Field Test of Visibility Markers for Snow Maintenance Equipment

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ABSTRACT

Due to the evolution of the use of private contractors in Ontario for highway snow removal, a lack of consistency developed in the lighting and marking of maintenance vehicles. Due to safety concerns raised by operators of snow removal equipment, the Ministry of Transportation of Ontario (MTO) initiated the development of an updated standard for a lighting and marking system, to produce greater visibility/conspicuity of, and safety for, highway snow removal equipment and associated workers. The standard was developed through a multi-disciplinary value engineering study. This paper describes a series of tests that were carried out to assess the proposed lighting and marking system. Tests involved selection of highly conspicuous elements, determination of the conspicuity of brake lights, turn signals and rotators, in the presence of other system elements and assessment of driver ability to determine closing speed with the proposed system. The final standard included:

- A fluorescent yellow-green/black checkerboard with Type III/IV sheeting
- Constant Amber + Flashing Blue LED light bars to each side and above the checkerboard
- Red and white retro-reflective tape on an airfoil above the checkerboard
- Upper and lower tail and brake lights and
- Amber and blue rotating beacons, one on the roof of the cab and the other two near the top left and top right corners of the back of the snow removal equipment.

This design has now been accepted and published as a national guideline by the Transportation Association of Canada.

Keywords: Snow removal equipment, conspicuity, human factors, vehicle lighting,
INTRODUCTION
In May 2013, the Contractors responsible for Area Maintenance Contracts in Ontario expressed a safety concern for staff completing winter maintenance duties on Ontario highways. As a result of moving from Ministry of Transportation in Ontario (MTO) owned and operated equipment to the complete use of private contractors over the previous 15 years, there was a gradual reduction in consistency of lighting and marking of snow removal equipment (see Figure 1 for current practices as of 2013). Over the same period there have been many advances in lighting technology and the private contractors wanted to benefit from these. It was decided at a joint meeting between MTO and its maintenance contractors, to develop a consistent design standard, for a lighting and marking system, to produce greater visibility/conspicuity of, and safety for, snow removal equipment and associated workers. This paper describes a series of tests that were carried out to develop and assess the proposed lighting and marking system.

BACKGROUND
The proposed system was developed by a multidisciplinary team which included human factors and safety expertise, industry expertise (maintenance managers and operators) and lighting and equipment manufacturers, during the Snow Removal Equipment Visibility Value Engineering Workshop, which was held in July 2013.

The lighting and marking specifications current at the time of testing incorporated standard incandescent lighting in the configurations similar to those illustrated in Figure 1. Within the industry it was widely felt that improvements could be made to increase the conspicuity/visibility of snow removal equipment/sander units to aid in road safety. The existing design suffered from several shortcomings:

- No perceived consistent lighting or marking pattern
- Did not properly indicate dimension of unit
- Shortened life cycle of incandescent lights compared to LEDs
- Driver perception of closing rates difficult when approaching from the rear in snow cloud and
- Insufficient intensity of current incandescent lights

The lighting and marking specifications proposed at the Value Engineering Workshop are illustrated in Figure 2.

FIGURE 1 Lighting specifications as of 2013.
FIGURE 2 Proposed Lighting and Marking System: Fluorescent yellow green/black checkerboard with constant amber and flashing blue LED lights and rotating beacons.

To ensure the lighting and marking system was effective a sequence of three tests was carried out. The tests were designed to validate (or not) that the best options had been selected by 1) assessing visibility and conspicuity of various combinations of lights and markings, and 2) determining the ability of approaching drivers to assess their closing speeds.

TESTS

Test 1: Checkerboard Color/Reflectivity Selection

Goal
The goal of Test 1 was to select the most conspicuous harlequin pattern “checkerboard” from eight alternatives with various color and reflective sheeting combinations. A secondary goal was to assess the relative brightness of the amber and blue lights to ensure they were similar.

Test Materials
Eight checkerboards (3 feet tall x 6 feet wide, 1 x 1 foot squares), with three color combinations (blue & amber, blue & white, fluorescent yellow-green & black) and three types of sheeting (Type XI, Type III/IV, Engineer Grade), in addition to a black and white “standard” checkerboard, were tested. The fluorescent yellow-green & black checkerboard was not tested in Engineer Grade as sheeting was not available. The checkerboards were mounted on a steel frame on the back of a snowplow.

