IMPROVED UNDERBODY PLOWING

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ABSTRACT

One of the more severe winter hazards is ice or compacted snow on roadways. While three methods are typically used to combat ice (salting, sanding and scraping), little effort has been applied to improve methods of scraping ice from roads. In this study, a new test facility was developed comprising a truck with an underbody blade, which was instrumented such that the forces to scrape ice from a pavement can be measured. A test site was used with ice layers being sprayed onto the pavement and subsequently scraped from it, while the scraping loads were recorded. Three different cutting edges were tested for their ice scraping efficiency. Two of the blades are standard (one with a carbide insert, the other without) while the third blade was designed under the Strategic Highway Research Program (SHRP) H-204A project.

Results from the tests allowed two parameters to be identified. The first is the scraping efficiency which is the ratio of vertical to horizontal force. The lower this ratio the more efficiently ice is being removed. The second parameter is the scraping effectiveness which is related to the horizontal load. The higher the horizontal load the more ice is being scraped. The ideal case is thus to have as high a horizontal load combined with the lowest possible vertical load. Results show that the SHRP blade removed ice more effectively than the other two blades under equivalent conditions, and did so with greater efficiency and control. Furthermore, blade-angles close to 0° provide for the most efficient scraping for all three blades.

The study has shown that field testing of plow blades is possible in controlled situations and that blades can be evaluated using this system. The system has potential to be developed in many ways to provide the means for optimal ice scraping with improved safety for plow operators.

INTRODUCTION

Maintaining safe driving conditions in winter weather is a complex task. Accordingly, a variety of approaches are used to keep road conditions as safe as possible. There are three main methods used to remove snow and ice from the road surface. The first is to use salt, or another chemical, to depress the freezing point and thus melt the snow and ice from the road surface. The second method is to use sand to increase the friction of an ice-covered road and by that make the road more driveable. Often this method is combined with the first by applying a mix of salt and sand to the road. This creates an immediate improvement in traction caused by the presence of the sand and allows the salt to melt the ice over time. The third method is to remove the snow and ice mechanically by means of a plow. This can be extremely effective in heavy snow falls, but tends to be much less effective when ice or compacted snow is present on the pavement surface. These materials can form very strong bonds with the road surface and are hard to remove by scraping.

Of the three methods given above to remove ice from roadways, salting is probably the most widely used method, but it also poses several problems. Salt can cause serious degradation of bridges and pavements, and corrosive damage to automobiles. Environmental concerns, such as contamination of ground water and damage to vegetation, are also associated with the use of salt. Furthermore, the use of sand may lead to hazardous levels of airborne particulate. Given these concerns over the use of salt and sand, investigating methods of improving ice removal by scraping seems prudent.

Recent studies have shown that the shape of the cutting edge used on a plow blade is very important in determining the loads acting on the plow. These studies, which were part of the Strategic Highway Research Program (SHRP), examined the effect of several parameters on the forces required to remove ice from a sample of pavements in the laboratory (*1,2*). Some parameters studied included clearance angle, attack angle, rake angle, and blade flat width. These parameters are shown in Figure 1. It was found that if a blade had a non zero clearance angle (specifically, in this series of experiments, if the clearance angle was 2° or greater) then the forces on the blade were reduced by a factor of twenty when compared with a blade with a zero degree clearance angle. It was also found that the scraping forces increased when the blade flat width was more than 9.5 mm (3/8").

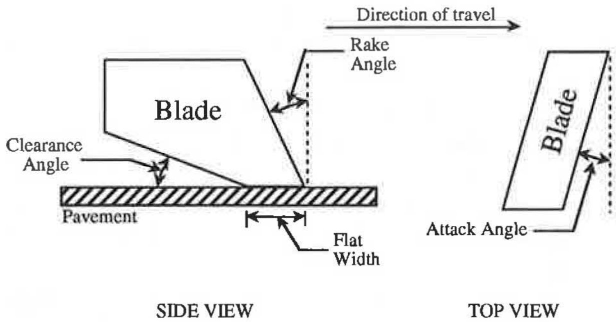

FIGURE 1 Definition of terms used in SHRP study.

The tests performed in the laboratory were under much more ideal conditions than those found on true road surfaces and were also on a much smaller scale. Because there is a lack of data on the loads experienced by a snow plow during ice removal, the need for full scale tests with current snow removal equipment became apparent. Accordingly, a project was conducted in which a truck with an underbody plow was instrumented. The instrumented plow was then used to scrape ice off a road surface. A full description of these results is given elsewhere (*3*).

