Improved Snow Plow Headlight Visibility and Reduced Driver Fatigue

Final Report 536

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16. Abstract

Inclement weather reduces visibility. This problem is further exacerbated by the need to mount headlights higher on the equipment so they shine over the plow blades. This often results in the plow lights being almost at the operators' eye level. This is the worst condition for reflecting light back into the snowplow driver's eyes, further obscuring their vision. This headlight position also reduces visibility for oncoming traffic since the headlights are higher than normal. The additional colored beacon lights that are used on plows as warning devices also reflect off of the snow into the operator's eyes. In addition to the reduced vision caused by these problems, increased driver fatigue is experienced.

The objectives of this research is to improve snowplow operator visibility and to reduce driver fatigue during plowing operations.

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LIST OF ACRONYMS

ADOT	Arizona Department of Transportation
DOT	Department of Transportation
ECE	Economic Commission for Europe (United Nations Regulations)
HID	High-intensity discharge
FMVSS	Federal Motor Vehicle Safety Standard
JDM	Japanese Domestic Market
LCD	Liquid crystal display
LED	Light-emitting diode
NHTSA	National Highway Traffic Safety Administration
PIAA	PIAA Corporation
SAE	Society of Automotive Engineers
TAC	Technical Advisory Committee

Executive Summary

Introduction

Plowing snow is very difficult, but very necessary. Inclement weather reduces visibility. This problem is further exacerbated by the need to mount headlights high enough on the equipment so they can illuminate the roadway when the plow is elevated to the travel position. This often results in the plow lights being mounted close to or at the snowplow operators' eye level, which is the worst possible placement during storm conditions because of the intense direct and indirect veiling light these lamp arrays generate obscures the operator's vision. A problem that is compounded by the additional flashing veiling light the rotating beacon(s) produce from the windshield forward. All of which increases driver fatigue and reduces safety.

The problems caused by the legacy snow plow lighting system doesn't stop with the plow operator, the high mount and existing beam patterns' glare also create a significant safety hazard for pedestrians on or near the roadway, on-coming and followed traffic. Since plowing snow is a difficult task, anything that obstructs or interferes with the operators' field of view, contributes to fatigue or creates a safety hazard for others should be minimized or eliminated.

This perennial problem was the focus of a National Cooperative Highway Research Program (NCHRP) study, report 250, Improved Visibility for Snowplowing Operations. In addition, the Arizona Department of Transportation (ADOT) has conducted several studies on efforts to improve winter storm operations and has made recommendations to improve plow operations. Though recommendations to improve visibility have been explored at the federal and state level, no specific recommendations on lighting configurations have been researched until now.

The objective of this research was to improve snowplow operator visibility and to reduce driver fatigue during plowing operations. This study was undertaken to evaluate a non-conformal asymmetrical shaped beam patterns as a possible solution. This research identifies the source of the problem, and provides recommendations on lighting configuration, equipment and policy suggestions to improve forward vision and safety while reducing debilitating glare and veiling light for the snowplow operator, motorists and pedestrians.

In Figure 2, the test snowplow was equipped with ADOT's typical automotive snowplow headlight and auxiliary lamp configuration, and a compilation of existing technologies to prove the hypothesis of the proposed asymmetrical shaped beam solution; purpose built for snow removal, high mounts, extreme conditions, to reduce fatigue inducing and operator safety impairing veiling light and to make snow removal operations safer for other roadway users.

Figure 1. ADOT snowplow headlamp configuration

As shown in Figure 2, the asymmetrical shaped beam system was comprised of DOT 4 harmonized HID high/low beam headlamps with modified asymmetrical left and right low beam patterns with stray light shield. In addition the headlights were mounted as low and far apart as practical thereby increasing the area without veiling light between them or structures to obscure the operator’s field of view. To further enhance the field of view in mission critical areas auxiliary lamps with sharp cutoffs were used to minimize both veiling light and glare for other roadway users. In extreme conditions each headlamp could be operated independently on high or low beam. The high beams retained their standard beam pattern.

Figure 2. ADOT standard headlamp configuration and asymmetrical shaped beam array

Conclusion
Asymmetrical shaped beams system is a matter of choice. Where do you want the light and where do you want it excluded from, and choosing the lamp and shield configurations to obtain those goals. The plow operator must have an optimized field of view absent veiling light that restricts their vision or increases debilitating stress and fatigue. With shaped beams this optimized field of view can be obtained while all but eliminating glare for the other roadway users.

Purpose built shaped beam systems will become easier to manufacture as technology advances, and using HID and LED light sources may live in many cases, the service life of the snowplows.

One phenomenon that became apparent was driver's lighting pattern preference was directly correlated to the driver's age. From interviews with the snowplow drivers, the older drivers rely more on close in illumination for guidance even when it is at the expense of distance. With a purpose built asymmetrical system these choices could be accommodated while still providing distance, too.

The asymmetrical shaped beam system in this study proved the hypothesis, that this is a sound platform base for a purpose designed standard and lamp array for snowplow use. However, further research may be necessary to convince the National Highway Traffic Safety Administration (NHTSA) to allow purpose built asymmetrical beam patterns to be used for snowplow use.

Background

Figure 3. High mount automotive headlamps required by law
Photo by David Gonzalez, Minnesota plow

NHTSA has now decreed that snowplows SHALL [13] use approved automotive headlamps as the primary lighting source. Thus, each project undertaken to solve the snowplow headlight problem, by mandate, incorporates as its core automotive headlight beam pattern configurations whose shortcomings are the primary source of problem. NHTSA suggesting to states it is ok to do as they wish (set their own rules) to plow with the automotive headlights turned off and rely only on the auxiliary lighting during storms, is not a solution. As for the auxiliary lamps, there is no guidance on use whatsoever for snowplow applications. Consequently, the status quo has left us with both headlights and auxiliary lamps that are inappropriate for snowplow use, opposing and followed traffic being permitted.

Figure 4. Clearroads.org, high mount light

Figure 5. MASS DOT, plowing with spotlights

As shown in Figures 4 & 5 some plow operators are using a myriad of even higher mounted light arrays, including cab-mounted spotlights to attempt to provide forward vision. When used to locate snow markers spotlights have been proven effective, but as with all these solutions it has been at the clear expense of other motorists.

ADOT was given a demonstration of existing shaped beam technologies to show how current snowplow lighting problems could be solved. The proposed asymmetrical shaped beam configuration received favorable support from the ADOT snowplow TAC team that chose to examine its merits with this study. The asymmetrical beam configuration implemented here is the culmination of years of field experience by the chief researcher equipping vehicles (commercial, racing, off road, snowplows, mining etc) to operate in extreme conditions: whiteouts, blowing snow, dust and sand storms, etc, at high and low speeds.

The issues addressed in this study include: 1) improving field of view while minimizing or eliminating veiling light for the operator, 2) making sure form factor and location of array reduced field of view obstructions, 3) minimizing veiling light from rotating beacon, and 4) minimizing or eliminating glare to other roadway users.