Test Location
The test was carried out on a by-passed section of road adjacent to a maintenance yard. The test road was closed for our use. The road is very gently curved.

Test Subjects
Twelve participants (4 under 26 years, 4 aged 26 to 55 years, and 4 over 55 years) were involved in both day and night tests. All participants were MTO employees or children of employees or past employees.

Test Procedure
Each of the participants was shown a black and white “standard” checkerboard and told that it rated 100 for conspicuity. Each of the participants was then asked to rate the subsequent boards in comparison to the black and white checkerboard, using any positive number above or below 100 from 0 on up. Prior to
analysis each participant’s numbers were normalized so all the distributions had the same top and bottom ends (see details of analysis below). This test method has previously been used to assess conspicuity of warning lights (Flanagan et al., 2008).

In addition to rating the checkerboard conspicuity, participants were also asked to rate the relative brightness of the constant amber and flashing blue lights during daytime and nighttime measurements. To avoid bias due to order of presentation, six orders of presentation of the checkerboard panels were used counterbalanced by subject age (<25 years, 25-55 years, > 55 years).

For the daytime measurements, study participants sat in a passenger vehicle that was parked 200 m away from the location of the checkerboards. The vehicle was aligned perpendicular to the checkerboards. Testing took place between 1:30 p.m. and 3:30 p.m. on November 4, 2013.

For the nighttime measurements, study participants sat in a passenger vehicle that was parked 120 m away from the location of the checkerboards and the vehicle headlights were on high beam. Testing started once it was fully dark.

**Analysis**

All data were normalized for each participant on a scale of 1-10. For each participant, the minimum score was scaled down to 1, the maximum was scaled down to 10, and the scores in between were pro-rated accordingly.

**Results**

The daytime conspicuity rating results are shown below in Table 1. Out of a maximum score of 10 and a minimum score of 1, the Yellow-Green and Black color combination had the highest scores, 9.1 for Type III/IV sheeting and 8.5 for Type XI sheeting.

**TABLE 1 Daytime Checkerboard Ratings: Mean (st. dev) Conspicuity Rating**

<table>
<thead>
<tr>
<th>Sheetig</th>
<th>Engineer</th>
<th>Type III/IV</th>
<th>Type XI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow-Green and Black</td>
<td>N/A</td>
<td>9.1 (2.2)</td>
<td>8.5 (2.6)</td>
</tr>
<tr>
<td>Amber and Blue</td>
<td>3.1 (2.6)</td>
<td>3.8 (3.4)</td>
<td>3.7 (2.8)</td>
</tr>
<tr>
<td>White and Blue</td>
<td>3.8 (2.5)</td>
<td>3.7 (1.5)</td>
<td>4.9 (2.7)</td>
</tr>
</tbody>
</table>

The night-time results are shown below in Table 2. Type XI sheeting produced the highest ratings, while the color combinations were less differentiated than was the case in the daytime.

**TABLE 2 Nighttime Checkerboard Ratings: Mean (st. dev) Conspicuity Rating**

<table>
<thead>
<tr>
<th>Sheetig</th>
<th>Engineer</th>
<th>Type III/IV</th>
<th>Type XI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow-Green and Black</td>
<td>N/A</td>
<td>6.6 (2.7)</td>
<td>8.3 (1.8)</td>
</tr>
<tr>
<td>Amber and Blue</td>
<td>1.8 (0.9)</td>
<td>6.8 (2.0)</td>
<td>8.4 (1.8)</td>
</tr>
<tr>
<td>White and Blue</td>
<td>2.1 (1.8)</td>
<td>5.9 (3.0)</td>
<td>7.1 (2.2)</td>
</tr>
</tbody>
</table>

An Analysis of Variance (ANOVA) statistical test was carried out. The data for the Engineering Grade results were omitted as this sheeting was not used for the fluorescent yellow-green and black checkerboard. The ANOVA test determined that there was a main effect of Color (p < .001). The
Fluorescent Yellow-Green and Black achieved significantly higher scores than the Blue and Amber (p < .001) and Blue and White (p < .001) color combinations. There was a main effect of Sheeting (p = .04).

