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**INVESTIGATION OF THE EFFECTIVE USE OF
WARNING LIGHTS ON INDIANA DEPARTMENT OF TRANSPORTATION (INDOT)
VEHICLES AND EQUIPMENT**

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16. Abstract This study was requested by INDOT to determine if current lighting packages used on INDOT maintenance vehicles, specifically snow plow vehicles, can be improved with other commercially available products. Different light products were obtained from various vendors, mounted on INDOT vehicles, and visual comparisons were performed under various lighting and weather conditions by a team of observers. The comparison evaluations were performed revealing that other light packages, LED models for most options, were brighter and certain colors more visible. The preferred light models are recommended. These recommendations were forwarded to appropriate individuals that make these decisions at INDOT. Implementation is dependent on purchasing decisions made at the Central Office and at each of the Districts.			
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Introduction

One of the Indiana Department of Transportation's greatest needs in terms of warning the motorist of work being performed along the roadway and protecting INDOT personnel is making work sites, vehicles and equipment as visible as possible. This includes providing adequate visibility during different weather conditions including snow removal operations. There are a variety of options and methods used by transportation agencies and other industries that use similar vehicles. The type, size, arrangement and color influence visibility of a vehicle. This study's objective was to evaluate and compare other lighting options to INDOT's current lighting practices to improve safety and visibility and to produce recommendations for consideration and implementation by INDOT Operations and Districts. The size and arrangement of lights was not a primary part of this study.

This study was requested by Calvin Lee, INDOT safety director at the time when the study started.

Other transportation agencies have investigated lighting issues and their work was reviewed to identify best practices. This synthesis information is summarized herein.

Other Studies

NCHRP Project 6-12 - Improved Visibility for Snowplowing Operations

This research identified and evaluated in limited field tests several potential features for improving visibility. The following is a summary of these evaluations:

- During snowfall, switching off the driver-side headlamp and using an auxiliary passenger-side headlamp will reduce the back-scattered light seen by the operator.
- Shielded headlamps, louvered or cut-off type, that reduce stray light above the horizontal plane will reduce backscattered light.
- Steady-burning light bars, mounted along the rear edges of the snowplow truck, will improve other drivers' ability to detect changes in the snowplow vehicle's speed and will provide an indication of the vehicle's width. Although the features evaluated in this research yielded some 50 percent improvement in visibility for motorists following the snowplows, it should be recognized that this and other research findings were based on limited field demonstrations.

Georgia DOT

Prior to June 2005, GDOT had two 360 degree strobes mounted to the top of their arrow board and two four inch strobes on the rear bumper. In June 2005 two LED traffic advisory bars were added made up of red and clear LED's and several individual red, clear and amber strobes mounted to the rear bed rail. GDOT also used similar light

configurations on the other trucks used in the strobe light study marking activities minus the traffic advisory bar. Since the addition of strobes and light bar they have had no accidents, before they averaged 2 to 3 per year. They credit this to the addition of the LED strobes especially the red ones. This information was provided by GDOT after a phone conversation.

Figure 1 - Georgia DOT

Figure 2 - Georgia DOT Rear

Minnesota DOT

The goal of this work was to understand how the processing of motion under the conditions created by blowing snow causes drivers to fail to detect that they are approaching a vehicle ahead. Light color was examined under blowing snow conditions to assess whether an equiluminant (equal brightness) situation was created. In this situation, contrast in light level is not detected, but differences in color are. When an

equiluminant situation is created by snow, a perceptual illusion lowers the ability to perceive approach. The results indicate that colors in the red-yellow part of the spectrum can create a dangerous equiluminant situation in blowing snow and fog. They were unable to find an optimum color to paint snowplows to make them less susceptible to rear-end collisions.

Perception studies investigated the ability of the visual system to detect the expansion pattern that drivers use to perceive that they are approaching a vehicle. They found that low contrast created by a snow cloud greatly reduces the ability to perceive approach. Flashing lights that increase conspicuity, substantially increased the chances of a crash. Additional ways to improve the placement of warning lights based on these findings were proposed.

This information was obtained from phone conversation.

