ACKNOWLEDGMENTS

The members of the technical panel below contributed to the successful completion of this study.

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INTRODUCTION

The Safety of the traveling public and our maintenance workers is of great concern to the South Dakota Department of Transportation. The Department of Transportation has experienced numerous accidents involving snow plows. The most serious problem seems to be the "rear-end" accidents on the interstate system.

The major contributor to the snow plow accidents seems to be the cloud of snow that is thrown up by the blade and caught by the wind. By using a blade that curls the snow rather than throwing it to the wind, the snow cloud may be reduced. These accidents may also be prevented by using a lighting system that motorists can see from a greater distance in low visibility conditions.

BACKGROUND

In the past years, there have been numerous rear end accidents involving snow plows, which may be attributed to poor visibility. Accident information for South Dakota snow removal equipment in the last five years is shown in Table 1. Also shown at the bottom of the table is the total number of hours maintenance forces have spent removing snow. The information was collected from the SDDOT Division of Operations Employee Injury and Accident Report.

Table 1 ACCIDENT SUMMARY

Region	88-89	89-90	90-91	91-92	92-93
Aberdeen	0	1	3	5	4
Mitchell	2	3	4	2	2
Pierre	3	1	1	2	4
Rapid City	2	5	2	3	1
Totals	7	10	10	12	11
labor hours plowing snow	58136	38864	45412	40469	49027 *
Labor hours snow & ice removal(not truck)	16028	6837	8484	8772	8510 *

* 92-93 Hours shown are up to February 5, 1993

These statistics indicate the DOT needs ways to improve snowplow visibility or to provide additional warning to the driving public. It was for this reason a technical panel was formed to fully define the problem and to develop project objectives and tasks, which are outlined later in the project definition section of this report. The panel decided the objectives of this study would be to determine which configuration of a variable angle blade would reduce the snow cloud further than the blades presently used and to determine whether brighter strobe lights with different flash patterns would increase visibility of snow plows over the present SDDOT lighting systems. This technical panel consisted of an SDDOT operations engineer, two maintenance coordinators, a maintenance foreman and research personnel.

A snowplow truck is approximately 8'6"- 9'6" tall and the snow cloud created behind the truck when removing snow from

the road, hides the truck from the driver's view. The wind will lift the snow as it comes off the snowplow, creating a snow cloud behind the truck. Direction of travel and wind direction will determine if there is a snow cloud behind the truck. The snow cloud is the worst when the wind blows the snow coming off the snowplow across the back of the truck. A flexible blade which may be adjusted by the operator on-the-fly may be able to reduce the snow cloud under various conditions.

The lighting system the DOT presently uses does not provide adequate lighting during plowing operations. The current uniform lighting system for DOT snowplow trucks is the Iowa Light System adopted on February 21, 1984. It consists of a revolving light of at least 50,000 candlepower with one mirror on each side of it, directed toward the rear of the truck. The system is mounted in the center of the cab guard. The Iowa Light configuration is shown in Figure 1.

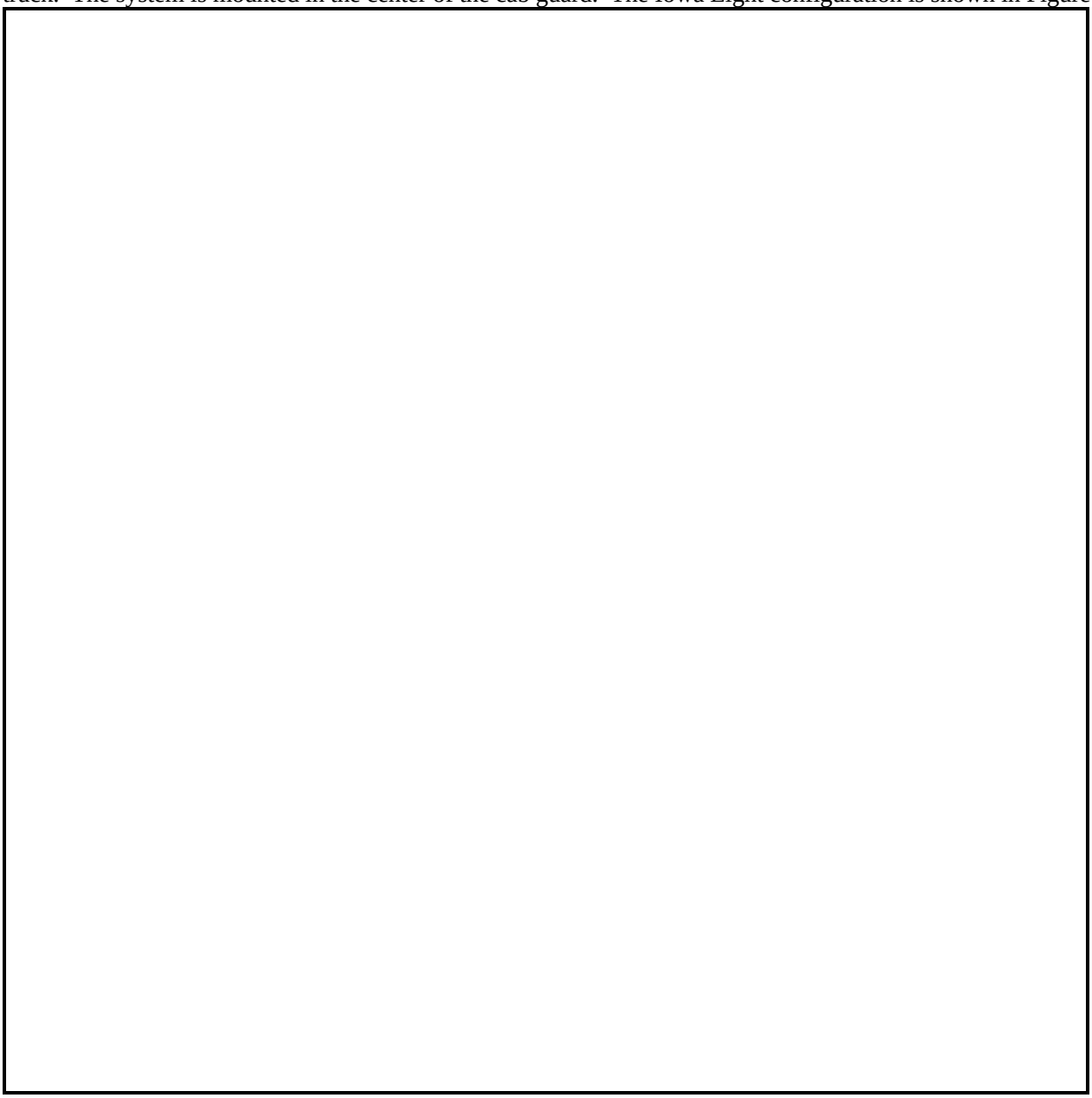

Figure 1 Iowa Lighting System

The Minnesota Department of Transportation, Light Study Report of 1989 listed the "snow cloud" created by the

snowplowing operations as a contributing factor in 54 percent of the accidents. Most of the accidents reported involved vehicles rear-ending the plow truck. The report also stated the warning light effectiveness on snowplow trucks decreased during the daylight hours.

The Strategic Highway Research Program (SHRP) has recognized that present plow designs aren't efficient. Fuel is wasted and equipment life shortened because of the forces working on the plow while handling the snow. SHRP is currently researching changing the design of snowplows.

