

# **EFFECTIVENESS OF HEAVY TRUCK CONSPICUITY TREATMENTS UNDER DIFFERENT WEATHER CONDITIONS**

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## **ABSTRACT**

The United States have had enhanced conspicuity standards for heavy trucks in place for over three years. The standards which were developed by the National Highway Traffic Safety Administration (NHTSA) dictate the use of retro-reflective tape as a means to primarily improve nighttime conspicuity. Effective January, 1997, Transport Canada has amended Canadian Motor Vehicle Safety Standard (CMVSS) #108 to adopt reciprocal standards. While both the Canadian and U.S. standards were based on the results of previous studies, little consideration was given to the effectiveness of different treatment patterns or colours under varying weather conditions.

The University of New Brunswick has undertaken a series of truck conspicuity tests under different weather conditions including clear, rain, snow, and fog. The effectiveness of nine different conspicuity treatments for the rear of the trailer, and five for the side, were evaluated.

A complete outline of solid white retro-reflective tape was found to be the most effective configuration to increase the threshold of visibility for the rear of the trailer under all weather conditions. The NHTSA configuration ranked no higher than fourth among the rear scenarios evaluated. A continuous stripe of white retro-reflective tape was found to be the most effective configuration to increase the threshold of visibility of the side of the trailer under three of the four weather conditions. The NHTSA configuration ranked the lowest of all side configurations considered under each weather condition.

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## INTRODUCTION

The enhancement of heavy truck conspicuity has been the target of modified motor vehicle safety regulations both in the United States and Canada over the past few years. In essence, the legislation dictates the use of retro-reflective tape on the sides and rear of heavy truck trailers in order to improve nighttime conspicuity. A number of studies have provided the basis for recommended *patterns* and *colours* of the tape; however, little is known about the performance of different combinations under adverse weather conditions. The primary objective of this study was to contrast the effectiveness of different retro-reflective tape configurations under four basic weather conditions: clear, rain, snow and fog. A total of nine different tape configurations were tested for the rear of the trailer and five for the side. The underlying premise was that a scheme which is more effective than that adopted in the United States by the National Highway Traffic Safety Administration (NHTSA) might exist when all weather conditions are considered.

This study was initiated at a time when Transport Canada was developing modifications to existing motor vehicle safety standards which would incorporate improved conspicuity treatments for heavy truck trailers. The development of the Canadian standards were a direct response to those established by NHTSA. A consideration for Transport Canada was the harmonization with the U.S., however, that does not necessarily ensure a configuration with optimal impact given a unique Canadian climate. The U.S. regulations apply to all trailers (with a gross weight registration of more than 10,000 pounds) manufactured after December 1, 1993. Straight trucks, truck-tractors, containers, and recreational trailers were exempt from the regulations. As illustrated later, NHTSA required retro-reflective conspicuity tape to be applied to the sides and rear of trailers using specific patterns and colours.

The Canadian regulations were recently adopted and took affect in January, 1997. Although the Canadian regulations follow those establish by the U.S., there are some fundamental differences. Where alternating patterns of red/white retro-reflective tape are required by NHTSA, Transport Canada has allowed the substitution of solid white, solid yellow, or alternating yellow/white (except for the horizontal member of the rear underride frame which must be red/white). It is noteworthy that British standards have prescribed rear markings, since 1971, of both retro-reflective yellow and florescent red to maximize both day and night benefits. It is currently proposed that the Canadian regulations might be extended to include tractors and straight trucks [White, 1996]. Note that these federal regulations can only apply to newly manufactured trailers; retrofitting existing trailers must be the responsibility of provincial or territorial governments.