Type XI achieved significantly higher scores than Type III/IV sheeting.

A Paired T-Test was used to determine if there was an effect of sheeting for the night data alone. Using data for all three checkerboard color combinations, Type XI was significantly better than Type III/IV sheeting (mean = 8.0 vs 6.4, p = .002).

At the end of each session participants were asked to assess the relative brightness of the amber and blue lights positioned on the back of the truck according to a five-point scale.

During the day, 8 out of 11 participants indicated that the solid amber lights were either “a little less bright” (n=7) or “much less bright” (n=1) than the flashing blue lights. After dark, 10 out of 11 participants said that the amber lights were either “a little less bright” (n=4) or “much less bright” (n=6) than the flashing blue lights.

At the end of the evening session participants were asked for their opinion regarding which color combination best illustrated a message of caution. Nine of the 12 participants responded to this question, including five who said fluorescent yellow-green on black and four who said amber on blue. No one suggested blue/white.

**Conclusion**

It was recommended that the fluorescent yellow-green color combination checkerboard and both Type XI and Type III/IV sheeting should be carried forward to Test 2. As for which color combination best illustrated a message of caution, there was almost equal preference for fluorescent yellow-green on black and amber on blue. No one suggested blue/white.

With respect to the relative brightness of the constant amber and flashing blue lights, both during the day and after dark, the constant amber lights were rated as being either “a little less bright” or a “much less bright” than the flashing blue lights.

**Test 2: Light Pattern Conspicuity Assessment**

**Goal**

The goals of Test 2 were to:

- Rate day and night conspicuity of brake lights, turn indicators, rotating beacons with the following LED lighting patterns:
  1. Constant amber, or
  2. Constant amber and flashing blue, or
  3. Flashing amber and flashing blue
- Rate relative conspicuity and distinctiveness of tow truck, police cruiser and snowplow lighting patterns (all lights were LEDs).
- Based on these ratings, select the most conspicuous lighting pattern for use in the last phase of testing.

The reason for comparing the conspicuity of the police vehicle and tow truck to that of the snowplow was a perception that tow trucks may have greater conspicuity than snowplows or police cars and the concern that drivers may be confused by the use of blue flashing lights on police cars and on snowplows. Ontario has used blue flashing lights on snowplows since 1948. Blue lights were added to police cars in 2007.

**Method**

As for Test 1, tests were carried out on a by-passed section of road near a maintenance yard with a parked snowplow with various lighting combinations being assessed for conspicuity by a total of 8 to 12
participants under day and night conditions from a parked vehicle 200 m behind the snowplow. The conspicuity of turn signals, brake lights, and rotating beacon were assessed with the three different lighting patterns. At night participants were asked to rate the similarity between the snowplow (Constant Amber + Flashing Blue), tow truck (Flashing Amber) and police cruiser (Constant Blue alternating with Constant Red) lighting configurations.

**Analysis**

As in Test 1, all data were normalized for each participant on a scale of 1-10. An ANOVA test was used to examine the effect of lighting pattern, time of day, and checkerboard sheeting.

For the afternoon session only ten out of the twelve participants were able to complete their measurements before sunset. Of those, only eight were able to complete their measurements before dusk. As a result, two ANOVA analyses were carried out. The first analysis included the ten participants that completed the afternoon session and all twelve participants that completed the night-time measurements. The main benefit of the first analysis was the inclusion of a larger sample of data, which has greater statistical power. The second analysis included only daytime and night-time data for those eight participants who completed the afternoon measurements before sunset. The main benefit of the second analysis was a balanced statistical test including, for the daytime condition, only those participants who completed daytime measurements under daylight conditions. The results of the two analyses were very similar, consequently only the results of the second analysis are reported below.