PROJECT DEFINITION

Research Objectives:

1. To determine which configuration of a variable angle blade will reduce the snow cloud further than the present blades.

2. To determine whether the Minnesota DOT lighting system increases visibility over the present SDDOT lighting system.

Research Tasks:

1. Prepare a work plan for this study;
2. Review available literature relevant to snowplow safety;
3. Install the variable angle blades;
4. Install the Minnesota DOT snowplow light system;
5. Determine method for observing equipment in operation;
6. Observe the equipment in field conditions and determine the following for each configuration;
   a. Height of blade
   b. Angle of blade
   c. Distance the lights may be seen
7. Determine whether the lighting or blade configuration would adversely affect the operator or motorists

WORK PLAN

The Technical Panel met at the DOT Central Office in Pierre, SD on October 22, 1991 and discussed the methods to be used during the study and other issues connected to the problem of accidents involving snow plows. The panel reviewed current warning lights and plowing equipment the DOT was using. The type and number of warning lights were different on snowplow trucks across the state. They even varied between Areas, in the same Region. These included using revolving lights mounted above the cab guard, with amber flashing lights, revolving lights, light bars, and cat eye lights mounted in different configurations on the rear of snowplow trucks. These various light systems used by DOT shops across the state indicate a need and a desire to be more visible to other vehicles on the highway.

The work plan for the study is as follows:

1. Install lights and flexible blades on trucks in Aberdeen, Mitchell and Rapid City regions.

2. Use a video camera to tape the lights and plows during snow removal.

3. Video tape the trucks from behind at 200, 500, and 1,000 feet.

4. Measure and record snowplow configurations and observations in each region. The data collection form is shown on the next page.

5. Determine if the three lighting systems used in this study increase visibility over the current SDDOT light system.

6. Determine how weather conditions affect the snow cloud when plowing snow.

7. Provide report including methods and findings by June of 1993.

Weather and snow conditions were to be collected during the videotaping. Information regarding the warning lights was also to be collected and recorded. The form used to record relevant information in this study is found below.

Snowplow Time of Day_____1. Plow Angle _____

2. Forward End Curl_____
3. Trailing End Curl_____

4. Temperature_____ Wind Direction_____
Humidity_____ Wind Speed_____
Type Snow:
Wet_____ Fluffy_____
Dry_____ Light Snow Fall_____
% Coverage_____ Heavy Snow Fall_____5. Vehicle Speed____ _____

6. Videotaped Distance:_____
200 ft._____ During Snow Fall_____
500 ft._____ During Cleanup_____
1,000 ft._____

Observations:_____ _____ _____

Lighting System

1. Videotaped Conditions:

Bright Sun Light____ Snowy Day_____
Cloudy Day_____ Snowy Night_____
Clear Night_____ Fog_____
During Plowing_____ Distance Videotaped_____
During Snow Fall____ at, _____ feet
During Cleanup_____

2. Record weather conditions and vehicle speed in numbers 4 & 5, above in snowplow section.

3. Vehicle Type & Light Type:
Vehicle No._____ Brand_____
Single Axle Truck____ Candle Power_____
Tandem Axle Truck___ Flash Rate_____
Road Grader_____ Flash Duration_____
Pickup_____ High or Low_____

4. System Configuration (Include Light Height):_____

5. Observations:_____

LITERATURE REVIEW

The National Cooperative Highway Research Program located in Washington, D.C. started research Project 6-12, "Improved Visibility for Snow Plowing Operations" in 1991.

The objective of the study is to identify and evaluate equipment improvements to increase visibility for snow plow operators and motorists. They are going to study numerous items including lighting systems, plow equipment and attachments (deflectors & belting) to see how they affect the operator's visibility. The final report should be available sometime in 1993.

"Rear Warning Light Configuration on Sander/Snowplow Trucks" Alberta Transportation and Utilities, of Edmonton, Alberta, Canada, 1992.

Two studies were done on rear lighting configuration of snowplow trucks from 1988-1990. Different types of lighting were experimented with including light sticks and halogen seal beams. The configuration they liked the best was two red clearance lights along with two amber flashing lights mounted above the sander at the rear of the truck. They retrofitted their trucks with these lights. They continued to use the rear revolving amber light along with the new clearance and amber flashing lights. The rear-end accidents were reduced from 14 to 4 accidents the year following the retrofit.

"Snowplow Scoop and Design Method" Strategic Highway Research Program (SHRP) Washington, D.C., April 1, 1993. SHRP has recognized that present plow designs aren't efficient. SHRP is currently researching changing the design of snowplows. With the use of a computer they have found that the compaction ahead of the plow causes most of the energy waste. They have installed a snow scoop in front of the cutting edge which reduces snow compaction. The final report will be out in 1993.

"Snow Plowing at 60 Miles per Hour" E.B. Hodgins, Maintenance Engineer, New Hampshire Department of Public Works and Highways, Public Works for August, 1971.

The New Hampshire Dept. of Public Works and Highway improved the warning systems on the snowplow trucks because of accidents resulting from vehicles overtaking the snowplows. They still had accidents so they hoped to reduce the accidents by increasing the speed of the plow truck. They used different plows mounted under the center of the truck. A test section was set up on Interstate 89, signs were installed warning traffic not to pass the plows. They had no accidents with the high speed plowing which is probably a direct result of installing the warning signs.

"Minnesota Department of Transportation, Snowplow Light Study" John Hale - Editor, Minnesota DOT, 1989. The study focused mainly on improving the warning light the Minnesota DOT was using, thereby improving the visibility of the snowplow trucks. The development of a new light manufactured by Whelen was a direct result of this study. The design of wings and snowplows was also considered in the study. Wing design proved to contribute to the creation of the snow cloud, they concluded that a wing shaped with more curl should be used to make the snow roll instead of fanning it out. Two wings were designed for use, but they had limited use.

The conclusions from the 1987-1989 test period are listed below:

1. A very slight snow cloud blocks out any light configuration installed on trucks.

2. Yellow (360) degree strobes mounted on door mirrors are not effective.

3. The Whelen DOT-2H strobe light with a white lens is quite visible.

4. Lights should be mounted on the cab shield, or higher, because the snow cloud is not as dense at that height.

5. The dancing effect created by the flashing strobe lights mounted on the cab shield and truck box "outlines" the snowplow.

6. Rotary lights perform well because they revolve slowly and thus the light can be seen for a longer period of time.

7. It wasn't possible to distinguish the three different colors when seen from a distance. Only the light burst was seen.

The significant recommendations of the Minnesota Task Force is listed below:

1. Install the Whelen "Minnesota DOT Design" strobe light system at 1.5 million peak candle power per strobe on all 1988 and newer trucks.

2. Continue to monitor the two Cameron wing designs.

3. Attempt further changes of plow and wing designs, to help reduce the snow cloud.

4. Review snow plowing operation procedures to determine if the snow cloud can be reduced and thereby reducing the potential for accidents.

5. Develop public information items.
   a. Make use of Public Service Announcements of prime-time commercial TV stations.
   b. Develop training packages for driver training classes.
   c. Revise the Minnesota Driver's Manual to include snowplow information.
   d. Promote public awareness through the use of billboard ads.
   e. Prepare Speaker's Bureau packets on this subject.