The purpose of this paper is to discuss some results from the instrumented plow study from the aspect of how they might lead to improvements in underbody plowing techniques and designs. A brief description of the experimental method and results is presented, followed by a discussion of ways in which these results could be implemented to optimize ice and compacted snow removal by mechanical methods.

EXPERIMENTAL METHOD

The tests were performed using a 1975 International Fleetstar 2050 25 ton gross vehicle weight (GVW) dump truck on loan from the Iowa Department of Transportation (IDOT). The truck was fitted with a Wausau truck grader (Model HH8-7983-5) from now on called an underbody plow. The underbody plow was bolted to the truck's frame midway between the front and rear axles. Five hydraulic control levers in the truck's cab allowed the operator full use of the underbody plow. The driver controlled the left and right vertical position (and thus download), the blade-angle, cast-angle, and cast-angle-lock. The most significant benefit of an underbody plow is the ability to place a variable download on the cutting edge or blade of the plow. This cannot be accomplished with standard front mount blades or "skippers" as they are called. Blades of this type have only their own weight for a download force. Underbody plows on the other hand can have download forces that approach the truck weight.

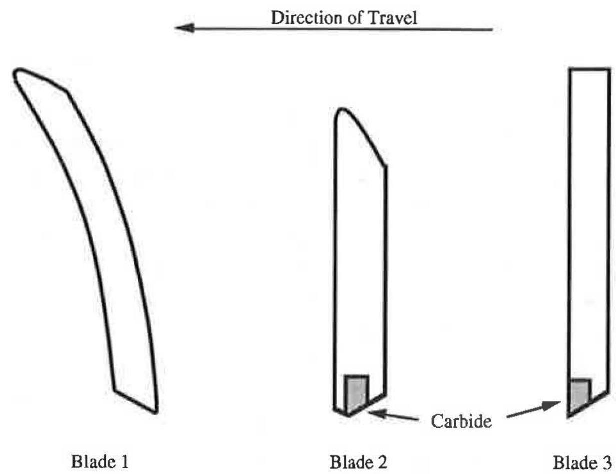

FIGURE 2 Cutting edges used in experimental study.

The cutting edge or blade was bolted to the blade support to allow for easy replacement. For this series of tests three different blades were tested. The first was a standard steel blade that came with the truck. This blade was 18 x 125 x 2440 mm (3/4 x 5 x 96 inches). The other two blades both had carbide inserts. The first was a commercially available blade, built by Kennametal. The second was a custom designed and built blade. This blade was designed under the Strategic Highway Research Program (SHRP) project H-204A, and built for use with this truck. The geometries of the blades are shown in Figure 2. The second and third blades were nearly the same dimensions as the original blade, except that each was made of two sections that were 1220 mm (48 inches) long.

Forces on the blade were measured using pressure gages in the hydraulic lines to the cylinders responsible for the download force or vertical displacement and the rotation of the blade. For this three International Pressure Products ST-420 0 - 20 MPa (0 - 3000 psi) gages were used; one gage for each side of the vertical motion and one for the pair of cylinders that rotate the blade-angle. Each gage had a self-contained signal conditioner that converted the pressure measurements into a voltage signal, which was recorded by a computer. After the calibration of the system, the vertical and horizontal forces on the blade were determined from the pressure gage data. The angle that the blade had with the pavement was measured with an inclinometer. A Schaevitz Angle Star Protractor System was used for this task. The inclinometer was located on the left side of the blade in a protective box.

Data signals from the sensors were collected on a portable PC. For these tests a Kontron IP Lite was used. This PC was chosen because it was shock rated for operation up to five g. This shock rating was needed to guarantee normal data acquisition because the truck bounced greatly during testing. An analog to digital circuit board in the PC allowed the software to collect and store the data. A Metrabyte DAS-8 analog to digital board was used along with the CODAS data acquisition software by Dataq Instruments. Data was written to the PC's hard drive during testing and then analyzed after testing at the Iowa Institute of Hydraulic Research (IIHR) ice laboratory. Power for the computer and sensors was obtained from the truck batteries through a power inverter and filter system built at IIHR.