Prior Practice

Prior automotive headlight practice and how it relates to snowplow operation: Typical DOT, ECE or DOT 4 harmonized headlamps require identical overlapping symmetrical beam patterns where the driver is positioned behind the left headlight and its beam pattern. When combined with the typical mounting location necessary for snowplow use, the extraneous light these beam patterns generate exacerbates debilitating glare and veiling light for the plow operator, blinds opposing driver, followed vehicles, pedestrians, and they cannot provide adequate foreground or shoulder illumination.

FIGURE 6. ADOT SNOWPLOW LIGHT ARRAY, PARTIALLY OBSTRUCTING DRIVERS' LINE OF SIGHT

The test vehicle in Figure 6 before the asymmetrical shaped beam system was installed. Notice how large the physical size of the array is which included 4 large 100-watt KC fog light (without sharp cutoff). In addition to the glare, refracted light and obstructed forward view this large light array causes for the driver, its uncontrolled light creates a safety problem for opposing traffic, followed motorists and pedestrians walking on or near the edge of the roadway.

In extreme conditions many ADOT operators are also using their windshield pillar mounted spotlights to illuminate snow stakes on the shoulders. The beam pattern of the spotlight produces minimal stray light and has worked well in this task, but as it crosses the driver's line of sight it does interfere with forward vision, and it too is not advisable for use with either opposing or followed traffic.

ADOT standard snowplow lighting system and driver choice

The existing snowplow light array:

Pair - 200 millimeter SAE 108 rectangular halogen headlight:
  Broad uncontrolled beam, high outboard mount

Pair - Perlux sealed beam fog lights with shutters:
  Oval dispersed beam, mounted outboard under headlights

Pair - Hella Micro DE fog lights:
  Wide beam with sharp cutoff, low intensity, high mount inboard, housing magnesium

Typical snowplow headlight and auxiliary lighting system lamp arrays partially block [Figures 7-9] forward vision while their beam patterns create an intense zone of veiling light directly in the driver's line of sight. In addition, the rotating beacon further illuminates the suspended particles in front of the windshield. All contributing to reduced depth and field of vision, increased driver stress and eye fatigue.

FIGURE 7. ADOT SNOWPLOW LIGHTING ARRAY   FIGURE 8. ADOT LIGHTING ARRAY – CLOSE UP

As shown in Figures 4 & 5 some plow operators are using a myriad of even higher mounted light arrays, including cab-mounted spotlights to attempt to provide forward vision. When used to locate snow markers spotlights have been proven effective, but as with all these solutions it has been at the clear expense of other motorists

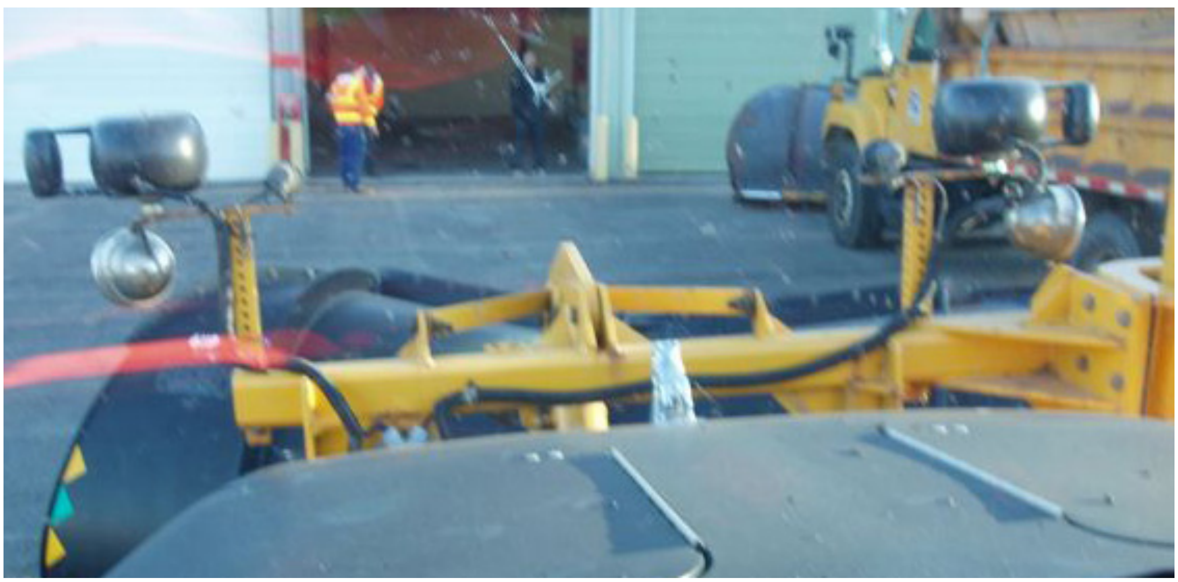

FIGURE 9. ADOT SNOWPLOW LIGHTING ARRAY FROM DRIVER'S VIEW

Note: Each driver to their personal preferences aims their truck's lamps and when comparing the stock set up to those trucks that are in field, it provides a consensus of the drivers' choice of what works best for them. Remarkably in Figures 7 & 9 both drivers have aimed their left fog light down to improve foreground lane guidance, variations of this was found on virtually every snowplow.

Shaped beam systems for snowplows

An asymmetrically shaped beam array can illuminate the roadway and the shoulders of the road, while eliminating or minimizing all refracted light sources within the drivers' direct line of sight. Thereby the driver can look into the illuminated area without having to look through light reflecting off of suspended snowflakes or ice crystals. Moreover this beam pattern can accomplish and maintain this optimum field of view even with opposing traffic.

What we do know is that during low visibility conditions the foreground and peripheral light becomes critical for the operator's guidance and lane position choices. On passenger vehicles the fog light pattern is low and wide to light the roadway ahead and shoulders below the line of sight, allowing the driver to see taillights and objects at greater distance through the minimized veiling light. In addition, further attempts to reduce veiling light is accomplished by many means in the automotive world, including placing the low beams in a set back position that does not allow horizontal stray light into the area immediately in front or above the hood line of the vehicle. The Volvo concept car here employs both the set back and vertical shields in their purpose built headlights.

FIGURE 10. VOLVO CONCEPT CAR HEADLIGHTS - SET BACK AND VERTICALLY SHIELDED MAIN BEAM

Caltrans' use of PIAA 959 fog lights below benefitted from the hood and the low headlamp mounting position for the same reasons. The operators consistently responded favorable to this configuration in Figure 11 that was originally installed in the mid 1990's and in operation today.

FIGURE 11. CALTRANS SNOWPLOW LIGHTING, DISTRICT 9: BISHOP, CALIFORNIA

Beam pattern, mounting location and the ability to control the zones that are illuminated are the critical ingredients of an asymmetrical shaped beam system. There are many ways it can be accomplished as shown on the Volvo shown in Figure 10 and the Caltrans plow, Figure 11.

Headlights

The asymmetrical shaped beam headlamp system was comprised of DOT 4 harmonized HID high/low beam headlamps with modified asymmetrical left and right low beam patterns and for optimum effect. In addition the headlights were mounted as low and far apart as practical thereby increasing the area without veiling light between them or structures to obscure the field of view. In extreme conditions each headlamp should be able to be operated independently on high or low beam. The high beams retained their standard beam pattern.

