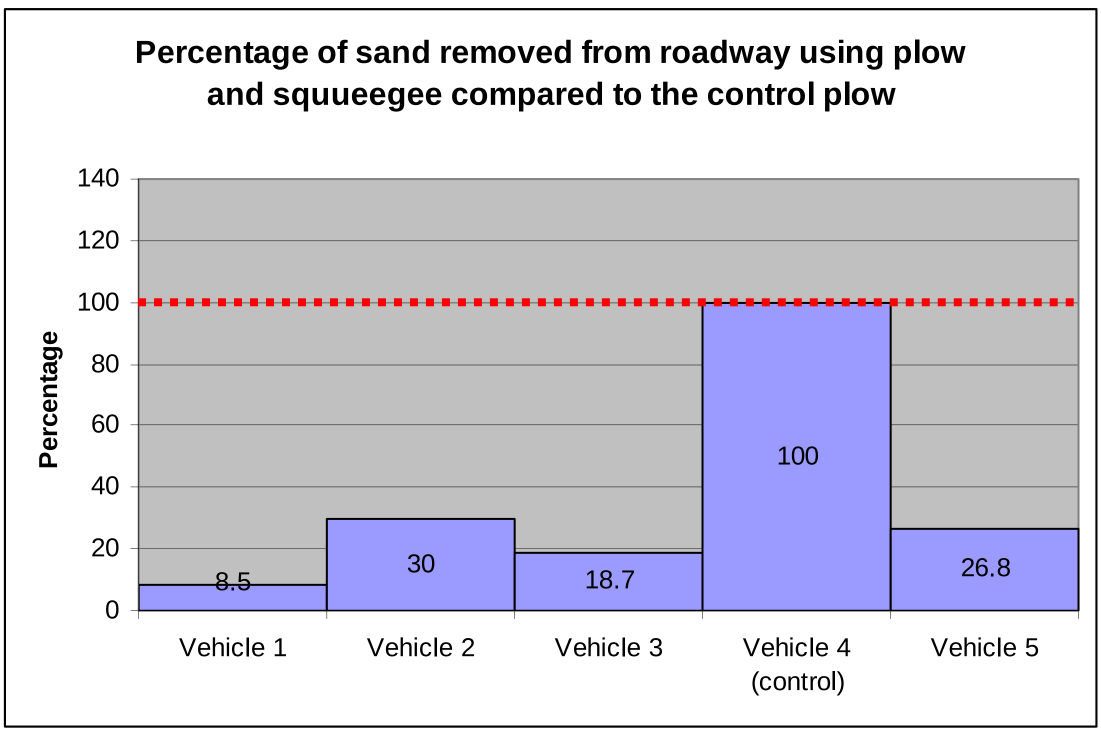


Figure 26 Plow and squeegee on actual roadway

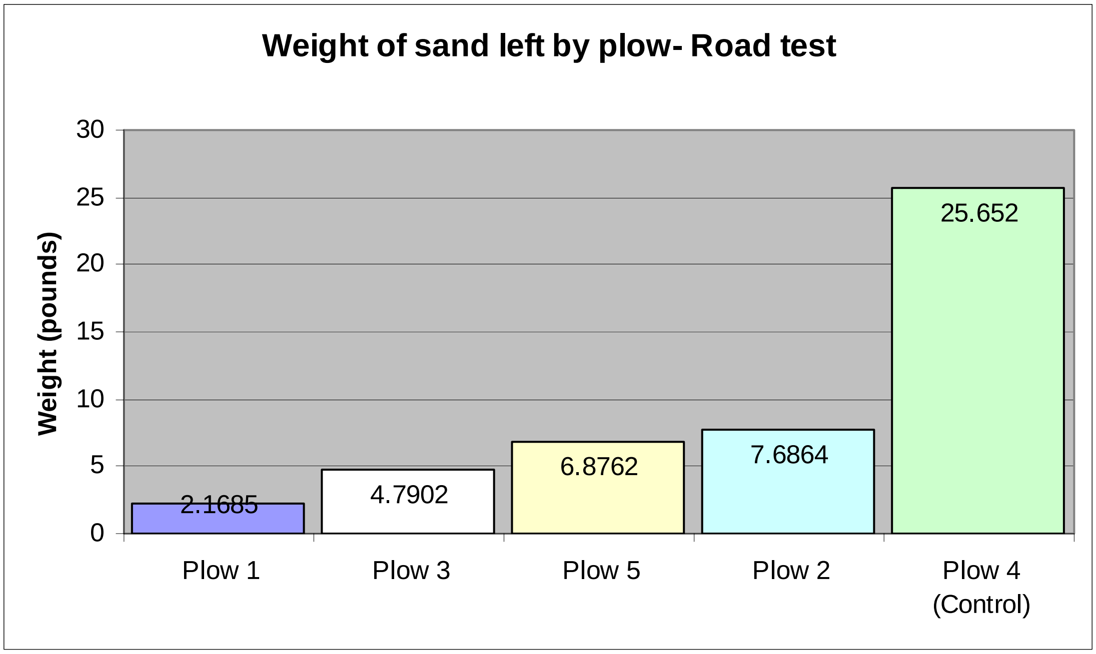


Figure 27. Weight of sand left behind each plow during road test

Conclusions

In the tests conducted near the Bedford garage on a level surface there were only moderate differences in performance between the standard Iowa DOT plow and any of the test plows. The standard plow in this test area removed approximately 96% of the materials from the surface while the best performer (Flex Edge) of the test plows was able to remove nearly 99% of the material using the plow and squeegee blade. Though the difference in percentage between the test and control plow appear to be small the percent of material left when compared to the control plow is actually about one third less (Figure 24) for the Flex Edge system.

The road test portion of this evaluation on a wheel rutted road shows the standard Iowa DOT plow removing approximately 76% of the material from the roadway while the best performer (Flex Edge) of the test plows was able to remove approximately 98% of the material, an improvement of approximately 22%. Figure 26 shows the Flex Edge system left about one-twelfth the amount of sand as the standard Iowa DOT plow in the test on an actual roadway surface.

The gap between the segmented sections of the Active Adaptor System and Flex Edge System seem to be where the majority of the sand was found after each pass. To allow flexibility in both systems the segmented areas are separated by approximately ¼ inch. This allowed small windrows of sand to be left behind after each pass. The windrows were included in all measurements.

If the test plows perform in snow conditions as they did when removing sand from the test areas, the amount of snow and ice removed from the roadway should be greatly increased with each pass. More snow and ice removed from the roadway surface with each pass should reduce the amount of deicing chemical needed to treat the roadway and reduce overall material costs for snow removal. The squeegee blade will help remove any snow left behind the front plow but will also be helpful in removing in excess liquids from the roadway. Less snow or liquids will help return the roads to normal much faster.