All tests were performed at the spillway apron of the Coralville Reservoir located approximately five miles north of Iowa City. This site was chosen because it was flat and inaccessible to the public during the winter months. Water was sprayed onto the pavement surface using a truck mounted tank and spraying system. Water used to make the test ice was obtained from the University of Iowa Water Treatment Plant and taken to the testing site where the temperature of the water and the air were recorded. The water was then sprayed on the concrete using the previously mentioned spray system. The water was applied by driving back and forth over the testing area. The area covered was approximately 7.7 x 55 m (25 x 180 ft). The truck traveled at approximately 0.62 m/s (2 ft/s) during the spraying process. Provided the temperature was low enough, the water was frozen within two minutes, and the entire 2800 liters (750 gallons) were sprayed in 40 minutes. The ice was then left to harden overnight and the testing took place the following morning. The ice sheet formed was six to 12 mm (1/4 to ½ in.) thick. Further details of the ice sheet preparation process are given in Reference (*3*).

To provide better tire traction during testing, the area around the tank in the box of the truck was filled with gravel, and the tank was filled with water. This gave the truck a total weight of 20 Mg (44,000 lb.) with a full tank of water. Air temperature at the concrete surface, ice thickness and ice conditions were recorded before testing. The truck was positioned in line with the ice sheet approximately 46 m (150 ft) from the ice. This allowed enough distance for the truck to accelerate to the desired testing velocity of 24 kph (15 mph). The angle of the blade was set using the display of the inclinometer in the cab. When the truck began to drive on the ice, the download on the blade was applied until the desired pressure was shown on the computer screen in the cab of the truck.

The pressure gages were calibrated by means of a set of calibrated hydraulic jacks. The blade was first set in position, the jacks were then used to push against the blade at known increments and the voltage from each pressure gage was recorded by the computer at each increment. The known pressures of the jacks was then used to relate the voltage directly to a force and the calibration coefficient was calculated. This was performed for both horizontal and vertical components of the blade force.

Vertical force on the blade was calculated from the readings on two pressure gages located on the hydraulic cylinders for the vertical motion. Horizontal forces were determined from the pressure in the cylinders that rotate the blade-angle. This pressure however, includes a vertical component that varies with the blade-angle. As the blade-angle increased, the pressure in the cylinders due to the vertical component also increased. From recording the pressure due to a known vertical load over a range of angles, the relation between angle and vertical loads was determined. Calibrating in this way allowed for the change in the lever arm length of the blade mechanism, or how the mechanical advantage changed with the angle. Once the vertical component was known for a given download, as a function of the blade-angle, the horizontal force on the blade was determined. The calibration of the inclinometer required measuring the blade-angle with a protractor level for various angles and determining the calibration coefficient.

The testing parameters studied were the blade, down pressure, and angle of the blade. For each of the three blades previously described the down pressure was tested at a low (3.45 MPa - 500 psi) and high (8.27 MPa - 1200 psi) value. These were the value of the pressure in the hydraulic cylinders responsible for the download. The angle of the blade was set to nominal values of 0°, 15°, or 30°. In reality, these values were not achieved with great accuracy, but a sufficient range of angles was tested to provide some measure of the effect of the angle on the forces. Due to the physical limitations of the system, achieving the 0° blade-angle for blade two and three was not possible. A total of 65 tests was conducted.

RESULTS

Examples of raw data obtained from the sensors on the truck are shown in Figures 3 and 4. For this test

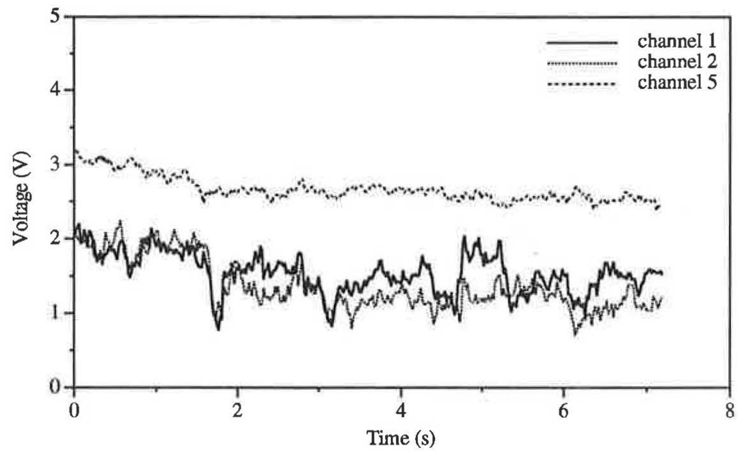

FIGURE 3 Raw data from sensors for test number 28.