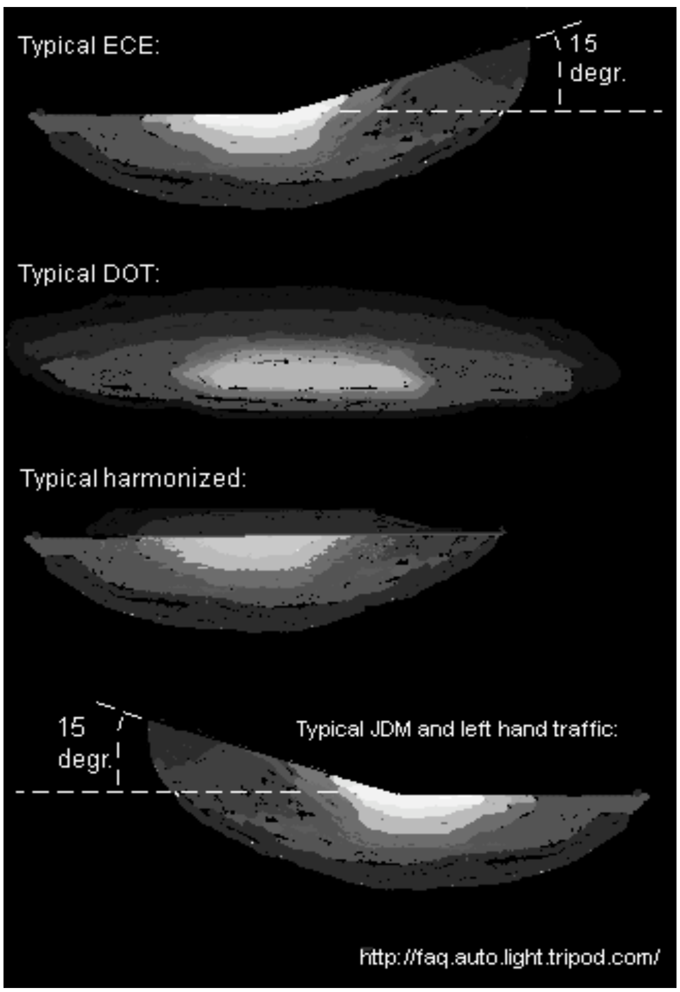

FIGURE 12. TYPICAL AUTOMOTIVE SYMMETRICAL LOW BEAM PATTERNS

Notice the typical ECE lamp has a razor sharp cutoff with no light above the cutoff. Likewise on our test vehicle, we added a horizontal light shield to our asymmetrical left and right beam patterns to virtually eliminate all stray light above the cutoff of the HID harmonize beam headlights we modified for this test. In Figure 12, the Japanese Domestic Market (JDM) mirror the ECE standard for vehicles that drive left of the centerline.

The object of the harmonized beam pattern as shown in Figure 12, is to have a sharp cutoff on the left side (2.5” per 25’ forward down gradient) to illuminate the road without creating glare for the opposing driver. Whereas the higher cutoff beam pattern on the right is to illuminate the shoulder and road signs without placing the intense beam in followed vehicle(s) rear view mirrors. The vertical rise to the right begins at the centerline of each headlamp.

For snowplow use when the driver is placed behind the light beam, the US automotive beam patterns and typical mounting position of the left headlamp contributes to a significant increase debilitating veiling light as illustrated in Figure 12 ‘typical DOT’ and ‘typical harmonized’. In particular look close here in Figure 13 at the left headlight’s beam pattern, notice the light’s intensity flares higher to the right, from the center of the left headlight thereby placing most intense part of the beam directly in front of the driver at eye level. Creating an intense veiling light source directly in the driver’s line of sight, the equivalent to driving with high beams on in a whiteout. Even if they could be mounted lower, the amount of refracted veiling light directly in front of the vehicle is very problematic. This is well known and mitigated for by the auto manufacturers in their headlight designs, by recessing the main beams as Volvo did in Figure 10 it minimizes the veiling light source immediately in front of the driver.

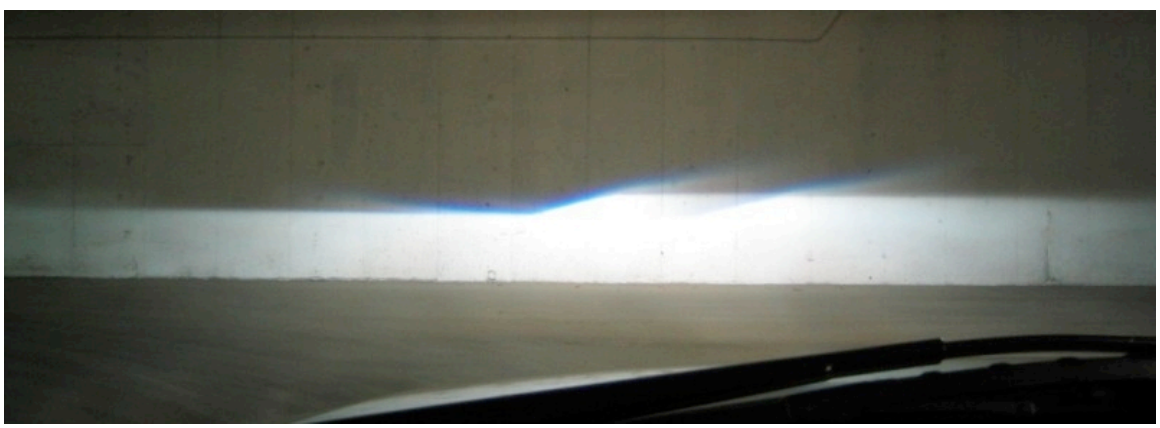

FIGURE 13. HID DOT 4 AUTOMOTIVE HOMOGENIZED BEAM PATTERN; 2 HEAD LAMPS

Lamp choice is critical because there are great inconsistencies in automotive headlamp and auxiliary beam patterns regardless of the manufacturers’ nomenclature. Compounding this, and unique to the US, NHTSA has required, by law, that there be significant light above the horizontal plane to illuminate overhead signs. Regardless of merit in automotive applications, this sign illuminating veiling light source is not needed for high mounted snowplow lighting configurations. Hence, our current STANDARD headlight for snowplow use includes: copious amounts uncontrolled direct and indirect veiling light sources, inconsistent, yet symmetric, beam patterns and inadequate coverage.

Creating asymmetrical shaped beam systems.
Left low beam: Flat beam pattern with sharp cutoff with no light above the horizontal axis, and all light greater than 30 degrees to the right of the vertical center axis was also blocked.

Right low beam: Stock homogenized beam pattern, with all light above the horizontal cutoff and 35 degrees to the left of the center vertical axis was blocked.

Because of the high mounting position the low beam cutoff was aimed at downward gradient of 6 inches for every 25 feet to optimize distance and reduce glare to opposing and followed traffic. In Figure 14, by moving the headlamps to the outboard position and as low as practical the driver was no longer sitting behind the light array or beam pattern trying to look through illuminated particles. In addition, the deep domed light shields blocked all stray light above the horizontal cutoff, and in the area between the headlights to a convergence point beyond the snowplow.