**Results**

**Conspicuity of Turn Signals**

The Constant Amber lighting pattern had the highest score (4.0) as compared to the Constant Amber + Flashing Blue (3.5) and Flashing Amber + Flashing Blue (3.5). There was no effect of lighting pattern (p = .583) or time of day (p = .313) on turn signal conspicuity. At night, there was no effect of sheeting on turn signal conspicuity (p = .638).

**Conspicuity of Brake Lights**

Flashing Amber and Flashing Blue had the highest score (6.4) as compared to the Constant Amber + Flashing Blue (5.7) and Constant Amber (5.5). Overall, there was no effect of lighting pattern (p = .528) or time of day (p = .339) on brake light conspicuity.

**Conspicuity of Rotating Beacons**

Overall, there was an effect of lighting pattern (p = .025); the rotating beacon was much less noticeable with the Constant Amber lighting pattern as compared to the other two lighting patterns (4.6 vs. 6.3 and 6.6) (see Figure 3).
relative brightness of blue and amber lights

During the day participants were asked to use a 5-point scale to rate the relative brightness of the blue and amber lights. The average score was 2.5 (halfway between amber a little less bright and equally bright to blue) and half of all participants rated amber a little less bright than blue.

At night the average score was 1.9 and more than half (64%) of all participants rated amber a little less bright than blue.

Comparison of Snowplow vs. Tow Truck Lighting Pattern

At night participants were asked to use a 5-point scale to rate the similarity between the snowplow (Constant Amber + Flashing Blue) and tow truck (Constant Amber + Flashing Amber) lighting configurations where 1 signified the two configurations are very different and 5 signified that the two configurations were very similar. The average score was 1.6 signifying that the two lighting configurations were very different.

Comparison of Snowplow vs. Police Cruiser Lighting Pattern

At night participants were asked to rate the similarity between the snowplow (Constant Amber + Flashing Blue) and police cruiser (Constant Blue alternating with Constant Red) lighting configurations. The average score was 1.3 signifying that the two lighting configurations were very different. See Figure 4.
There were no statistically significant differences in the conspicuity ratings of the turn signal or the brake lights in relation to the three light patterns. As for the rotating beacon, it was more conspicuous with the patterns with flashing elements (Flashing Amber + Flashing Blue and the Constant Amber + Flashing Blue) than with the Constant Amber lighting pattern. There was no effect of time of day for the conspicuity ratings. There was no effect of sheeting (Type III/IV versus Type XI) on brake, turn signal or rotator conspicuity.

There were two concerns with the Flashing Amber + Flashing Blue lighting pattern. First, earlier studies have shown that driver perception of closing velocity is better with constant rather than with flashing lights (Hanscom & Pain, 1990). Second, in consideration of the fact that snow removal vehicles drive in echelon formation on wider highways, the Flashing Amber + Flashing Blue lighting pattern may be distracting to approaching drivers. Given these concerns as well as the study findings, it was recommended that the Constant Amber + Flashing Blue lighting pattern be the flashing pattern used in Test 3.

With respect to the similarity between the snowplow lighting pattern (Constant Amber + Flashing Blue) and the police cruiser lights or the tow truck lights, participant ratings indicated that the snowplow lighting configuration was very distinctive. When participants were asked to describe the unique aspects of the proposed snow removal equipment lighting configuration, those mentioned included the larger size, evident in the day as well as at night due to the lighting layout as well as the presence of a checkerboard panel.
Conclusion

It was recommended that the Constant Amber + Flashing Blue lighting pattern be carried forward to Test 3. It was concluded that the snow removal equipment lighting configuration was visually distinct from police cruiser lights and tow truck lights.

Test 3: Perception of Closing Velocity and Conspicuity Assessment

Goal

The goals of Test 3 were 1) to compare the existing and proposed lighting pattern with respect to ease of perception of closing velocity and 2) to assess conspicuity of the proposed vs. existing lighting pattern.

FIGURE 5 Proposed Lighting System: Fluorescent Yellow Green/Black Checkerboard with Constant Amber and Flashing Blue LED Lights and Rotating Beacons.

The existing lighting system is shown in Figure 1. The proposed lighting system (see Figure 5) had a Conspicuity Panel which consisted of:

1. Air Foil (wind deflector): Mounted above the rear checkerboard and allows airflow to keep the rear facing sign and lights clear of snow.