South Dakota DOT

South Dakota did a study on this topic and produced the following recommendations for their plow trucks:

1. Additional plow head lights, turn signals and clear 100 watt fog lights (8-10" convex mirror mounted on the passenger side).
2. 2 (Whelen #S360SAP) Amber color strobe lights mounted on the corners of rock rack elevated 9" to prevent flashback in the mirrors.
3. One 4" white spot light mounted bottom of the cab to light mid-mount wing.
4. Amber color (Whelen #70A00FAR) LED light mounted top back of wing.
5. 2 Elevated amber color (Whelen #70A00FAR) LED lights mounted at least 11' above the ground.
6. 2 Elevated red stop/turn (Whelen #70R00XRR) LED lights mounted just below the elevated amber lights.
7. 2 White (Whelen #70C00FCR) LED lights mounted outside top corner of truck box.
8. One 4" white spot light mounted above sander chute on drivers side to light discharge of material at night.

This information was obtained as a result of a phone conversation.

Kansas DOT

Kansas DOT has used the Whelen DOT 3 System 102A strobe system on their dump trucks for years, but have began purchasing the following for approximately half of their trucks. It is an LED system from Whelen and is more visible compared to the other Whelen systems. It is a Whelen KDOT L16 DOT-LED System consisting of one [1] 96" Edge Bar Mounted in the center of the cab roof area consisting of two [2] Freedom Linear 12 Amber LEDS on each corner and two [2] Freedom 400 Series Linear 12 directional amber LED's on the front and rear middle of lightbar.

This information was obtained as a result of a phone conversation with KDOT.

Wisconsin DOT

The Wisconsin DOT contracts with 72 local county highway departments in Wisconsin to maintain the state highway system. The county highway departments are responsible for the purchase and maintenance of any equipment necessary to perform this highway maintenance service. WisDOT provides a winter maintenance truck lighting guideline in their Maintenance Manual. The extra lighting they recommend for snow plow trucks includes :

- 1) High intensity discharge (H.I.D.) lamps as auxiliary lighting to the truck headlights
- 2) A LED light on the end of the wing plows to make them more visible.

This information was obtained as a result of a phone conversation with WisDOT.

Nevada DOT

The below images show the lighting system used by Nevada DOT. These images show the lighting configuration on the front and back but no description of the type of lights used.

Figure 3 - Nevada Rear

Figure 4 - Nevada Front

This information was obtained as a result of a phone conversation.

Alaska

Alaska uses combinations of blue and yellow strobes mounted front and rear on their heavy equipment. This provides great visibility even in light and blowing snow conditions.

This information was obtained through a phone conversation with an Alaskan DOT employee.

Caltrans

The California Department of Transportation (Caltrans) currently has a current research project on warning lights. The project is being developed as a Caltrans sponsored University of California, Berkeley research project. The project consists of two parts and is estimated to run for three years. The plan is to develop and test improved emergency warning lights for work zone vehicles (year 1), and enhanced rear warning lights for shadow trucks (years 2 & 3), both intended to improve visibility and improve reaction times for drivers approaching the work zone. The research group aims to design, fabricate and test an emergency warning light package that will uniquely identify Caltrans maintenance vehicles and which will thus convey to the public the special hazardous nature of the portion of the highway where they are seen. The improved emergency warning lights will employ ITS principles and should be able, if deployed, to lead to meaningful reductions in work zone collisions. This study will examine the visual properties (speed of human response) of our proposed improvement. A prototype will be delivered for possible field operational testing at project's end.

This information was obtained from CALTRANS as a result of a phone conversation

Work Plan

This research project investigated various lighting options available to provide the most desirable level of visibility for vehicles and equipment. INDOT vehicle lighting vendors were contacted and asked to participate in the study. Each vendor described their product lines for this application and demonstrated some of their products. Light emitting diode (LED) lights are the latest technology. They produce brighter and better quality light but they are significantly more expensive. The vendors committed to donating some of their products, some of the more expensive items (light bars) were purchased. The vendors that presented were:

Federal Signal
PSE
Whelen
Soundoff Signal
CRS

The lighting equipment obtained from the vendors were field evaluated by personnel associated with INDOT safety, Research, equipment and the district(s) to determine their effectiveness from a visibility perspective. Lighting recommendations are made for implementation. More specifically the activities are:

1. Accumulate information on similar studies. Evaluate the findings and talk with personnel involved in these studies.
2. Contact light vendors and provide information on the study and ask for participation.
2. Purchase and install lighting systems on two trucks to be used for field evaluations. The field evaluations were performed under four different weather and lighting conditions by an observation team averaging 6 individuals. The observations were individual comparisons between similar lighting options. The results of these observations are reported.