The Literature review information contained in the Minnesota DOT, Snowplow Study of 1989 showed 3 studies related to warning lights. These studies were as follows:

"Emergency Vehicle Warning Systems" A.I. Rubin, G.L. Howett, National Bureau of Standards, Washington, D.C. May, 1981.

The study gave information on signal effectiveness, signal visibility, and factors relating to a warning system. This report recommended standardization of lighting, using effective colors in combination, specifically alternating with white, and greater intensity, along with more effective duty time.

"Information Transfer Characteristics of Moving Light Signals" J. Berkhout, Human Factors Laboratory, Department of Psychology, University of South Dakota, Vermillion, S.D. 1979.

The study rated eight configurations and color combinations of rotating-beam emergency vehicle lights. Its focus was on flash rate and direction of travel when viewed at night. The main points were that information was only 25%-33% perceived; twin beams gave good indication of travel of vehicle in motion but gave the false perception that the vehicle was moving away when it was actually standing still.

"Conspicuity of Beacons for Emergency Vehicles" R. Kare, Dept. of Psych. University of Upsala, 1974.
The study supplied graphs comparing various types and colors of warning lights under different lighting conditions. The results indicated that the rotating orange beacon appeared to be most effective under the largest number of

lighting conditions.

The Literature search provided some beneficial information. The Minnesota study recommended using the Whelen DOT-2H lights and a different blade to keep the snow close to the ground. The Alberta study information was not available until the SDDOT research study was done. The lights added in the study apparently helped to reduce rear end accidents. The Panel decided to install the lights and variable angle blades to determine if visibility is improved over the present snow removal equipment.

VARIABLE ANGLE SNOWPLOW INSTALLATION

The Aberdeen Region, Mitchell Region, and Rapid City Region, installed a Frink Revers-a-Cast Plow, Model RAC 3351-RR on one truck in each Region. This snowplow was selected because the curvature of the moldboard is adjustable to any plowing conditions. The objective was to determine which configuration of the variable angle moldboard plow would reduce the snow cloud behind the truck. The moldboard is made of 3/8" thick polyethylene. To plow dry snow it can be curved down to 33" or if plowing wet snow the discharge end can be opened to 51". The snowplow is 11 feet long. The curvature of the moldboard and the plow angle is changed using hydraulic cylinders. The snowplows cost $7,286.00 each, purchased by the SDDOT Office of Research. The Frink Revers-A-Cast Plow is shown in Figures 2, 3 & 4. Literature on the Frink plow can be found in Appendix A.

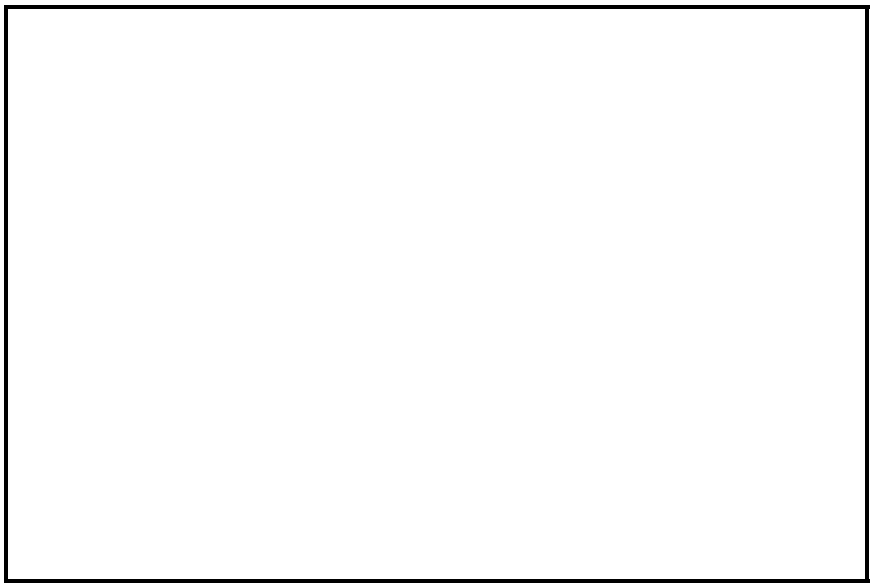

Figure 2 Frink Revers-a-Cast Plow

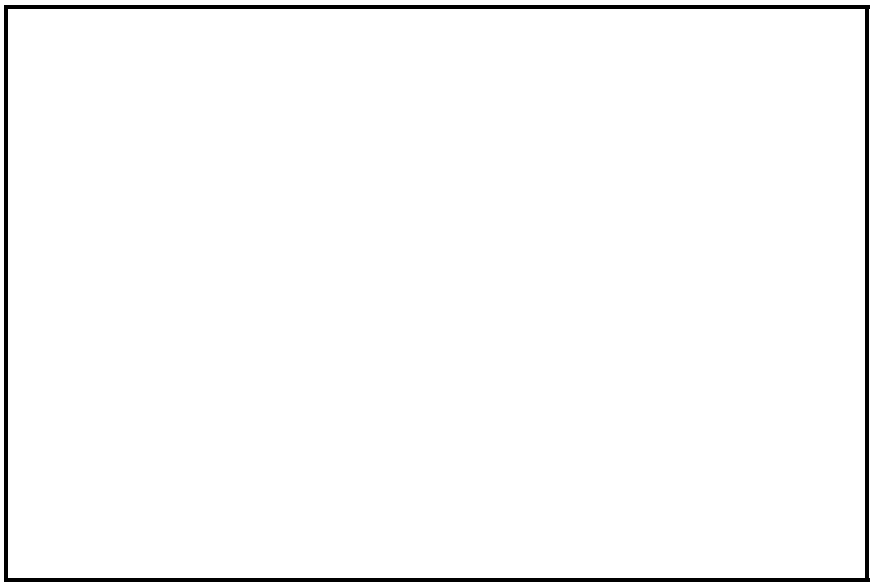

Figure 3 Frink Revers-A-Cast Plow

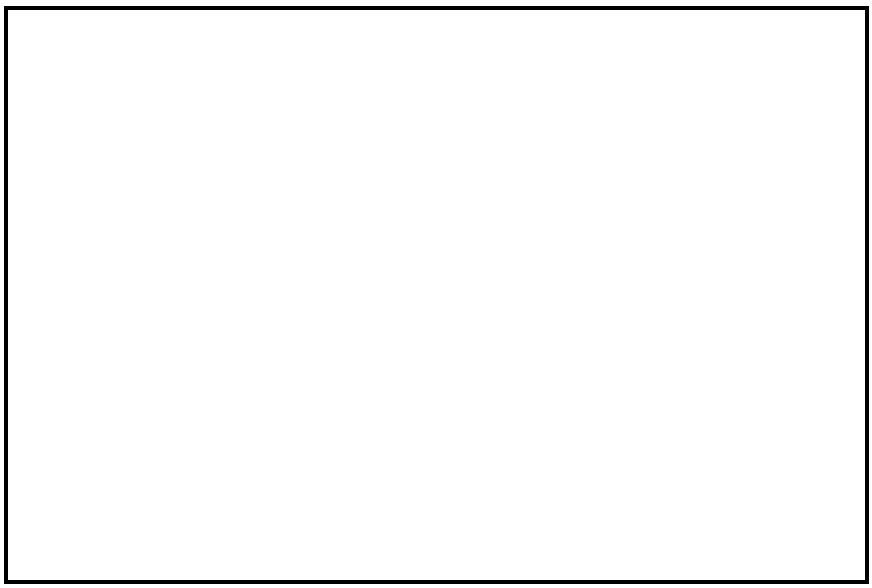

Figure 4 Frink Revers-A-Cast Plow

The Frink plows were mounted by SDDOT maintenance mechanics at each region repair shop in January of 1992. The Mitchell and Rapid City regions mounted the plows tandem axle trucks. The Aberdeen Region mounted the plow on a single axle truck. The plows were mounted on the same trucks that had the Minnesota DOT-3 light systems. The light systems and the snowplow could then be observed and data recorded at the same time. Operators were told to observe the new snowplows and note any benefits and/or disadvantages. The plows were observed and videotaped during 1992 and early 1993. There was not very much snow during this period, so little information was collected.