2. Checkerboard Sign: Mounted on a steel frame as part of the Conspicuity Panel and had the following properties:
   a. Rectangular in shape; 900mm x 1800mm (3’ x 6’) overall size
   b. Each square was 300mm x 300mm (1’ x 1’)
   c. The squares were a combination of fluorescent strong yellow/green and black
   d. Sign material was plywood backing with Type III/IV sheeting

3. Lights: Provided by LED Light Manufacturers, SWS Warning Systems Inc.:
   a. Light System #1 (Minibar): Rotates in amber then in blue, in a clockwise manner in synchronization with the beacons and directional warning sticks. Placed on either side of checkerboard and aligned vertically.
   b. Light System #2 (Beacons): Rotates in amber then in blue, in a clockwise manner in synchronization with the minibar and directional warning sticks.
   c. Light System #3 (Directional Warning Sticks): The amber segments were steady-on, with the blue segments flashing in synchronization with the minibar and beacons blue flashing segments. Placed just above the checkerboard on the left and right sides and aligned horizontally.
In Test 1, XI sheeting was significantly brighter than III/IV sheeting. Both XI and III/IV were significantly brighter than Engineering grade. Given concerns about glare (there can be too much conspicuity), and that no difference was found between the two sheeting types in brake, turn signal or rotator conspicuity in Test 2, it was decided to use the III/IV sheeting for Test 3. To allow for easy comparison between systems, one snowplow vehicle was equipped with two lighting systems: the existing lighting system and the proposed lighting system. Controls inside the cab allowed the driver to quickly switch between the two lighting patterns while the vehicle was in motion. Due to the impossibility of changing the checkerboard while in motion, it was not installed on the rear of the snowplow. Due to the need to supply electrical power to the new LED lighting pattern, the power was cut to the small lower amber and blue flashing lights which were part of the existing lighting pattern. (In plowing conditions these low level lights may well be snow-encrusted and not very visible.)

The second snowplow was equipped with a tow plow and was used for snowplow/tow plow deployment and return observations (not reported in this paper).

**Location**

The test location was Huntsville, Ontario under typical winter conditions. The perception of closing velocity assessment was carried out on a four-lane highway with a wide grassy median and a posted speed limit of 100 km/h. There was no illumination on this portion of the highway with the exception of a single light standard at all five at-grade intersections in the study area.

The conspicuity assessment was carried out on Highway 60 on a segment which was urban in nature, with streetlighting on both sides of the highway, signalized intersections, and several business entrances with lighting at night on both sides of the highway. The urban area was five lanes wide and was posted at 70 km/h. The rural section was two lanes wide with no streetlighting and a posted speed limit of 80 km/h.

**Participants**

Six participants (2 under 26 years, 2 aged 26 to 55 years, and 2 over 55 years) were recruited to participate in both day and night tests. All were MTO or former MTO employees. One participant (aged over 55 years) was not able to participate in the night tests on Day 2.

**Procedure**

The tests were carried out on two separate days. On the first day the perception of closing velocity assessment was carried out using a similar methodology to that used in the Bullough et al. (2001) study and is described below (Bullough, Boyce, Bierman, Hunter, Conway, Nakata, & et al., 2001). This assessment was carried out under daylight and nighttime conditions on straight and mostly flat segments of Highway 11. The first experimenter sat in the passenger seat of the snowplow while the snowplow drove at 60 km/h, the speed at which active snowplowing operations are conducted. The following car was driven by a second experimenter who maintained a distance of 100 m behind the snowplow. A Lidar device was to be used for this purpose but its design made such use cumbersome and impractical. Instead, markings were added to the windshield showing the width of the snowplow when it was a distance of 100 m. These markings were used by the experimenter/driver to keep a constant distance behind the snowplow. The participant sat in the passenger seat. A third experimenter sat in the back seat and was in constant telephone communication with the first experimenter positioned in the passenger seat of the snowplow.