Perform field tests and subjective evaluations of the lighting system in various weather conditions. Due to safety concerns all field evaluations were off road at the Research Division facility. The evaluations or observations were from the approaching vehicle (front and back) perspectives. Field observations were done in four different weather and lighting conditions: snow, cloudy, bright sun, and night.

Figure 5 - Field Observations

Figure 6 - Cloudy Observation

Figure 7 - Snow Observation

The evaluations were recorded manually using paper forms. A partial form is shown below.

Table 1 – Field Observation form

Date 3/29/07	Weather Conditions: Partly Sunny						observation done at 250ft.
	LIGHT #	LIGHT #	very little difference				huge difference
No difference	0	1	1	2	3	4	5
No difference	2	1	1	2	3	4	5
No difference	2	3	1	2	3	4	5
No difference	2	10	1	2	3	4	5
No difference	2	11	1	2	3	4	5
No difference	2,15 combo	4	1	2	3	4	5
No difference	11(RED)	14(BLUE)	1	2	3	4	5
No difference	12(AMBER)	14(BLUE)	1	2	3	4	5
No difference	8	12	1	2	3	4	5
No difference	8	9	1	2	3	4	5
No difference	8	15	1	2	3	4	5
No difference	9	15	1	2	3	4	5

The observer indicates with light is brighter and to what degree and if no difference then indicate accordingly.

The vendors that participated and their light models were the following. These light products are sold to agencies and companies for the sole purpose of safety warning. They are used on various types of maintenance, construction, and emergency vehicles.

Federal Signal

252653-03 blue strobe
 252651-02 amber strobe, class 1
 607123 red
 607123 blue
 607123 amber
 QL64XFC-R quadflare red
 QL64XFC-B quadflare blue
 QL64XFC-A quadflare amber
 454202-25 amber highlighter
 454202-35 blue highlighter

Whelen

Microedge 400 LED
40AA5SCR 400 LED Split
700 Series Super LED AMB/CLR
50A02ZCR 500 LIN LED Flash AMB
500 Series TIR Super LED AMB/CLR
4" Extd Synch Super LED A/C

SoundOff

ETL5000 –57.5" with PE; TD(in location 14 and 17); no modules in 15 or 16; CA modules (for 11-13, 18-20, 31-36, 38-40); spare CR modules for (31-33,38-40); 5 spare CB modules; yellow modules for A,B,C,D; external digital wiring.
EPRDDSSDBK
EPRDDSSDBA
EPRDSSMDBA
EL3S00PA LED3 amber marker light
EL3S00PR LED3 red marker light
ECVML121Y Slim-line (eliminated from evaluation)
E756IEB0A
ECVR43SST
ECVR43TY
ECV063TY
E36b1W (is this made for steady burn applications) back up light
ERDREBZA 4" round amber light for rear
ERDREBR 4" round amber light for rear
3207LMC Beacon Lights
EP2DGS0W

CRS Electronics

G2F8500A 7" Amber LED warning light
G2F8500R 7" Red LED warning light
10-103-30 red 4" stop light
10-103-20 red 4" turn light

Code 3

OPXB6S-AAH

OPXB6S-ABH

OPXB6S-ARH

OPXB6S-AWH

RNDALS1H 4" ROUND AMBER

RNDRLS1H 4" ROUND RED

LXTAFW-AAH

LXTAFW-ARH

LXTAFW-ABH

LXTAFW-AWH

LXEX1F-AH

LXEX1FW-AH

LXEX1FW-RH

LXEX1FW-WH

LXTAF-ABH

LDB4X

Figure 8 INDOT test truck being equipped with study lights

Figure 9 - INDOT Test Truck being equipped with test lights

Current Light Configurations

Figures 10 and 11 show the current light configurations on an INDOT maintenance truck. Districts have some latitude with lighting configurations so this could vary by District. Looking at these two images the main lighting components for the front are a light bar on top with two pairs of flood lamps. The back side has a column of round tail lights on each side, starting with amber on top, two reds, and a white backup light.

One of the study questions is: Are there brighter, more visible lights that can be used to increase the safety and visibility of INDOT equipment? To answer that question two INDOT salvaged vehicles were setup with the lighting products previously listed, and field observations made under differing weather and light conditions. The observations consisted of direct comparisons between similar light products in the categories: round and oval, LED surface, light bars, beacons, and white lights. The comparison asked the observer to select which option was brighter and more visible.