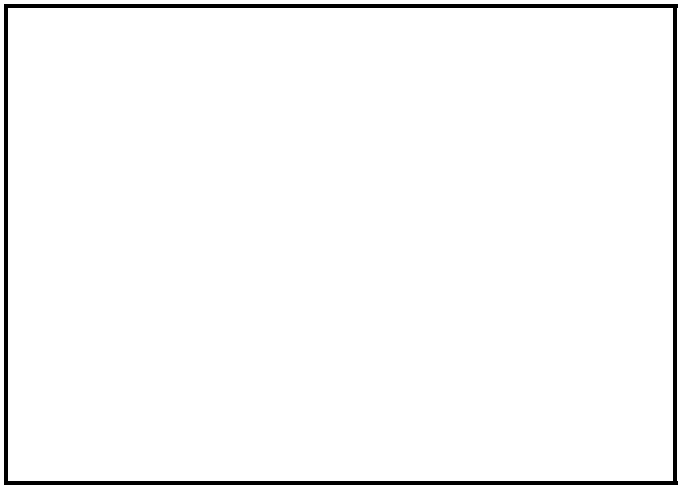

Figure 5 Mitchell Truck - Whelen System 102-C

LIGHTING SYSTEM INSTALLATION

Whelen strobe DOT 3 "System 102-A" was installed on a truck in the Rapid City Region and a Whelen strobe DOT 3 "System 102-C was installed on a truck in the Mitchell Region. This is a three light system with a 360 degree strobe mounted above the cab guard and two rear vertical mounted strobes. The light systems are shown in Figures 5, 6 & 7.

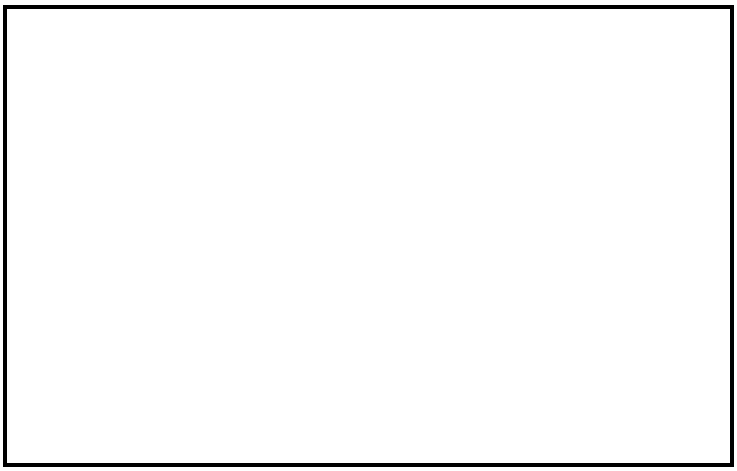

Figure 6 Mitchell Truck - Whelen System 102-C

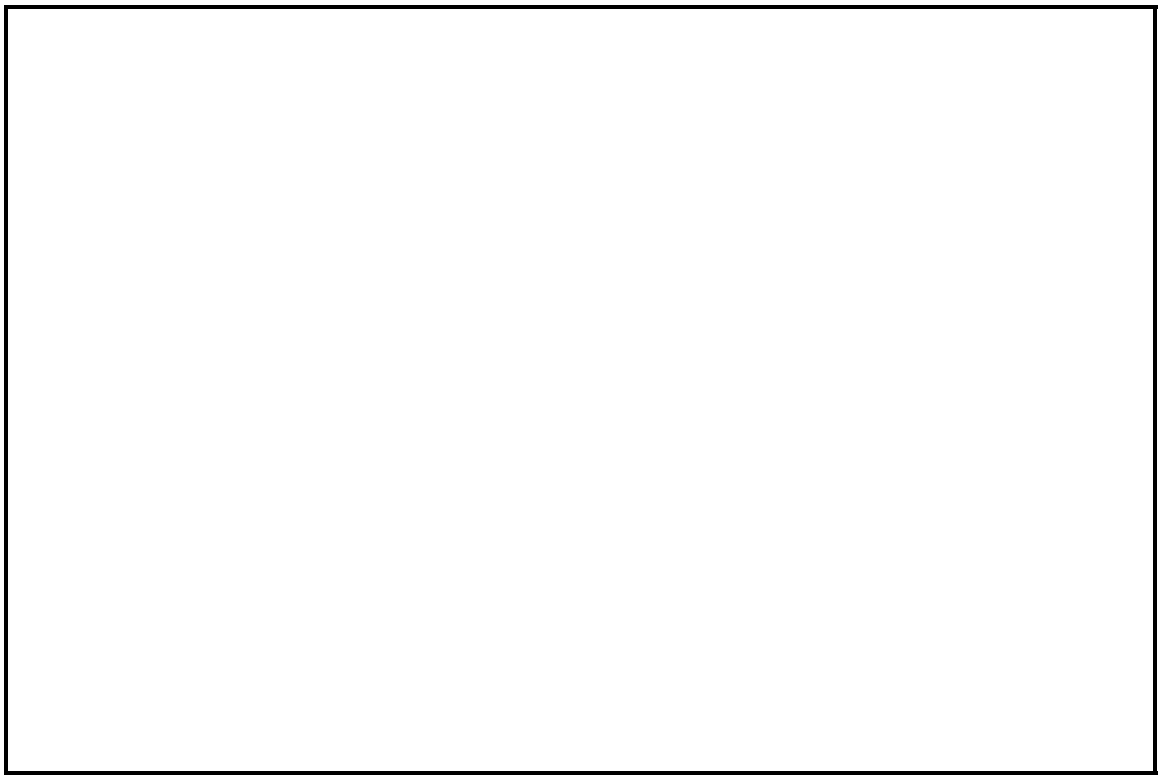

Figure 7 Rapid City Truck - Whelen System 102-A

A Whelen strobe DOT 3 "System 101-D" was installed on a truck in the Aberdeen Region. This is a four light system with one light mounted above each mirror on the truck cab and two rear directional strobes mounted on the side of the truck box. All three light systems were installed in early 1991. The Whelen "System 101-D" is shown in Figures 8 & 9.