Thereby creating a zone without lamp arrays, veiling refracted light or glare to hinder the driver's forward vision.

FIGURE 14. TEST SNOWPLOW, TYPICAL ARRAY VERSUS ASYMMETRICAL LIGHT PLACEMENT

The object of the asymmetrical shaped beam system is to allow the driver a clear field of view in all directions without having to look through any illuminated particles. In Figure 15 the shaped beam system the roadway and shoulders are uniformly lit by light converging from the both sides while the fog lights extended the peripheral vision 180 degrees with no illuminated particles obstructing the drivers view in any direction or causing glare to other roadway users. Note: The zone between the 2 headlamps where the light has been blocked in not apparent to the driver, except for the absence of illuminated particles.

FIGURE 15. ASYMMETRICAL SHAPED BEAM ARRAY ON ADOT SNOWPLOW DURING SNOW SQUALL

In Figure 15, the asymmetrical shaped beam lamp array shows virtually no glare or light above the cutoff in the opposing drivers' eyes or veiling light obstructing operators' forward line of sight during ADOT's snowplow test drive during heavy snowfall.

Left and right side shaped beam fog lights

The fog lights pattern chosen had a sharp upper cutoff, 110-degree beam width with a shallow u shaped fill pattern below horizontal as shown in Figure 16. We used PIAA 959 clear projector beam fog lamps equipped with 100-watt H3 bulbs. During operation the lens and housing became hot enough to resist ice build up, thereby allowing the lamp to maintain its sharp cutoff even during extreme conditions.

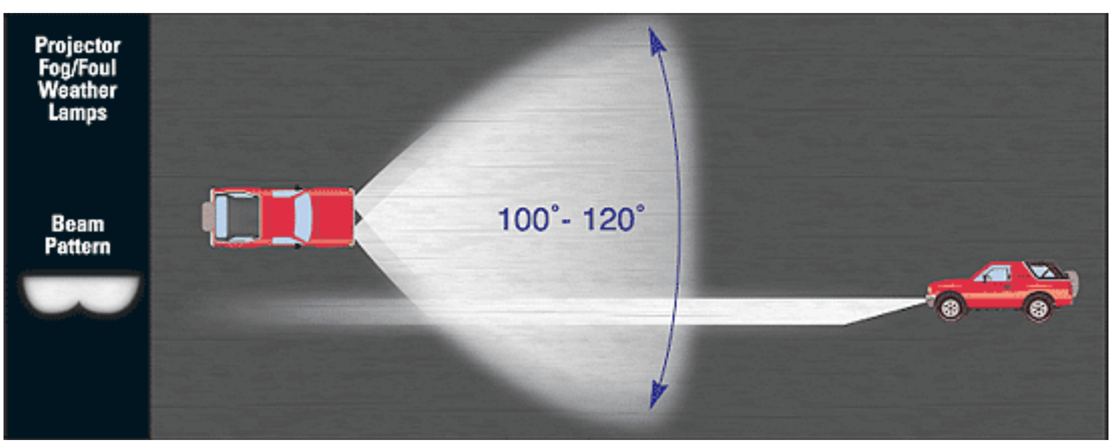

FIGURE 16. TYPICAL AIMING REGIMEN AND BEAM PATTERN OF PROJECTOR BEAM FOG LIGHTS

To accomplish the beam pattern we desired we mounted the projector beam fog lights as low as practical below and outboard of the headlights in Figure 17. Then we aimed them to create a uniform overlapping 180-degree field of view that included both shoulders. The sharp cutoff was aimed down 5 inches for every 25 feet. The sharp cutoff virtually eliminates the stray refracted light above horizontal while reducing glare to other roadway users. Thereby the increased field of view could be maintained even with opposing and followed traffic. Each fog light operated independently based on driver's preference.

FIGURE 17. HID HEADLIGHT WITHOUT BEAM SHIELD AND LEFT PROJECTOR BEAM FOG LIGHT

Right side shaped beam snow marker light

For this project, we turned a PIAA 959 projector beam fog light 90 degrees on its side, creating a vertical cutoff. We mounted it inboard of the head and fog light and aimed the cutoff to the right of center about 3 inches for every 25 feet as shown in Figure 25. Thereby the shoulder and the snow stakes could be illuminated without refracted light or glare for the opposing traffic or would it shine into right side mirrors of followed vehicles. The fog light's sharp cutoff was critical in followed traffic but the beam pattern should have been a 25-40 degree driving beam pattern to give us greater distance, but no such sharp cutoff driving light exist on the market.

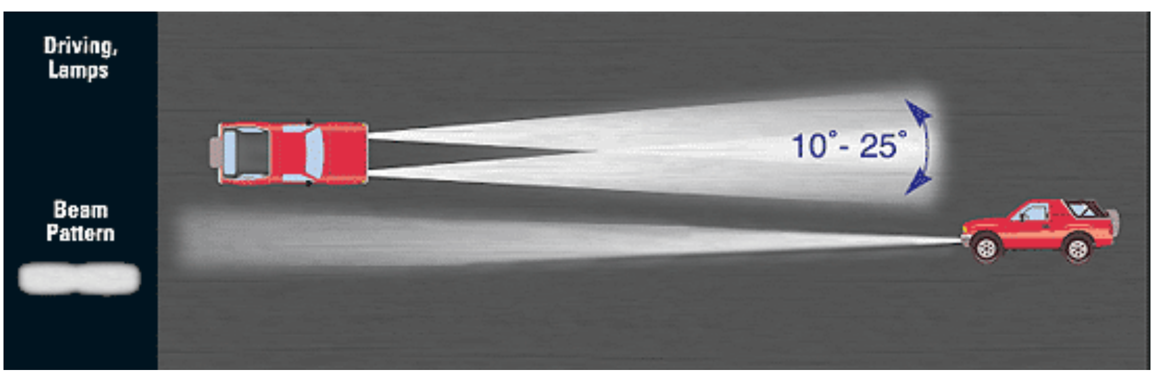

FIGURE 18. TYPICAL DRIVING LAMP BEAM PATTERN

The beam pattern in Figure 18 would ideal as a shoulder/marker beam light if we turned it 90 degrees on its side and added a sharp vertical cutoff to keep the beam out of the mirrors of followed traffic and the eyes of opposing traffic.

Snowplow blade mounted fog lights

The objective was to place the light source as low and as far in front of the vehicle to light the roadway and reduce refracted light that the operator has to look through. ADOT attempted a plow mounted light solution in a previous ADOT project (SPR-473) shown in Figure 19; for this project (SPR-536) we mounted the lamps in a more survivable location shown in Figure 20. The sharp cutoff was aimed down 3 inches for every 25 feet forward with a 180-degree beam pattern. We mounted them inboard of the top leading edge of the blade on the outside corners.