Figure 10 - INDOT Truck Lighting front

Figure 11 - INDOT Truck Lighting Rear

Light Categories

There were five different light categories evaluated:

1. Round and oval
2. LED surface
3. Light Bars
4. Beacons
5. White lights

The field observations consisted of a direct comparison between the light options in each category. For each category, the light options are shown and the comparison results given.

Round and oval

<u>Part No.</u>	<u>Color</u>	<u>Description</u>	<u>Manf.</u>	<u>Notes</u>
1157 light bulb	Red	Brake Light	INDOT	
RNDRLS1H	Red	4" Round	Code3	
607123	Red	4" round - LED	Fed Sig	rubber grommet deterioration
607123	Blue	4" round - LED	Fed Sig	rubber grommet deterioration
607123	Amber	4" round - LED	Fed Sig	Partial burnout / malfunction on light sequence. Preferred.
Erdrebzr	Red	4" Round	Soundoff	GEN2 LED
ECVR43sst	Red	4" Round	Soundoff	GEN2 LED
Erdrebza	Amber	4" Round	Soundoff	GEN2 LED
RNDALS1H	Amber	4" Round	Code3	
E756IEB0A	Amber	7" LED round light	Soundoff	internal moisture, Preferred
10-103-20	Red	4" Stop/Turn tail light	CRS	
10-103-30	Amber	4" Turn Signal	CRS	
Ecvr43ty	Amber	4" yellow	Soundoff	GEN2 LED
1157 incandescent bulb	amber	4" round	Soundoff	
G2F8500R	Red	7" round LED warning	CRS	moisture inside light
1157 incandescent bulb	Red	Truck Brake light	INDOT	
Par36	Amber	Truck rear hazard light	INDOT	
2EA00ZCR	Amber	4" round super LED	Whelen	

In the direct comparison with the current INDOT lights and the others shown in the above table, two lights were rated more visible and brighter than the others. They were:

Federal Signal, part # 607123, amber 4" round LED and
Soundoff , part # E756IEBOA, amber 7" round LED

There was not a direct comparison between the two due to the size difference, 4" and 7". The Soundoff product had internal moisture problems.

Figure 5 - Federated Signal 4" Round Amber

Figure 6 - Soundoff 7" Amber

LED Surface Lights

OPXB6S-ARH	Amber/Red	LED 5" x 2"	Code3	
OPXB6S-AWH	Amber/White	LED 5" x 2"	Code3	
OPXB6S-AAH	Amber/Amber	LED 5" x 2"	Code3	
OPXB6S-ABH	Amber/Blue	Led 5" x 2"	Code3	
LXEX1F-AH	Amber	LED 3" x 2"	Code3	Preferred
LXEX1FW-AH	Amber	LED 3" x 2" Wide Angle	Code3	
LXEX1FW-RH	Red	LED 3" x 2" Wide Angle	Code3	
QL64xfc-r	Red	LED - 4" x 6" quadflare flasher	Fed Sig	
QL64xfc-a	Amber	LED - 4" x 6" quadflare-flasher	Fed Sig	Partial burnout, Preferred
LXEX1FW-WH	White	LED exterior - 5" x 2"	Code3	Possible plow lights
Predator II extreme angle	White	LED - 5" x 2"	Soundoff	
QL64xfc-b	Blue	LED quadflare - 4" x 6" -flasher	Fed Sig	
G2F8500A	Amber	7" LED warning light	CRS	
LXTAFW-AWH	Amber/White	LED - 9" x 2"	Code3	
LXTAFW-AAH	Amber/Amber	LED - 9" x 2"	Code3	moisture inside light
EL3s00pr	Red	LED3 marker 3" x 1"	Soundoff	moisture inside light. Preferred
EL3s00pa	Amber	LED3 marker 3" x 1"	Soundoff	
Ecv063ty	Amber	6" oval -LED	Soundoff	GEN2 LED
Ecvml121y	Amber	LED 5" x 2"	Soundoff	not evaluated due to intensity
Eprddsmdba	Amber	LED - 5" x 2.4"	Soundoff	internal moisture
Eprddsdbk	Amber/Amber	LED - 5" x 2.4"	Soundoff	internal moisture
Eprddsdba	Amber/Red	LED - 5" x 2.4"	Soundoff	internal moisture
LXTAFW-ARH	Amber/Red	LED - small rectangle	Code3	
LXTAF-ABH	Amber/Blue	LED - small rectangle	Code3	
40AA55CR - 400 series	Amber	LED - 5" x 3"	Whelen	
70A02FCR	Amber	Super LED	Whelen	
01-0664633110	Amber	500 Series Linear LED	Whelen	
02-0363763314	Amber	500 Series Linear LED	Whelen	