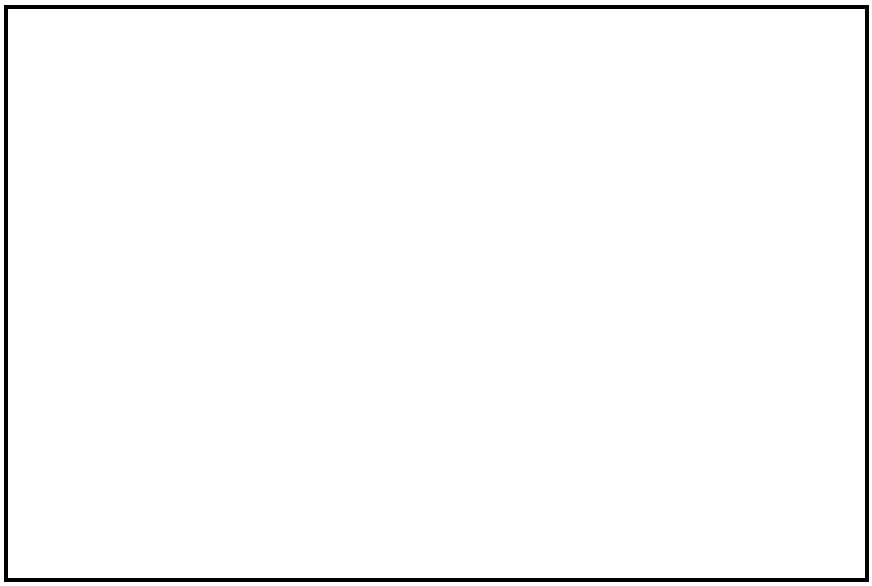

Figure 8 Aberdeen Truck - System 101-D

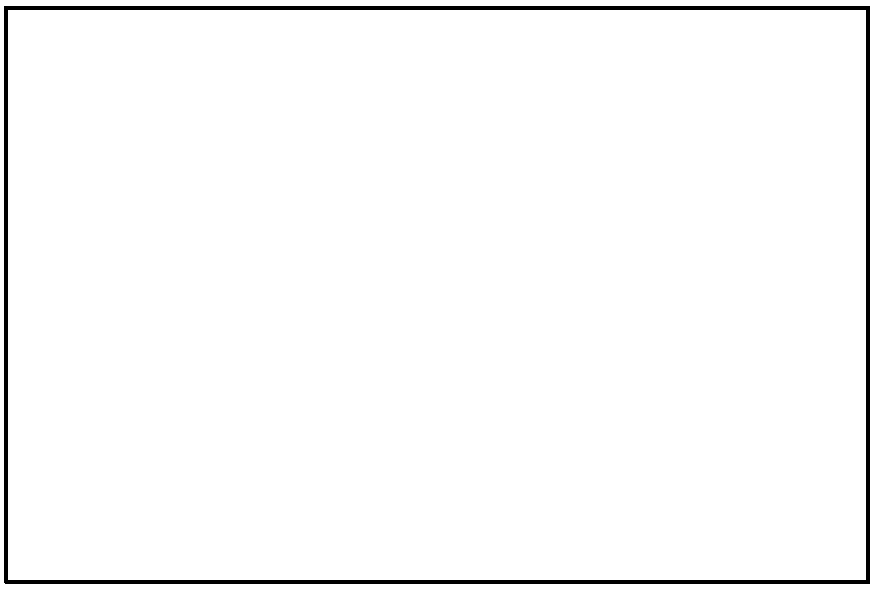

Figure 9 Aberdeen Truck - System 101-D

The Mitchell Region installed a Whelen (360 degree) strobe for testing. The Aberdeen Region also installed a Target Tech (360 degree) strobe, an Austin 2 light directional strobe system, and a Whelen (360 degree) strobe for testing. Other lights besides the Whelen DOT 3 lights were chosen for testing because the Regions felt we needed to try other lights that were less costly to determine if they would perform well enough to be used on our snowplow trucks. The lights were purchased by the Aberdeen and Mitchell Regions. Light configurations are described in Table 2.

Table 2 Summary of Lighting Systems

Vehicle Number	Light Brand	Light Height Measured from ground level to bottom of light
DL038	Target Tech Superstrobe	10'7" left side 11'0" right side - one light mounted on each corner of cab guard
	Changed to Whelen SS-360C on 11-13-92	Superstrobe 12'0" - mounted in center of cab guard; has prism mounted on each side of strobe 14" from each light
DF219	Whelen DOT 3 System 101 D	8'6" high cab mirror mounted 6'2" box mounted
DL575	Target Tech	10'8" Mounted in center of cab guard; had diamond grade reflectors on each side of strobe 14" from light
	Austin system RP-200S	12'0" 2 strobes mounted on rear of sander, one on each corner
	Target Tech was replaced with Whelen SS-360C on 11-16-92	11'1" mounted in center; it has mirrors on each side of strobe mounted 14" from light
DL056	Whelen Comet 3 light system	Superstrobe 9'10" mounted in center of cab guard; has prism on each side of strobe 14" from light
		11'0" - 2 strobes mounted on rear of sander, one on each corner
DL039	Whelen DOT 3 System 102-C	Model 6H strobe mounted in center of cab guard 11'4"; one strobe light mounted on each side of box 6'8" from ground at rear of truck
DL527	Whelen 360C	Superstrobe 11'4" mounted in center of cab guard
DL528	Whelen DOT 3 System 102-A	Model 6H strobe mounted in center of cab guard 11'; one strobe light mounted on each side of box 6' from ground at rear of truck

The joule rating, type of flash, and flash rate of the strobes tested are shown in Table 3 below.

Table 3 Lighting Information

BRAND	MODEL	JOULES	TYPES OF FLASH	FLASHES PER MINUTE
Target Tech	951	16	Single	80
Austin	RP-200S 2 Light System	20	Double	70
Whelen	360C	24	Four	80
Whelen	DOT-3 System 101-D; 4 Lights	98	Double	F-140 R- 70
Whelen	DOT-3, 102-A,C 3 Light System	52	Double	F-70 R-70
Whelen	Cometflash 3 Light System	54	Four	F-70 R-70

Note: Joules rating includes total of all lights in a system. One joule is equivalent to the work done when a current of 1 ampere is passed through a resistance of 1 ohm for 1 second.

F= Front Lights R= Rear Lights

Table 4 Lighting cost and warranty information

BRAND	MODEL	HIGH-LOW	WARRANTY	COST($)
Target Tech	951	No	1 Year	105.00
Austin	RP-200S 2 Light System	No	Flash Tube-6 Mo Power Supply-18 Mo	195.00
Whelen	360C	Yes	Flash Tube-2 Yrs Power Supply-5 yrs	200.00
Whelen	DOT-3 System 101-D	Yes	Flash Tube-1 Yr Power Supply-5 yrs	1200.00
Whelen	DOT-3 System 102-C	Yes	Flash Tube-1 Yr Power Supply-5 Yrs	800.00
Whelen	DOT-3 System 102-A	Yes	Flash Tube-1 Yr Power Supply-5 Yrs	830.00
Whelen	Cometflash 3 Light System	Yes	SS-361 Strobe-2 Yrs Power Supply-5 Yrs 2 Rear Strobes-1 Yr	405.00

The Whelen DOT-3 light systems were installed at each Region maintenance repair shop by maintenance mechanics in March

of 1991. The Mitchell and Rapid City Regions mounted their light systems on tandem trucks. The Aberdeen Region mounted their light system on a single axle truck. Selection of trucks on which to mount the plows was based upon the maintenance unit in which the truck was located. The truck needed to be located close to the observer's work station for effective data and video recording. The other lighting systems the Aberdeen Region tested were mounted on snowplow trucks at various times during 1991 and 1992, by the region repair shop. The trucks selected were from the local maintenance unit again for ease of observation and data recording by the observer.