FIGURE 19. ADOT PROJECT, SPR-473

FIGURE 20. SPR-536 PLOW MOUNTED FOG LIGHTS

In Figure 20, the snowplow blade mounted fog lamps were also part of this beam pattern trial. Notwithstanding these lamp configurations and field of view shown in Figure 21 they cannot be legally used without the vehicle headlights also being turned on in most jurisdictions. The 959 PIAA projector fog light beam pattern worked well when mounted on the plow, but in short order the glass lens on one of the lights was broken and the high vibration caused the halogen bulb on the other lamp to fail soon thereafter. Technologically a polymer lens and LED lamp could be designed to survive in this environment and on those plows where the angle of the blade during plowing changes, an optimum aiming regime would need to be determined.

FIGURE 21. OBJECTIVE OF SNOWPLOW BLADE MOUNTED BEAM PATTERN

Rotating beacon forward beam diffuser

The object of this task was to maintain the rotating beacon's apparent forward beam conspicuity while reducing the intensity of the refracted flashing light in front of the windshield. To mitigate this problem we installed a 4'x11' panel of smart glass in front of the rotating beacon. Smart glass: electro chromatic and optical films or coatings laminated between two plies of glass or plastic that can be electrically energized to change opacity or color, shown in Figure 22. In this instance we used a version that was clear when power was applied (auto on with beacon), and opaque (diffused/frosted) when deactivated by the driver.

FIGURE 22. SMARTGLASS BEACON DIFFUSER INSTALLED ON ADOT SNOWPLOW

Components used in this project

Figure 23. Sylvania/Valeo: Xe7 Bi-Xenon

- Headlights that were modified: Figure 23 Sylvania/Valeo: Xe7 Xenon Bi-Function HID headlamp module harmonized DOT4
  Estimated market price $900 per pair
- HID Bulbs: Gen 3 DS1 - 4300Kelvin & 5000Kelvin
  Estimated market price $70 each
- Fog Lights: PIAA 959 projector - clear – 100 watt bulbs
  Discontinued, special order in quantities of 100 $125 each
- Smartglass beacon diffuser
  Custom built with wiring $300
- Headlamp Covers: Replex Plastics Domes
  Lexan deep draft domes built to order $25 each

Observations and Recommendations

Based on the complexities of snowplow operations, it is recommended that more than one snowplow be equipped with a test lighting array to account for potential equipment failure and other unexpected events. Though overall during the trials there were only a few hours of ideal adverse weather conditions, at infrequent intervals, which made documentation difficult. Such conditions include when there was snowfall (to test whiteout hypotheses with standard lighting), when there was no snowfall (to test horizontal cutoff and improved visibility with asymmetrical beam patterns), and more importantly, when plowing operations occur at night. Unfortunately, during the study period of winter seasons in 2006 and 2007, most of the snowfall, hence snowplowing, occurred during daylight hours so there was no need to operate the test lights.

After the field trials were completed the test set up was damaged before we could get the results captured on video. However, Figure 24 is another screen shot from the limited video taken during test runs.