At pre-determined locations along the highway, participants were instructed that the snowplow ahead would begin slowing, without braking, sometime in the next 10 to 50 seconds. The participant was instructed to say “NOW!” when they were certain that the headway to the snowplow ahead was decreasing. At some point during this interval the experimenter in the snowplow silently instructed the snowplow operator to release his foot from the accelerator. As soon as the snowplow operator released his
foot from the accelerator the experimenter in the snowplow started a stopwatch and then stopped the stopwatch when the participant in the trailing vehicle was heard to say “NOW!” This procedure was followed twice with the existing lighting system and twice with the proposed lighting system for each participant. The observation orders were balanced with respect to which lighting system was observed first.

The snowplow and the test vehicle were driven in the right lane. In order to ensure that no outside vehicles interfered with the testing, a blocker truck was positioned behind the test vehicle in the right lane and a second blocker truck was positioned in the left lane.

Daytime observations were carried out between 1:30 and 3:30 p.m., and nighttime observations between 7:00 and 9:00 p.m.

On the second day, a conspicuity assessment was carried out under daylight and nighttime conditions with the existing and the proposed lighting systems in urban and rural sections of Highway 60. The first experimenter sat in the passenger seat of the snowplow. The test vehicle was driven by a second experimenter who maintained a distance of approximately 50 m behind the snowplow. The third experimenter sat in the back seat of the test vehicle. Two participants were tested at a time.

In the urban area the first experimenter in the snowplow switched the lighting on the back of the truck back and forth between the existing and proposed lighting pattern, with each lighting system exposed for approximately 5 seconds. At the end of the urban area the third experimenter asked the participants to do the following:

1. Rate the relative conspicuity of the proposed lighting pattern as compared to the existing lighting pattern using a 5-point scale (much less, less, equal, more, much more conspicuous)
2. Rate the adequacy of the existing lighting pattern using a 3-point scale (less than adequate, adequate, more than adequate) and
3. Rate the adequacy of the proposed lighting system using a 3-point scale (less than adequate, adequate, more than adequate)

Participants were also encouraged to describe their observations and impressions of the two lighting systems.

In the rural area this procedure was repeated with one difference. When switching back and forth behind lighting patterns, each lighting system was exposed for approximately 10 seconds each. At the end of the rural area participants were asked to make the same three ratings as at the end of the urban area.

Analysis
A paired T-test was used to analyze the results of the perception of closing velocity measurements. No statistical tests were carried out of the subjective ratings due to the small sample size.

Results
In the complete dataset, there were three instances (27.9, 28.2, 24.7 seconds) where measurements were taken on a slight downgrade which resulted in the snowplow decelerating at a slower rate thus extending the time taken by participants to determine that they their closing distance was decreasing. In another instance the test vehicle was more than 100 m back from the snowplow when it (the snowplow) started to decelerate, resulting in a measurement (20.6 seconds) that was significantly higher than the average. In one instance the participant had an unusually short response time (2.8 seconds). If these outliers (all 2 standard deviations or greater from the mean) are removed, the revised results are as follows in Table 3.

During the day participants took an average of 11.0 seconds with the existing lighting pattern and 9.6 seconds with the proposed lighting to determine that the distance to the snowplow was decreasing. At
nighttime, participants took 11.2 seconds with the existing lighting pattern and 9.3 seconds with the proposed lighting pattern to determine that the distance to the snowplow was decreasing. A paired T-Test determined that, with day and night data combined, there was a trend towards better perception of closing velocity with the proposed lighting pattern (11.1 seconds) as compared to the existing lighting pattern (9.5 seconds) (p = .08).

**TABLE 3** Results: Perception of Closing Velocity – Outliers Removed (SD in brackets)

<table>
<thead>
<tr>
<th></th>
<th>Existing Lighting Pattern (n=21)</th>
<th>Proposed Lighting Pattern (n=21)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day (n=21)</td>
<td>11.0 (2.7)</td>
<td>9.6 (2.9)</td>
<td>14%</td>
</tr>
<tr>
<td>NIGHT (n=21)</td>
<td>11.2 (2.8)</td>
<td>9.3 (3.5)</td>
<td>20%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11.1 (2.7)</td>
<td>9.5 (3.2)</td>
<td>17%</td>
</tr>
</tbody>
</table>

**Relative Conspicuity of Lighting Patterns**
Participants were asked to rate the relative conspicuity of the proposed lighting pattern as compared to the existing pattern. The average ratings in the urban segment were 5.0 both during the day and at night. The average ratings in the rural segment were also similar, 4.8 during the day and 5.0 at night (1 = much less conspicuous, 3 = equal, 5 = much more conspicuous).