METHOD OF OBSERVING EQUIPMENT

The lights and snowplows were videotaped by using a camera mounted in a trailing vehicle. Weather conditions were recorded to help determine if they contributed to the snow cloud behind the truck. Conditions such as light or heavy snow, wet or dry snow, wind direction, and wind speed were recorded. The height of the forward end curl and trailing end curl was recorded to help determine if different configurations would reduce the snow cloud. These measurements were taken before videotaping the snowplow during the snow removal process.

The snowplow truck was videotaped at distances of 200, 500, and 1,000 feet. These distances were determined with a range tracking system. The lead vehicle (snow plow) contains a distance measuring instrument (DMI), a range transmitter and an antenna. The trail vehicle contains a DMI, a range receiver/comparator, and an antenna. The distance between the vehicles is compared and displayed on the comparator in the trail vehicle. This equipment was used only on truck number DL575. Distances between the trail vehicle and other snow plows was estimated. These distances were used to determine whether the warning lights would penetrate the snow cloud. The information recorded was day or night, cloudy or sunny, snowy, foggy conditions, and if the snow removal process was done during cleanup or initial plowing. The information was recorded to help determine how the lights performed under all conditions. Videotaping the snowplow truck worked very well. By using the video camera and also recording the data on paper we had a permanent record of the light and snowplow test. The only limitation to videotaping is that the camera does not record the bursts of light nearly as well as the naked eye.

OBSERVATIONS OF SNOWPLOW AND LIGHT SYSTEMS

A. Snowplow Observations

Aberdeen Region

The lower the moldboard is curled down, the closer snow stayed to the ground as it was discharged. It also reduced the amount of snow that blew back on the cab and windshield of the truck.

Example 1: When the front end is curled down to 45 inches and the trailing end curl was set at 51 inches the snow traveled a few feet farther into the ditch than it did when the moldboard was curled down all the way at both ends. The plow was at a 37 degree angle and cutting a path 8'9" wide. When the plow was set at 51 inches the wind was blowing the same direction as the snow was being discharged. When the plow was curled down all the way at 33 inches on both ends, the wind was blowing against the discharge end. The wind was blowing at 13 mph during both situations. When plowing against the wind there was a very slight snow cloud and the truck could still be seen. The truck was traveling at 25 mph during both observations and there was only a light wet snow fall.

Example 2: With the front end curl set down all the way and the trailing end curl set at 51", then 39", then 33". The results of these various setting are listed below:

1. 51 inches; The snow cloud behind the truck was 10-12 ft. tall and hides the snowplow truck.

2. 39 inches; The snow cloud was 9-11 ft. tall and still hides the truck.

3. 33 inches; The snow cloud was reduced, could see the top of the sander and truck better.

The plow was at a 37 degree angle and cutting a path 8'9" wide. The wind was blowing at 13 mph against the discharge end of the snowplow. The truck was traveling at 25 mph, there was only 1.5 to 2 inches of dry snow. The snowplow truck operator reports that the plow stays down and cuts the snow very well.

Mitchell and Rapid City Regions

The Mitchell and Rapid City Regions like the Frink plow. The plow cuts the snow better than other plows. The snow cloud is reduced and the ability to change configuration is a great advantage.

B. Light Systems Observations

Aberdeen Region

Light systems were observed and videotaped during 1991, 1992, and early 1993. The snowplow trucks were followed at 200, 500, and 1,000 feet and the necessary information was recorded. The trucks were videotaped when plowing snow during the day under cloudy and sunny conditions. They were also videotaped at night. The lights were more visible under cloudy weather than in sunny conditions. The lights are very visible during nighttime use.

The DL038 truck had 2 strobes mounted on the cab guard, one on each corner. The Whelen Superstrobe light could be seen better than the Target Tech under most conditions because it flashes more often. The Target Tech is a single strobe and the Superstrobe is a double-flash strobe light. During cloudy, snowy weather conditions the lights could be seen from a distance of 1.5-2.0 miles.

Truck number DL575 had a strobe mounted with a Diamond Grade sign sheeting reflector installed on each side of the strobe in the Iowa Light configuration. This reflector did not enhance the effectiveness of the light. The reflectors were replaced with mirrors. The mirrors reflected the light toward the rear of the truck at night but during daylight conditions they had no effect on light enhancement. Two directional strobes were mounted at the rear of the sander, 12 feet above ground level. These strobes are double flash lights. This light system configuration is very noticeable. Under dark conditions the rear lights are bright. These lights can be seen one mile away in sunny conditions. The rear strobes have one power supply and the center mounted strobe has a separate power supply. When the truck had only the center strobe mounted, the light could be seen two miles away at night. This light system is shown in Figures 10 & 11.

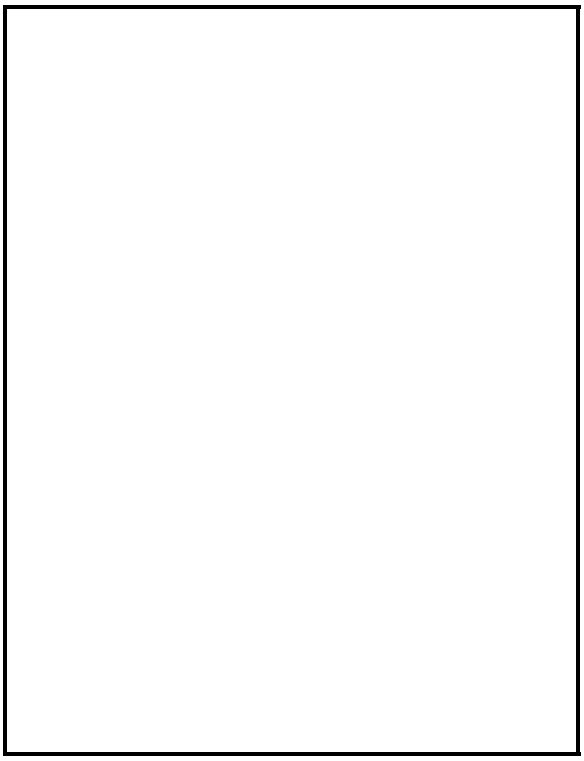

Figure 10 Aberdeen Region Truck

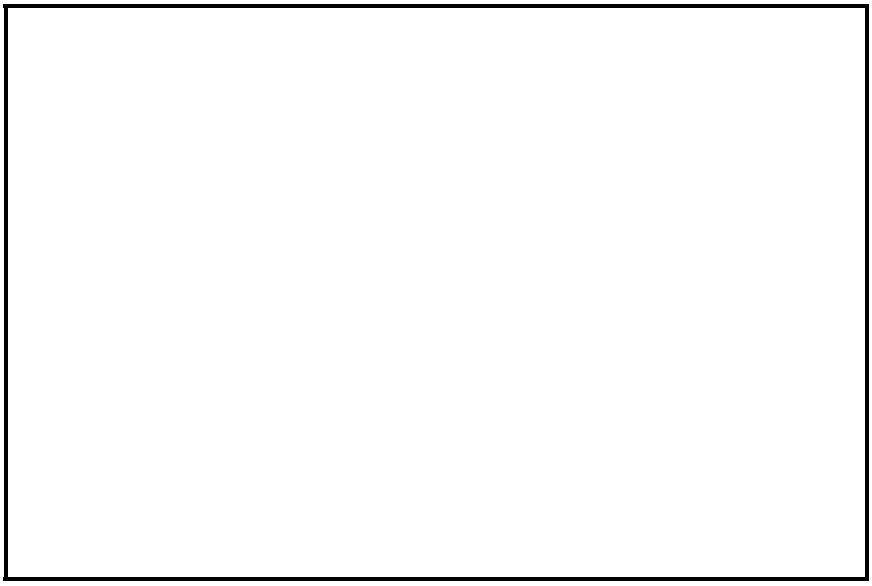

Figure 11 Aberdeen Region Truck

The DL056 snowplow truck had a 3 light system installed. It has one power supply that runs all three lights. This is a strobe system that has the Cometflash feature manufactured by Whelen. This feature provided four pulses per burst. The light is on for a longer period of time than the double flash light. The two directional lights mounted on the rear of the sander are eleven feet above ground level and the center mounted light is 9' 10" high. This system produces a very noticeable light at 200, 500, and 1,000 feet. The system is even more noticeable at night. The light system is shown in Figures 12 & 13.