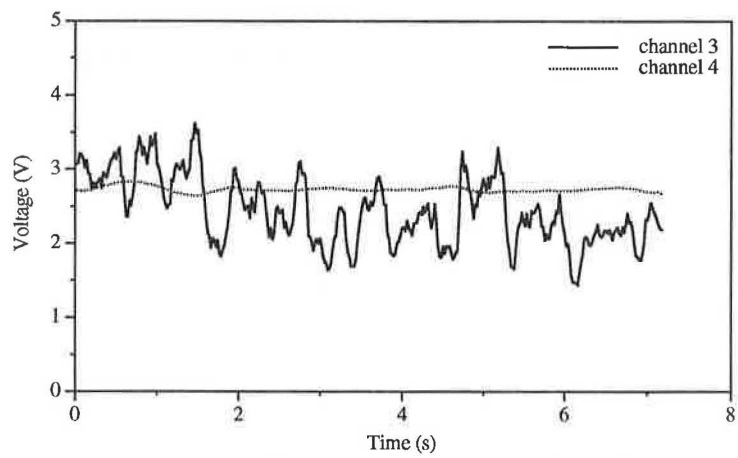

FIGURE 4 Raw data from sensors for test number 28.

(number 28) blade three was used with a low download pressure and a blade-angle of 30°. Figure 3 displays the voltage from the left and right download sensors and from the speed wheel showed as channel one, two and five, respectively. Figure 4 displays the horizontal loading cylinders and the blade-angle sensor, shown as channel three and channel four, respectively.

The raw data can then be transformed to show the loads, blade-angle and speed of the truck as shown in Figures 5 and 6. The vertical force is the sum of channels one and two. The horizontal force is the difference of channel 3's recorded force and the force due to the vertical loading as determined from the calibration of the system. It should be noted that all values are plotted against the distance traveled from the beginning of the test. The starting point was taken as the point where the raw data of channel one and channel two leveled off indicating that the download pressure was no longer being increased. A complete presentation of the test results is given in Reference (*3*).

One aim of this project was to maximize the quantity of ice removed by scraping. The more ice removed by the blade, the greater is the effectiveness of the blade. From the test results it appears that the quantity of ice removed is directly proportional to the horizontal load. Accordingly, in this study, it was assumed that the horizontal force is a measure of the effectiveness of the blade, with a higher horizontal force suggesting a higher effectiveness. It should be noted, however, that it is not clear how well effectiveness is consistent from blade to blade. Thus a horizontal force of 50 kN on blade one may not be as effective (i.e., may not remove as much ice) as a 50 kN horizontal force developed by blade three. Further work is required to

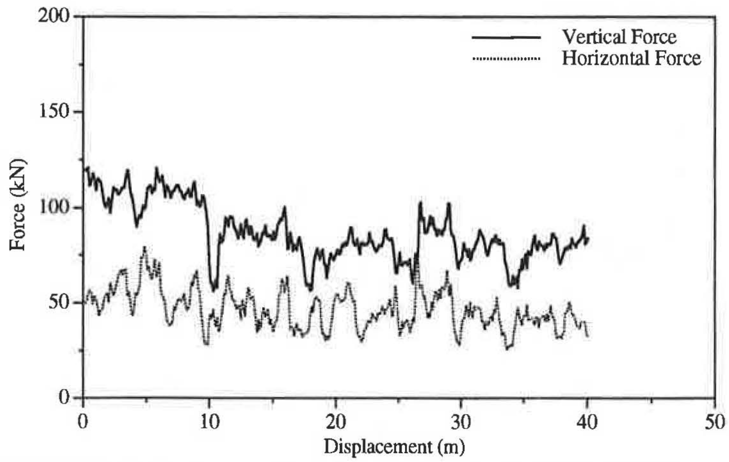

FIGURE 5 Vertical and horizontal forces on blade for test number 28.

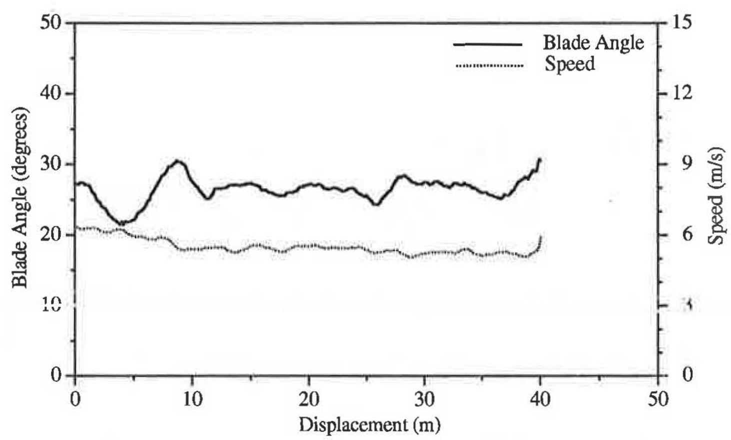

FIGURE 6 Blade-angle and speed of truck for test number 28.

develop this correlation. Nonetheless, a high horizontal load is desirable.