**Perceived Adequacy of Existing Lighting Pattern**
Participants were asked to rate the adequacy of the existing lighting pattern. The average ratings for the existing lighting pattern in the urban segment were 1.2 during the day and 1.0 at night. The average ratings in the rural segment were 1.0 during the day and 1.6 at night (1 = less than adequate, 2 = adequate, 3 = more than adequate).

**Perceived Adequacy of Proposed Lighting Pattern**
Participants were asked to rate the adequacy of the proposed lighting pattern. The average ratings of the proposed lighting pattern in the urban segment were 2.3 during the day and 2.6 at night. The average ratings in the rural segment were 2.3 during the day and 2.8 at night (1 = less than adequate, 2 = adequate, 3 = more than adequate).

**DISCUSSION**
With respect to the perception of closing velocity, there was a trend to better performance with the proposed (Constant Amber + Flashing Blue) lighting pattern as compared to the existing lighting system with detection at 9.5 seconds vs. 11.1 seconds after slowing started from an initial separation of about 100 m). Our mean times to perception of closing velocity agreed with those found in a previous study (Bullough, Boyce, Bierman, Hunter, Conway, Nakata, & et al., 2001).

With respect to the conspicuity of the proposed and the existing lighting patterns in various conditions:
- The proposed lighting system was rated more conspicuous than the current one. However, the level of nighttime brightness for the proposed system was rated too bright for rural areas (as compared to the urban area where there were more lights), and experience indicated that the glare could be unpleasant for following drivers.
- A number of participants found that the upper amber and blue rotator lights were not bright enough in comparison to the LED constant amber and flashing blue lights. The blue color was noted particularly as being washed out.
CONCLUSION
The proposed pattern of Constant Amber + Flashing Blue was found to be more conspicuous and to afford better perception of closing velocity as compared to the existing pattern. However, the upper amber and blue rotator lights should be brighter to better match the LED Constant Amber + Flashing Blue lights. In addition, consideration should be given to a slight reduction in brightness of the LED lights at night.

RECOMMENDATIONS
Based on the results of three tests, carried out during the day and at night, two tests on a closed course and the last, on-road, the proposed markings are recommended:

- A fluorescent yellow-green/black checkerboard with Type III/IV sheeting
- Constant Amber + Flashing Blue LED light bars to each side and above the checkerboard
- Red and white retro-reflective tape outlining the checkerboard
- Upper and lower tail and brake lights and
- Amber and blue rotating beacons, one on the roof of the cab and the other two near the top left and top right corners of the back of the snowplow (see Figure 5)

The proposed lighting pattern, absent the checkerboard due to practicalities of testing, was definitely preferred over the existing lighting pattern. The proposed lighting pattern was found to be more conspicuous and to afford better perception of closing velocity as compared to the existing pattern. A number of small changes in the proposed pattern are recommended. First, the upper amber and blue rotator lights should be brighter to better match the LED Constant Amber + Flashing Blue lights. Second, consideration should be given to a slight reduction in brightness of the LED lights at night. Finally, separation of beacons from taillights should be such that these lights are easily distinguishable from each other at night at a distance of 200 m.

Due to lack of the requisite equipment, the project team were unable to make observations in medium/heavy snowfall or during plowing of snow covered roads of a snowplow or of a snowplow/tow plow combination both using the existing lighting system or both using the proposed lighting system. Such observations were subsequently made by MTO staff using test units in various parts of the province, in daylight and night conditions, in order to confirm that the lights were conspicuous under plowing operations, and that the nature of the attachment between the snowplow and the tow plow was clear.

This design has now been accepted and published as a national guideline by the Transportation Association of Canada.

REFERENCES