We recognize that sand is not the same as snow but seemed to be the best method to test the experimental plows in a non winter event. We also did not perform multiple tests for each plow but the results were good indicators that the experimental plows were an improvement over standard plows.

During the winter of 2007-2008 the Iowa DOT will do additional field testing of the experimental plows during actual snow and ice conditions to determine if the improvements found in the sand tests are also seen under actual conditions.

Appendix C: Contact Information for Participating States and Vendors

States

Indiana
William Burton
Special Projects Manager
Indiana Department of Transportation
Seymour District
185 Agrico Lane
Seymour, IN 47274
(812) 524-3934
wburton@indot.in.gov

Iowa
Jim Dowd
Winter Operations Research Analyst
Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010
(515) 239-1724
Jim.Dowd@dot.iowa.gov

Mike Hagen
Garage Operations Assistant
Iowa Department of Transportation
Hanlontown Garage
753 Hwy 9
Hanlontown, IA 50444
(641) 896-3100
Michael.Hagen@dot.iowa.gov

Minnesota
Kelvin Smith
Shop Supervisor
Minnesota Department of Transportation
District 3 - St. Cloud
3725 12th Street N.
St. Cloud, MN 56303
(320) 223-6560
Kelvin.Smith@state.mn.us

Ohio
John Thorpe
Transportation Manager
Ohio Department of Transportation
Stark County - District 4
2088 S. Arlington Road
Akron, OH 44306
(330) 325-7996
john.thorpe@dot.state.oh.us

Wisconsin
Larry Adlebush
Shop Superintendent
Brown County Highway Department
2198 Glendale Avenue
Green Bay, WI 54303-6495
(920) 662-2177

Kurt Wranovsky
Northeast Region
Wisconsin Department of Transportation
944 VanderPerren Way
Green Bay, WI 54304
(920) 492-5645
kurt.wranovsky@dot.wi.gov