Working against the benefit of a high horizontal load is the tendency of the blade to ride up onto the top of the ice surface, thus cutting no ice. To counteract this tendency to ride up, a vertical download is applied to the blade essentially forcing it into the ice. This vertical load is not directly beneficial to the scraping process, other than forcing the blade into the ice. Further, a high vertical download is cause for concern because it reduces traction from the truck's axles, and makes the truck rest predominantly on the cutting edge. Accordingly, the most desirable condition for ice scraping is a high horizontal load (implying much ice removal) and a low vertical load (implying the truck is supported on its axles, rather than on the blade). Thus the ratio of vertical to horizontal force provides a good measure of what might be termed scraping efficiency. However, some care must be taken in the use of this force ratio, because when both vertical and horizontal loads are very low, no ice is being cut. Very low values of the force ratio may be observed, apparently implying excellent scraping efficiency, when in fact no ice is being scraped at all. As the value of the force ratio rises it suggests the condition of the blade riding across the surface of the ice as opposed to scraping of the ice. The ideal situation for ice removal is thus a low efficiency ratio and a high effectiveness (horizontal force).

Using the efficiency ratio allows a comparison to be made among the three blades. The mean efficiency ratio is plotted against the mean blade-angle for each test and shown in Figure 7. Not all tests are shown,

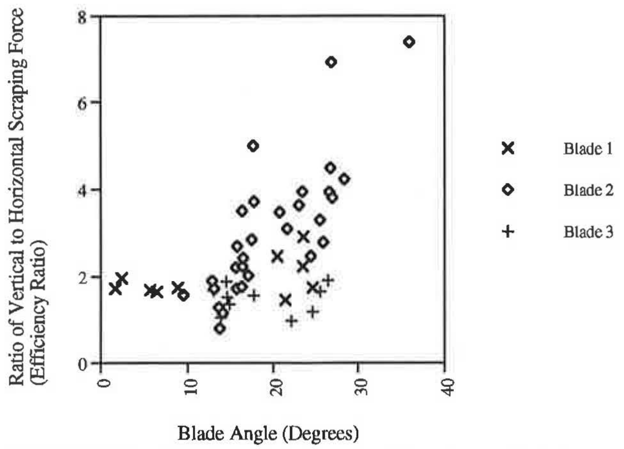

FIGURE 7 Efficiency ratio as a function of blade angle.

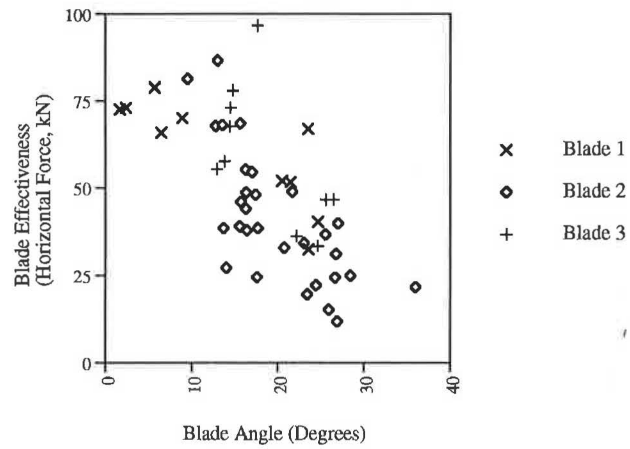

FIGURE 8 Effectiveness as a function of blade angle.

since some results were greatly affected by excessive wear of one blade during a severe storm. The horizontal force experienced by the blade during testing allows a comparison to be made of the scrapingeffectiveness of the three blades. The mean horizontal force for each test is plotted against a mean blade-angle in Figure 8.

As can be seen in Figures 7 and 8, there is a considerable scatter in the results. Such scatter is to be expected given the nature of field tests. After some statistical analyses (*3*) three trends became apparent. First, the blade effectiveness clearly decreases with increasing blade-angles for all three blades. Second, for blade two only, the efficiency ratio increases with increasing blade-angles. Third, of the three blades, the best overall performance was given by blade three. The implications of these results are considered below.