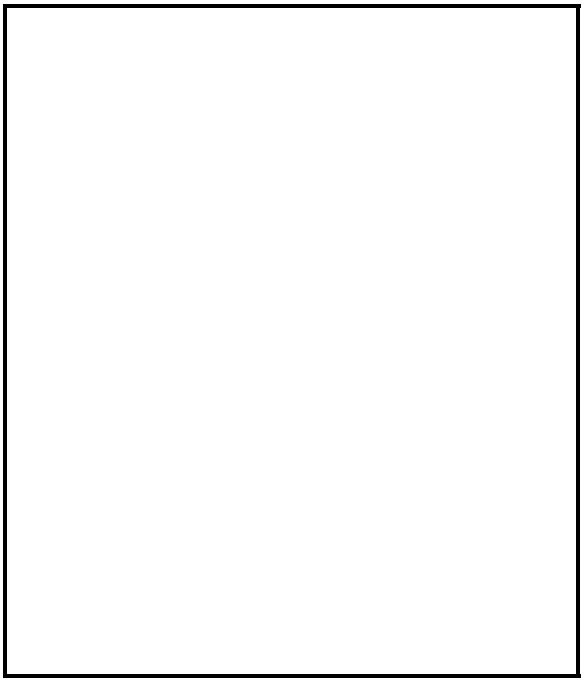

Figure 12 Aberdeen Region Truck

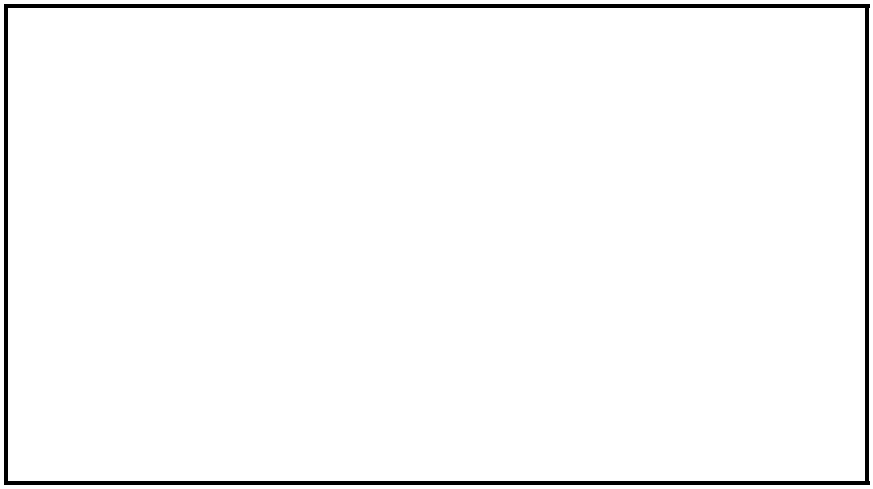

Figure 13 Aberdeen Region

The DL219 truck had the DOT-3, 101 Whelen light system installed. One light was mounted above each front cab mirror and the two rear directional strobes mounted at the rear of the box. This system is a double-flash strobe system. The front lights are 8' 6" above the ground and the rear lights are 6' 2" above the ground. The lights system has two power supplies mounted inside the truck cab, one for the front lights and one for the rear lights. During plowing operations in snowy, cloudy, or sunny weather the light system is very visible. The lights are mounted in the corners of the truck which defines and outlines the truck making it easier to see. These lights are really eye-catching, which informs motorists that there is an extraordinary vehicle on the highway. The light system produces 98 joules of light which is the largest amount of light produced by the light systems we tested. These lights are bright at night and have to be run on low power setting. This light system is available with the Cometflash feature which would provide more light because the lights are on longer and they would be even more prominent.

Mitchell Region and Rapid City Region

The DL039 truck had the Whelen DOT-3, 102 system mounted with the two rear strobes installed one on each the side of the box and the 360 degree strobe mounted in the center of the cab guard. The light system has one power supply and it produces a total of 52 joules. It is a double strobe flash system and can be seen under snowy, cloudy and sunny weather very well. The rear directional strobes should be mounted above the sander for better visibility.

The Mitchell Region also installed a Whelen 360C strobe on DL527 snowplow truck. It was mounted in the center of the cab guard at 11' 4" above ground level. This Cometflash light produces 24 joules and it is on longer than double flash lights. This light is shown in Figure 14.

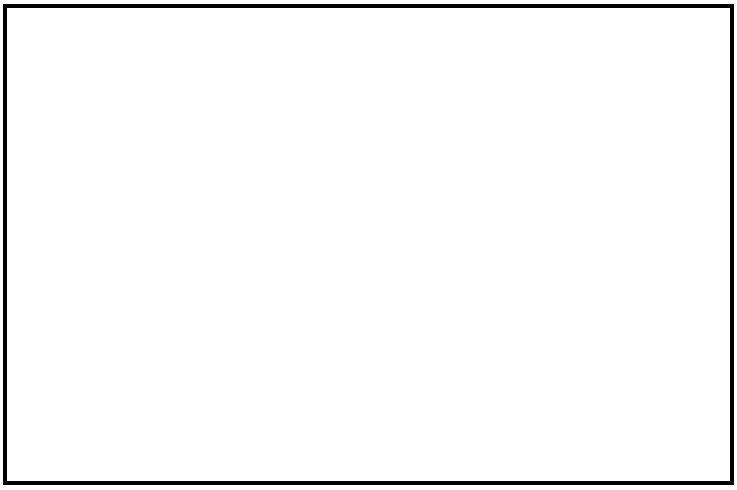

Figure 14 Mitchell Region Truck

Truck number DL582 at the Rapid City Region also had a Whelen DOT-3, 102 system installed on it. This system was also conspicuous during snow removal operations. The center strobe is 11 feet above ground and the two rear directional strobes are 6 feet above ground level. The light system gets the attention of traveling public. The rear directional lights should be mounted above the sander for better visibility. This light system can be seen from greater distances than the Iowa Light System.

Manufacture Recommendations

The Austin RP-200S light system is recommended by the manufacture to help protect from the common rear end accidents. The strobes are mounted in an impact rubber resistant housing, which pivots for adjustment.

The Target Tech 951 light is the brightest strobe Target Tech manufactures. The power supply is one-piece and is mounted for vibration protection. The 951 strobe is a recommended light for snow plows by Target Tech.