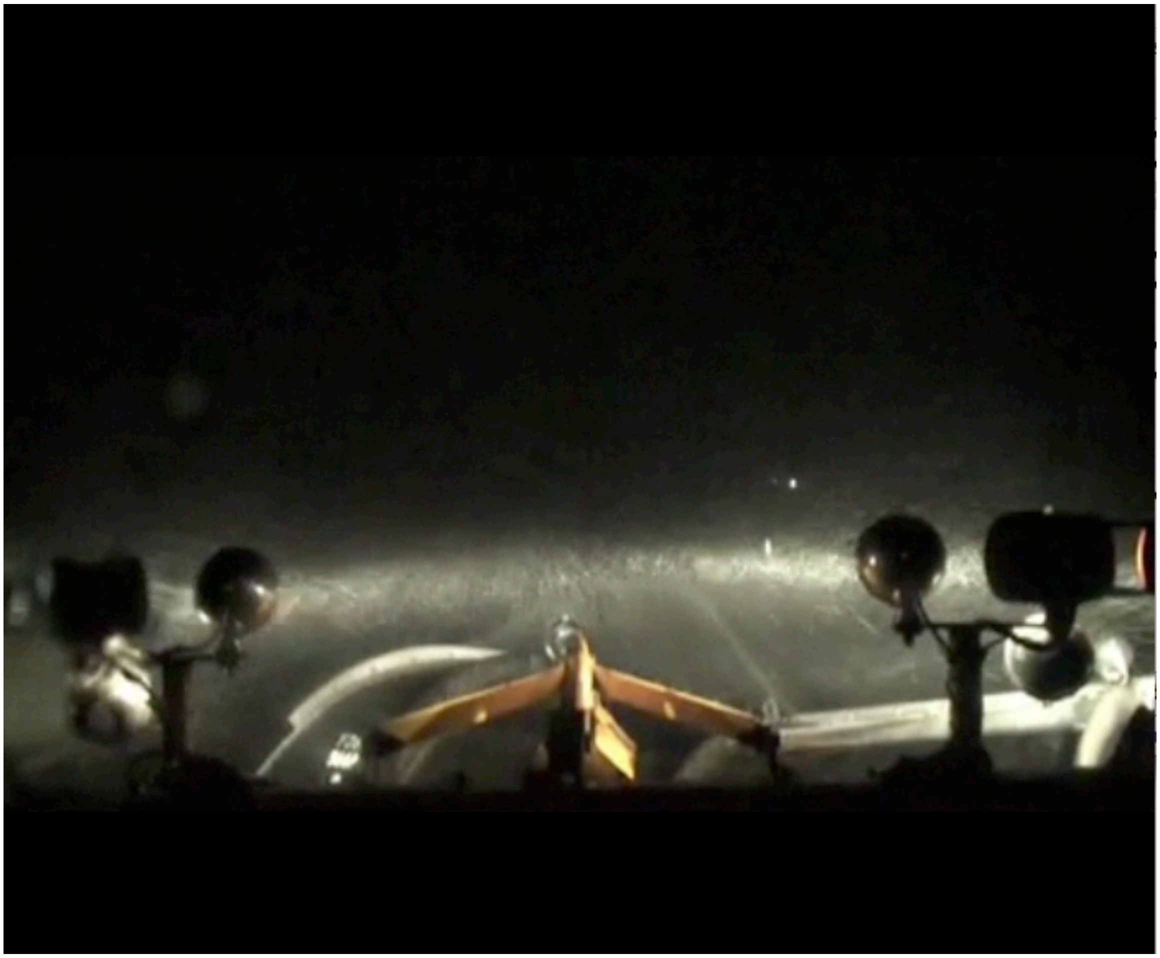

FIGURE 24. ASYMMETRICAL SHAPED BEAM ARRAY ON ADOT SNOWPLOW IN SNOW SQUALL

Asymmetrical shaped beam lamp array

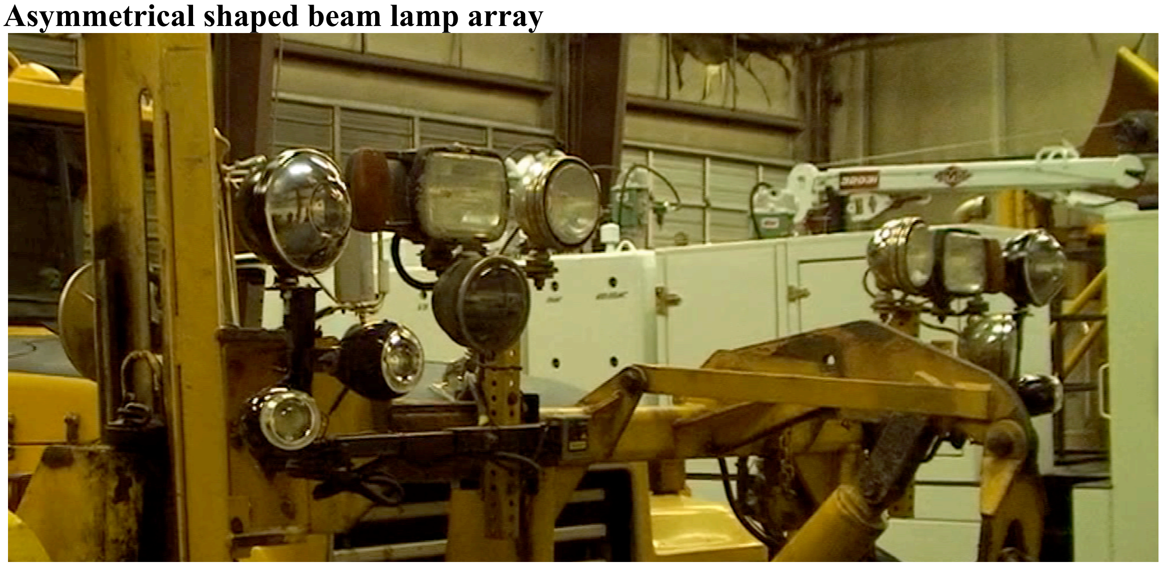

FIGURE 25. ASYMMETRICAL LIGHTING ARRAY SYSTEM: SHOWN OUTBOARD OF STANDARD SNOWPLOW CONFIGURATION. HEADLIGHT SHIELD DOMES NOT SHOWN.

The test vehicle used right and left asymmetric headlight beam patterns, 2 sharp horizontal cutoff fog lights for peripheral vision, one fog light turned 90 degrees on the right side to light the shoulder and highway stakes, and a beam diffuser for the rotating beacon. An illustration of this lighting array in operation is shown in Figure 26 where the dark yellow left and right fog patterns, green left and right asymmetrical headlights, single light on right for shoulders and snow stakes. Note: no direct or indirect refracted light appears in driver's line of sight.

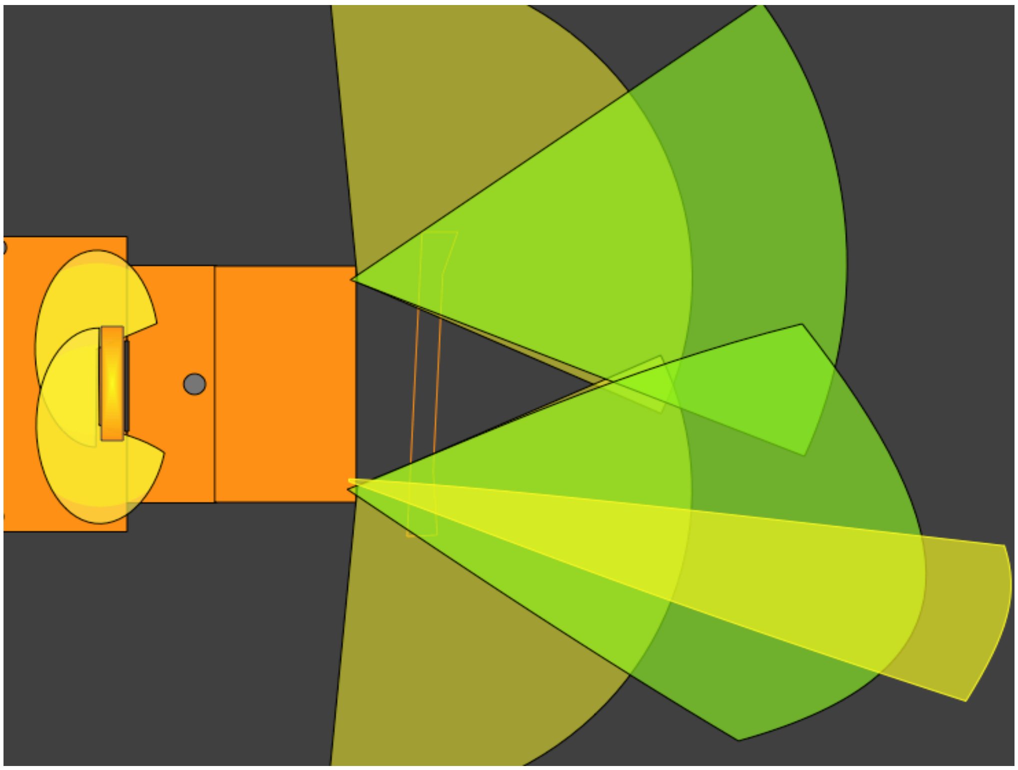

FIGURE 26. BIRD'S EYE VIEW ILLUSTRATION ASYMMETRICAL SHAPED BEAM PATTERN

The asymmetrical shaped beam pattern worked exactly as planned in every aspect from reduced glare for the driver and other road users alike to improved field of vision with one unexpected caveat. When you mount any beam this high close-in foreground lighting becomes problematic. As drivers age their ability to see at night decreases and they tend to rely more on foreground lighting for guidance even when it's at the expense of distance. The oldest driver in the test was turning on both systems during whiteout conditions. He preferred using the existing driver's side fog lamp that was aimed down to the left of the vehicle track to increase lane guidance. This close-in guidance preference was consistent with how most of the other drivers had chosen to aim their auxiliary lighting.

This critical additional close-in lane guidance needs to be added and could be achieved while maintaining all the other objectives of the shaped beam system. Therefore a purpose built system should also include a directed foreground area beam on the driver's side and an additional one for the wing plow with its light source shielded from other road users.

Aside from this exception, all drivers reported significantly improved forward and peripheral light on the roadway, while at the same time this system minimized oncoming glare for opposing drivers as well as followed vehicles.

Rotating beacon forward beam diffuser

The rotating beam intensity diffuser worked in reducing the forward intensity of the beacon but the desired benefit was not achieved. The debilitating refracted light from the beacon, in front of the windshield, remained at unacceptable levels. However, a solution was indentified using an LED beacon and a shaped beam, but it was too late in the process to be included in this trial. The obvious solution is to mount the light in such a way and or to use a physical shield to block all forward light 10-15 degrees or greater below the beacon's horizontal plane. Thereby the light is clearly visible to approaching traffic yet there is no light source in the area in front of the windshield to illuminate particles, and because LED lamps do not produce white light veiling refracted light from the beam would be minimized.

Technology and Configurations

Snowplow operations generate significant levels of vibration so lights and light housing need to account for these vibrations.