FUTURE DIRECTIONS

There are three major implications of the study undertaken on the Iowa DOT truck and reported in (*3*). The first is that there now exists a test bed upon which a variety of underbody blades and cutting edges can be tested. The effectiveness of these blades at removing ice and compacted snow from pavements can be measured in a rational and quantitative way, and thus blade designs and operating conditions for ice and snow removal can be optimized. Some work still needs to be undertaken before the full potential of this system can be realized. In particular, it must be shown that the results obtained in the "closed track" field trials reported in Reference (*3*) represent real field conditions. It is hoped that a study will be undertaken to verify these results, which will provide confidence that the "test bed truck" can provide useful guidance for operating trucks. One result in this area that shows the promise that this "test bed truck"notion may hold is the excellent performance of the SHRP blade which outperformed the other two "traditional" blades at ice removal. In short, the "test bed truck" has the potential of delivering significantly improved ice and compacted snow removal cutting edges.

Another major area of technological promise is that of providing more information to the truck operator. From discussions with truck operators the standard way of setting underbody plow blade down pressures is apparently, quite literally, by the seat of the pants. This means that training new operators is difficult and costly, since such a calibration method of necessity implies a high degree of experience. By using data from the pressure sensors, the download and horizontal force experienced by the underbody blade can be displayed directly in the cab, enabling the operator to adjust the pressure much more accurately and effectively, and thus allowing "good" plowing even by inexperienced operators.

The third area of potential development lies in the possible use of computers to control the plowing process. This would have significant safety benefits, since operating both the truck and the plow on an icy road is hazardous. It would also provide the optimal ice removal conditions, if an expert system was created which ensured that those conditions were created by adjusting pressures and blade-angle. The start of such an expert system lies in the work already done and described herein, in which the ideal blade-angle and combination of horizontal and vertical force were found. The system would have to incorporate the experience of current operators also. While such a system might be futuristic, many pieces for such a system are already in place on the test bed truck. The benefits of such a system would include improved safety, plow performance and a reduced need for highly experienced plow operators. Of course, developing such a system will be costly, but the final product need not be too expensive and should provide a healthy cost-benefit ratio.

CONCLUSIONS

From the work performed in this study, the following conclusions can be drawn.

- A test technique was developed which can measure and record forces on a cutting edge while scraping ice in near field conditions. The testing apparatus is available to use with other blades and can be a useful tool in the development of new cutting edges.
- Two parameters (efficiency and effectiveness) were defined which provide a measure of how well a cutting edge removes ice from the pavement. The efficiency is the ratio of vertical to horizontal force. The lower this is the more ice is being removed for a given download. Effectiveness is related to the horizontal load. The higher the horizontal loads is the greater the depth of ice being removed.
- Three blades were tested and compared in this study. All three blades performed best (removed the most amounts of ice) at angles close to 0° with high downloads. Blade three displayed the best effectiveness and efficiency of the three blades by removing the largest amount of ice with the smallest vertical to horizontal force ratio.
- Advances in computers and feedback control systems make it possible to develop an automatic control system to adjust the blade (angle and download) for the best scraping performance. Concomitant with development of such a system is the need to survey practitioners who operate plows with underbody blades, to help in the development of the expert system required to exercise computer control over the cutting edge during testing. Besides optimizing ice removal, an automated computer controlled system of this sort would have significant safety benefits.
- Many further tests could be made using the system developed in this study. The system is now operational. Its use is limited only by the scope of testing required. Possible tests that could be conducted include the following:
  - Tests of other, more exotic cutting edges, such as scalloped blades;
  - Tests of automated systems as described in the previous point, along with in-cab display systems to provide more operator information;
  - Tests of the relationship between horizontal forces and the depth of ice removed; and
  - Tests of the effectiveness of chemical pre-treatment on ice scraping forces.
- The final series of tests which are an obvious development of such a system are a full scale field trials. While this limited field study has suggested that the new cutting edge appears more effective than a regular cutting edge, only field use will determine if this is really the case. Accordingly, a study could be envisaged in which two trucks in a given District are equipped with appropriate measuring devices, one with the new blade and one with a more standard blade. They would be deployed in appropriate weather (with suitably trained personnel) and real comparisons between the two cutting edges could be made. Now that forces have been measured successfully on one truck, the application of similar measuring devices to other trucks is much simpler, and more easily accomplished.

ACKNOWLEDGMENTS

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