Whelen manufacture of the DOT-3 system light recommends the light for large slow moving vehicle because of the hazard they pose. The flashing, high intensity strobes identify the hazard and define the size and speed of the vehicle. The front strobes provide light to the front and sides of the vehicle. The rear mounted directional strobes provide an effective warning system to the rear of the vehicle. The supplier of the Whelen lights recommends buying a quality system that will last for a long period of time. Length of continuous usage should be considered when purchasing lights because some lights are only designed to run for short time periods.

The 360C Whelen strobe is designed for a variety of vehicles including highway maintenance vehicle. The manufacture recommends it because it is a highly effective, self-contained strobe designed for numerous application. The unique dome is designed to illuminate the flash over the entire lens surface.

LIGHT RELIABILITY

The Aberdeen Region has 80 lights installed on their snow plows. Of these lights, the following problems have been encountered:

A. The power supply for the Austin Model RP-200S (2) light system, mounted on DL575 burned out 1 year after it was installed and one of the PAR-36 bulbs burned out in April of 1992.

B. Both rear strobes of the Whelen CometFlash (3) light system burned out within 3 months of being installed on DL056.

C. One of the Target Tech Model 951 power supplies burned out just a little over one year of use.

E. We have replaced 2 power supplies on the Whelen 360 strobes in November of 1992.

F. The Target Tech Model 951 strobe affects the AM radio reception in the vehicles they were installed on.

The Mitchell Region said that the workmanship of the lights has been outstanding. There have been no repairs or burned out bulbs in the three installed systems in the two years they have been in use. The 360C Whelen Strobe hasn't caused any maintenance or bulb problems.

The Rapid City Region didn't have to make any repairs to the Whelen DOT-3 lights at all. They had four light systems which were all included in the study.

CONCLUSIONS AND RECOMMENDATIONS

This study consists of two parts, an evaluation of snow plows and light systems. Conclusions and recommendations are given here for each.

VARIABLE ANGLE SNOWPLOW

CONCLUSIONS

1. When the moldboard is curled down all the way it keeps most of the snow from coming over top of plow and onto the truck hood and windshield even in the wind.

2. The plow does keep the snow down closer to the ground at the discharge end and it reduces the height of the snow cloud behind the truck.

3. The truck operator reports that the plow stays down on the road and cuts the snow off better than the plow he had used previously.

4. There has not been enough snow to get a real good test of the plow since they were installed.

5. There were no adverse effects documented for the traveling public or for the snowplow truck operator, only positive results have be noted during the testing of the Frink flexible snowplow.

6. The plow reduces the amount of snow that is thrown up on the hood and windshield. This in turn reduces problems with vision, wiper blades, wiper motors, and windshields.

RECOMMENDATIONS

The results so far are very promising for this type of plow. Further study of the snowplow is recommended since there hasn't been very much snow since they were installed. This follow up research would be necessary to determine whether the flexible blades are effective enough to warrant buying more of them.

Objectives of further research:

A. Find an alternative for snow cloud reduction that could be achieved by modifying the fixed moldboards on current snowplows.

B. Determine if the added cost of the flexible moldboard and the reduction in the snow cloud would warrant changing from the fixed moldboard to the flexible moldboard.

Possible solutions to reduce the snow cloud of exiting fixed moldboard snowplows:

1. Install air foil on top of plow to deflect snow downward.
2. Install rubber flap on discharge end of snowplow.
3. Install metal deflection fin to lower discharge height of snow.
4. Install metal panel on the nose end of one-way snowplows to reduce snow coming around the end of the plow.

The Panel recommends the research should be conducted during the winter of 1993-1994. If enough testing is accomplished by the end of the period a recommendation should be given in the Spring of 1994. The benefits of such research could be great. Modifying the existing snowplows instead of purchasing new snowplows would save tax dollars. Benefits would also include an accident reduction for the DOT and the traveling public, therefore reducing injuries and preventing fatalities.

LIGHT SYSTEMS

CONCLUSIONS

1. Strobe lights are more visible than revolving lights, a strobe can be seen from a distance of 1 mile and a revolving light can be seen from a distance of one-half a mile during the daytime.

2. A slight snow cloud behind the truck covers up the warning lights.

3. Lights should be mounted as high as possible because they are seen quicker when the snow cloud disappears.

4. The DOT-3 "System 101-D" four light system defines the size of the truck and produces the most light of the systems we experimented with.

5. Truck operators need to keep all warning lights clean so they will emit the maximum amount of light available.

6. The warning lights can be seen better with the naked eye, than when viewed on the video tape.

7. The Whelen Cometflash (four flash) stays on longer than the double flash or single flash light, which makes it more detectable.

8. No light system can been seen through some snow clouds behind the truck under some conditions.

9. Need to use lights with a Hi-Low feature so they can be turned down on low during nighttime operation.

10. Mirrors used in the Iowa configuration block the warning light from view when the light is observed from the side of the truck.

11. The strobe lights do affect some people while following the trucks. One individual following a snowplow truck had to stop driving for about a half an hour to rest his eyes. Some snowplow drivers reported that they couldn't follow the truck ahead of them very close because the strobe lights were too bright. These incidents occurred at night but we don't know if the strobes were on high or low setting. The lights need to be prominent so drivers will avoid the snowplow trucks.

RECOMMENDATIONS

1. Install a three light strobe system on all trucks statewide over a three year period. There are 418 trucks statewide that need lights installed. The recommended three light system costs $400 per truck. The estimated cost per year is $55,733 for a total of $167,200 excluding labor. The three light system consists of one 360 degree strobe mounted above the cab guard in the center of truck and 2 directional rear strobes mounted a minimum of 11 feet above ground level or 1 foot above the top of the sander whichever is higher. The minimum specifications for the light system is listed below in Table 5. The new recommended light system is shown in Figures 15 & 16.

Table 5 Minimum Specifications for recommended three light system

TYPE OF STROBE	NUMBER	HIGH-LOW	JOULES	TYPE OF FLASH	FLASHES PER MINUTE
360 Degree	1	YES	20	Double	80
Rear Directional	2	YES	13	Double	70

Figure 15 Minimum Lighting System

2. Retrofit first trucks that plow on four lane divided and interstate roads. This consists of 173 trucks statewide. At a cost of $400 for the minimum lighting system, the estimated initial cost is $69,200.

3. Before purchasing lights, the warranty period and construction quality should be evaluated..

Figure 16 Two possible rear vertical strobe mounting locations

4. SDDOT should adopt methods to keep records of SDDOT snow plow and other maintenance vehicle accidents, including date, costs, causes and more specific category codes, which will be readily accessible to Division of Operations personnel.

5. The recommended specifications for an optional four light system is listed in Table 6. This system provides more light and warning capability, costs about $1200 per system, and is left to the region engineer's discretion.

Table 6 Minimum specifications for optional four light system

TYPE OF STROBE	NUMBER	HIGH-LOW	JOULES	TYPE OF FLASH	FLASHES PER MINUTE
Micro Edge Strobe Assembly	2	YES	60	Double	140
Rear Directional Strobes	2	YES	60	Double	70

The (2) Micro Edge Strobes may be mounted on each corner of the truck cab guard. The (2) Rear Directional Strobes shall be mounted the same as the rear directional strobes in the 3 light minimum system.

The benefits of installing the lighting systems will be accident reduction to the SDDOT and the traveling public. If an improved lighting system will reduce injuries, fatalities and property damage, replacing the warning lights on snow plows will have been well worth their cost.

Appendix