Main beam

- The headlights should be asymmetrical projector beam HID units because they have the highest lumen output, service life and no filaments to break from vibration. The Kelvin output (color temperature) should not be less that 3500k or exceed 5500k, 4500-5000k is best.

- Color temperature characterizes the spectral properties of a light source. Low color temperatures are warmer, more yellow/red, light while high color temperature produce more blue light. Daylight has a rather low color temperature near dawn 3500k, and a higher one during the day 5500k.

- Bi-xenon hi/low headlight units with internal shutters are more costly but have a much smaller form footprint. LED headlamps whose beam shape can be designed to meet the need are in sample stages (2009) and should be commercially available in the next few years.

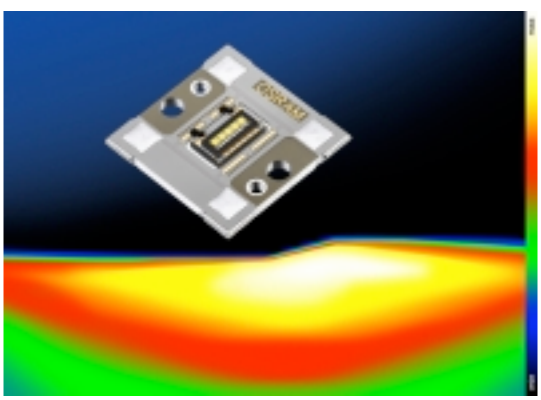

FIGURE 27. OSRAM: OSTAR HEADLAMP LED

- The blackout zone between the lamps needs to be adjustable to optimize the beam pattern for the application – mounting height of lamps, size of plow and distance in front of vehicle to the lamps, and the distance between lamps.

- The purpose built headlamp array assembly should be as small a vertical form factor as practical, with the fog, road stake, close-in lane and wing plow arrays mounted below the main beams.

Fog, fog, road stake, close-in lane and wing plow arrays

- The auxiliary area lighting should be LED units because of long service life, low power requirements, minimize refracted light and they are not affected by vibration. The problem, there isn't a single vendor currently or on the immediate horizon that makes the appropriate beam patterns in LED form, or any other form for that matter. The current state of aftermarket lighting is driven by marketing, form and feature claims, not performance of usable function. In fact the lamps used in the test were discontinued and there were no suitable commercial equal units available. PIAA did say they would build them to order, but the H3 bulbs are short lived in high vibration environments.

- The good news with modern rapid prototyping, suitable beam patterns, LED optics and heat sinking solutions are known, and can be incorporated into a purpose built assembly.

- The purpose built headlamp array assembly should be as small a vertical form factor as practical, with the fog, road stake, close-in lane and wing plow arrays mounted below the main beams.

Other options

- LED directed beam lamps that light the roadway on both sides in front of the rear drive wheels. Thereby when operator glanced into their mirrors (or dash monitor), their relative location to the roads edge and lane position would be easier to discern in heavy snow conditions.

- Install low profile plow blades that allow the lights to be lowered, as shown in the Caltrans plow photo, Figure 27.

Figure 28. Caltrans Snowplow Lighting, District 9: Bishop, California

All weather capability

- There are several commercial available systems that could be adapted to allow the operator to clean the lamp lenses from the cab. This is critical during some storms for operator safety and maintaining productivity.

- Research on hydrophobic nano coating is progressing and several manufacturers will be soon producing products. If the lens surface were coated with these materials ice and debris accumulations would be dramatically reduced.

Form factor

FIGURE 29. TYPICAL SNOWPLOW LIGHTING ARRAY, LARGE FOOTPRINT OBSTRUCTING DRIVERS LINE OF SIGHT

Compare the purpose built headlight form in Figure 29 to the existing snowplow light array in Figure 28.

FIGURE 30. IFR AUTOMOTIVE'S ASPID ROADSTER - WELL-DESIGNED HEADLAMP ENCLOSURE WITHIN THE DRIVER'S FIELD OF VIEW

The contrast in regards to placement and obstructed view of the legacy snowplow lighting systems and a purpose built asymmetrical system that is lower and as close to the outside of the vehicle as practical would be remarkable.

Cost range of purpose built asymmetrical configuration

Purpose built asymmetrical shaped beam snowplow assemblies as described here (HID main beam, LED auxiliary) – estimated cost including control panel switches, wiring harness, relays etc range between 1100 to 1500 dollars per set in quantities of a few hundred sets. An all LED system would probably be even higher initially but should last service life of vehicle. Mounting frame, brackets, and purpose-built design costs are not included as they are contingent on snowplow type.

Conclusion

This trial was to determine if an array of asymmetrical shaped beams could reduce the fatigue causing refracted light and glare, improve operator safety, vision as well as reduce glare for opposing, followed traffic and pedestrians on or near the roadway. The test conclusively validated this hypothesis.

The asymmetrical shaped beam system was able to illuminate the roadway and the shoulders of the road while minimizing virtually all refracted light from the driver's line of sight. Moreover, the asymmetrical beam pattern allowed the driver to maintain this optimum field of view on a two-lane highway, even in the presence of opposing and followed traffic.

Action item

The National Highway Traffic Safety Administration (NHTSA) needs to be convinced that snowplow lighting is an ongoing safety problem that needs to be addressed, and solutions such as purpose-built asymmetrical beam patterns for snowplow use should be allowed. NHTSA establishes the national standards for headlight use on vehicles and its rules must incorporate legal highway use solutions that meet the safety needs of the plow operators and the public. The interested states that operate snowplows should petition NHTSA per CFR 49, 552.4 for a rule change; allowing the use of asymmetrical beam headlamps for snowplow use.

Appendix: ADOT Snow Plow Driver Questionnaire

ORG NO: _________ORG NAME: ________________ DATE:___________

Operator: _________________________________ Snowplow Truck: _ F285________

Normal Plow Route: __SR 64________ MP's: ________ to _________

SPR 536, Snowplow Shaped Beam (SB) Lighting System -

Operator's 2007-2008 Evaluation Survey

Part 1.1 Shaped Beam - Hi/Low Headlamps (circle one)

1. It improved my ability to detect and react to things on or near the road. Agree 1 2 3 4 5 Disagree
2. I could see better during low visibility and whiteout conditions. Agree 1 2 3 4 5 Disagree
3. It improved my overall driving and lane tracking ability. Agree 1 2 3 4 5 Disagree
4. It reduced glare and eye strain for the plow operator. Agree 1 2 3 4 5 Disagree
5. It decreased my overall level of stress or fatigue. Agree 1 2 3 4 5 Disagree
6. Would you recommend that the SB Hi/Low headlamps be installed on ADOT snowplows? Yes / No / Unsure

   Please explain:

Part 1.2 Shaped Beam - Left Shoulder Lamp (circle one)

1. It improved my ability to detect and react to things on or near the road. Agree 1 2 3 4 5 Disagree
2. I could see better with it during low visibility and whiteout conditions. Agree 1 2 3 4 5 Disagree
3. It improved my overall driving and lane tracking ability. Agree 1 2 3 4 5 Disagree
4. It reduced glare and eye strain for the plow operator. Agree 1 2 3 4 5 Disagree
5. It decreased my overall level of stress or fatigue. Agree 1 2 3 4 5 Disagree
6. Would you recommend that the SB left shoulder lamp be installed on ADOT snowplows? Yes / No / Unsure