For these lights, 45 different comparisons were made. Observers rated all the LED lights high in terms of brightness and visibility. Most observers preferred the amber color. Preferred lights were:

Code 3 - LXEX1F -AH Amber
 Soundoff - EL3S00PR Red
 Soundoff - EL3S00PR Amber

Federal Signal – QL64XFC-Amber

Figure 7 - Code 3 - LXEX1F -AH Amber

Figure 8 – Soundoff - EL3S00PR Red

Figure 9 – Whelen 01-0664633110 Amber

Figure 10- Federal Signal QL64XFC-A

Light Bars

21 L	Duo Beam LDB4X	amber	LED Beam light for top of truck	Code3	
26	454202-25	amber	minilight bar	Fed Sig	Magnetic mount
27	454202-35	blue	minilight bar	Fed Sig	Magnetic mount
71	Highlighter	Amber	Mini light bar	Fed Sig	Current rotating light
71			Clear Light Bar	Whelen	
36	ETL5000	amber (Amber/Red)rear	light bar	Soundoff	Preferred
1		Amber	Yellow Cube on truck top	Whelen	

Nineteen different comparison combinations were made among the light bar products. One light bar was preferred by the observers over the others and that was: Soundoff model ETL5000.

Figure 11- Soundoff Model ETL 5000

Beacons

25	252651	Amber	Strobe - Beacons	Soundoff	Magnetic mount
28	3207lmc	White	3000 Beacon Light	Soundoff	
65	252653-03	Blue	Strobe - Beacon	Fed Sig	
66	252651-02	Amber	Strobe - Beacon	Fed Sig	Preferred

The one beacon or strobe preferred over the other was:

Federal Signal – 252651-02 Amber strobe.

Since beacons and light bars are located on the top of the truck cab they were compared against each other. These comparisons revealed that light bars are preferred over beacons.

Figure 12 - Federal Signal 252651-02 Amber

Summary

The state agencies described in this report used various lighting systems on their vehicles. Some are using LED lights which INDOT has not adopted yet. This study is recommending that INDOT rethink the use of LED lights. Other agencies are specifying and using this type of light. Light configurations vary among the agencies but commonalities exist like the use of strobes and a light bar. This study did not evaluate configurations so no recommendations are made.

The direct light observation was the methodology used to make the recommendations described in the previous section. These results have been compiled by using various observers and using the elimination process to perform comparisons. A major conclusion was that the LED lights were observed as brighter than others and very similar across all observation conditions. Also, in comparisons between the different light groups (round, surface, etc.), the LED lights were preferred.

One conclusion from the studies is that amber is the clear color preference across all color configurations. Amber was perceived by the observers as the brightest across all observation conditions. The second choice of color is bright blue. This is similar to color used by law enforcement vehicles and may be restricted. State law needs to be consulted.

Another factor to consider is size. Larger lights were observed to be more visible than smaller lights, even those smaller lights were brighter than the larger ones. These factors narrowed the field down to several lights. First, light 12(Amber), the ql64xfc-a quad flare, even with its partial burnout, was voted unanimously over the other lights tested against it. In the LED surface category there were three other lights recommended other than the ql64xfc-a.

The front of the truck is much easier to recommend due to the small number of lights typically used on this side of the truck. The lightbar, Light 36 (Soundoff - ETL5000) was the preferred one.

In conclusion, the results recommend INDOT to consider using these preferred light options. The preferences are based on visibility in various types of conditions, weather and lighting. Cost and arrangement of lights for INDOT vehicles are decisions that are to be made by Operations and the Districts.

The existing INDOT lights did not compare favorably with the recommended and preferred lights. Light choices are made by the Districts. The results from this study should be used by Operations and the Districts when making decisions on future light packages for INDOT equipment.

Implementation

For the current fleet, as lights need to be replaced they should be replaced with the recommended lights. It is not feasible to mandate changing lights that are currently used on INDOT vehicles since they would require some retrofitting of the truck chassis. The INDOT committee that oversees the approval and purchasing of vehicle light packages needs to consider these results and realize that current lighting packages used by INDOT can be improved by using the recommended study lights and make INDOT vehicles more visible, thereby increasing safety for INDOT employees and the traveling public.

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