   Please explain:

Part 1.3 Shaped Beam - Right Shoulder Lamp (circle one)

1. It improved my ability to detect and react to things on or near the road. Agree 1 2 3 4 5 Disagree

2. I could see better with it during low visibility and whiteout conditions. Agree 1 2 3 4 5 Disagree

3. It improved my overall driving and lane tracking ability. Agree 1 2 3 4 5 Disagree

4. It reduced glare and eye strain for the plow operator. Agree 1 2 3 4 5 Disagree

5. It decreased my overall level of stress or fatigue. Agree 1 2 3 4 5 Disagree

6. Would you recommend that the SB right shoulder lamp be installed on ADOT snowplows?Yes / No / Unsure

Please explain:

Part 1.4 Shaped Vertical Beam – Right Shoulder/Snowstake Lamp (circle one)

1. It improved my ability to detect and react to things on or near the road. Agree 1 2 3 4 5 Disagree

2. I could see better with it during low visibility and whiteout conditions. Agree 1 2 3 4 5 Disagree

3. It improved my overall driving and lane tracking ability. Agree 1 2 3 4 5 Disagree

4. It reduced glare and eye strain for the plow operator. Agree 1 2 3 4 5 Disagree

5. It decreased my overall level of stress or fatigue. Agree 1 2 3 4 5 Disagree

6. I liked it, but wish it had greater range down the road. Yes / No / Unsure

7. Would you recommend that the SB right snowstake lamp be installed on ADOT snowplows?Yes / No / Unsure

Please explain:

Part 1.5 Shaped Beam – LED Rotating Beacon (TBD) (circle one)

1. I could see better during low visibility and whiteout conditions. Agree 1 2 3 4 5 Disagree

2. The SB LED rotating beacon reduces glare and eye strain for the plow operator. Agree 1 2 3 4 5 Disagree

3. Would you recommend that the SB LED rotating beacon be installed on ADOT snowplows? Yes / No / Unsure

Please explain:

Part 2. Likes and Dislikes

1. What do you like most about the Shaped Beam lighting system, and why?

2. What do you dislike most about the Shaped Beam lighting system, and describe why. How can it be improved?

3. Does the Shaped Beam lighting system improve the safety of ADOT's winter operations?

Part 3. Your Plowing Experiences in 2007-08

1. Summarize over the entire winter - how useful was the Shaped Beam lighting system to you in or with:
   a. Fog?

   b. Rain?

   c. Light Snow?

   d. Heavy Snow / Whiteouts?

   e. Vehicles, animals, or other objects on the shoulders?

2. Did the Shaped Beam lighting system:
   a. Help minimize or avoid any accidents during snowplowing? Please describe:

   b. Cause you any serious problems or close calls while plowing? Please describe:

3. To your knowledge, did the Shaped Beam lighting system reduce glare to opposing drivers, and were you able to maintain a full field of view even with opposing traffic? Please describe:

4. Did you like the ability to control each lamp in the system individually? Please explain:

5. Would this system be useful to you in driving, apart from plowing operations? Please describe:

***** THANK YOU FOR YOUR HELP IN ADOT'S SNOWPLOW RESEARCH PROGRAM THIS WINTER! *****

Bibliography

3M Traffic Control Systems Division for Mn/DOT Snowplow Phase II, Operator Interface Design Report, September 3, 2002
http://www.dot.state.mn.us/guidestar/2001_2005/ivi_hwy_19.html (visited 2/01/2009)

Automotive lighting FAQ site http://faqlight.carpassion.info/ (visited 2/01/2009)

Bullough, J. D. and Rea, M. S. Rensselaer Polytechnic Institute, USAForward Vehicular Lighting and Inclement Weather Conditions. Improved Visibility for Snow Plowing Operations [report to. National Cooperative Highway Research Program].
http://www.lrc.rpi.edu/programs/transportation/pdf/PAL/PAL2001-bullough.pdf (visited 2/01/2009)

Gibbons, R.B., C. Edwards, S. Gupta; FHWA-HRT-04-147 Enhanced Night Visibility Series: Phase III – Characterization of Experimental Objects December 2005
http://www.tfhrc.gov/safety/hsis/pubs/04147/index.htm (visited 2/01/2009)

Glare from Headlamps, Federal Motor Vehicle Safety Standard No. 108; Lamps, Reflective Devices, and Associated Equipment Docket# 2127-AH81
http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=NHTSA-2001-8885 (visited 2/01/2009)

Josefowicz J. and D. Ha; November 2008 - Vision & Exterior Lighting: Shining Some Light on Scotopic & Photopic Lumens in Roadway Conditions
http://www.ledroadwaylighting.com/default.asp?mn=1.42.52 (visited 2/01/2009)

Lighting Design Knowledgebase: Glossary; Color Temperature, Correlated Color Temperature (CCT), Kelvin
http://www.schorsch.com/kbase/glossary/cct.html (visited 2/01/2009)

OSTAR Headlamp LED with new brightness data and accurate cut-off-line - Precisely defined headlight
http://www.osram-os.com/osram_os/EN/News_Center/Spotlights/Products/OSTAR-Headlamp-automotive-front-lighting-LED.jsp (visited 2/01/2009)

Sisiopiku V.P. Michigan State Univ., East Lansing, MI; Intelligent Transportation Systems, 2001. Proceedings. Winter road maintenance-ITS options
http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=948672 (visited 2/01/2009)

Thomas A., A, K. Linsenmayer, and P. Casey - CTC & Associates LLC Synthesis of Best Practices for Eliminating Fogging and Icing on Winter Maintenance Vehicles.
http://www.clearroads.org/05-01antifogging.html (visited 2/01/2009)

Thompson B.E., HK Nakhla - Journal of cold regions engineering, 2002 - cat.inist.fr Modeling of airborne debris around overplow deflectors during high-speed snowplowing.
http://cat.inist.fr/?aModele=afficheN&cpsidt=1385189310 (visited 2/01/2009)

US CFR 49: FEDERAL MOTOR VEHICLE SAFETY STANDARDS--Sec. 571.108 Standard No. 108; Lamps, reflective devices, and associated equipment.

US CFR 49: Sec. 571.108 - S5.3.2.2; FMVSS, Snowplow headlights

US CFR 49: Subtitle B; Chapter V—National Highway Traffic Safety Administration, Department of Transportation: Part 552--PETITIONS FOR RULEMAKING, DEFECT, AND NONCOMPLIANCE ORDERS
http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49cfr552_main_02.tpl (visited 2/01/2009)

Yen K.S, HS Tan, A Steinfeld, CH Thorne, B Bougler, "Advanced Snowplow Development and Demonstration: Phase I: Driver. Assistance," AHMCT Report No. UCD-ARR-99-06-30-03, June, 1999.
http://www.ahmct.ucdavis.edu/images/00063002.pdf (visited 2/01/2009)