## BACKGROUND

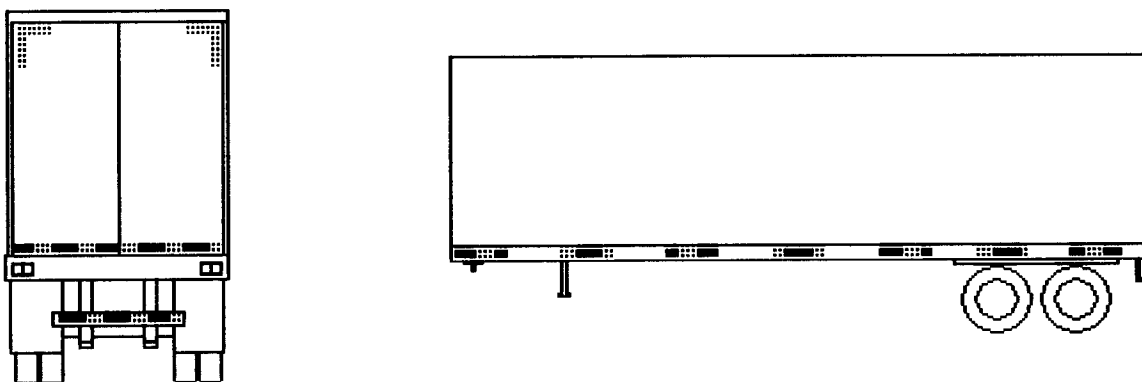
Over one-quarter of all conspicuity related accidents involving a tractor-trailer and a passenger vehicle, and nearly one-half of all conspicuity related accidents involving fatalities occur at night [Olson et. al., 1992]. Either motorists are unable to detect the heavy vehicle in time to stop, or they cannot identify the vehicle as a hazard, leading to erroneous driving decisions. Consequently, a

significant number of underride collisions occur at high speeds resulting in serious injuries [Badger, 1993]. The intended role of retro-reflective tape is to facilitate earlier nighttime detection and identification of commercial vehicles.

The Road Safety and Motor Vehicle Regulation Directorate of Transport Canada has estimated that nighttime underride collisions resulted in 21 fatalities and 640 injuries, annually, in Canada between 1984 and 1986 [Gutoskie, 1995]. Olsen et. al. indicate that rear impacts account for nearly 80 percent of conspicuity related collisions with heavy trucks, while the remainder are side impacts (1992). Rear impacts result primarily when passenger vehicles strike a heavy vehicle that is either slow moving or parked on, or straddling, the shoulder of a roadway.

One of the more significant North American studies to examine the enhancement of heavy truck conspicuity was conducted by Vector Research in California over a 23 month period beginning in 1983 [Vector, 1991]. The study, which would eventually provide a partial basis for the NHTSA legislation, involved retrofitting more than 1,900 trailers with conspicuity tape (using a configuration similar to that which was eventually adopted by NHTSA). A similar sized group was untreated to serve as a control group. Following an accumulation of more than 120 million nighttime kilometres, the treated trailers realized a reduction in both daytime and nighttime accidents of 18 and 21 percent, respectively [Burger et. al 1985]. Furthermore, the average accident cost for the marked trailers was approximately one-half that of the unmarked trailers.

The University of Michigan Transportation Research Institute (UMTRI) was commissioned by NHTSA in 1991 to define a range of minimally acceptable large truck conspicuity enhancements to provide a basis for the Federal regulations. The study's recommended requirements have been adopted as the NHTSA standard [Olson et. al., 1992]. The primary focus of the research was on hazard identification rather than visibility. The study relied on a series of experiments in which subjects were asked to rank or compare treatment schemes applied to mock trailers either in the field or from video in a laboratory. On the basis of these experimental results a recommended minimum coverage was adopted by NHTSA as portrayed in Figure 1. Alternating red/white tape is used to provide horizontal striping along the bottom of the trailer, while white chevrons are used to mark the top corners of the rear of the trailer.



**Figure 1. NHTSA Rear and Side Tape Configurations**

A conspicuity study commissioned by Transport Canada was undertaken by Carleton University in 1993 [Tansley and Petrusic, 1993]. Subjects were asked to observe video clips of approaches to a stationary tractor-trailer retrofitted with retro-reflective tape treatments. Each configuration was evaluated on the basis of visibility threshold, ability to distinguish dimension/size, and subjective comparative rating. This study resulted in a recommendation that a solid white outline configuration be adopted for the rear of trailers and, if alternating red/white tape is to be used, that shorter segments are preferred.

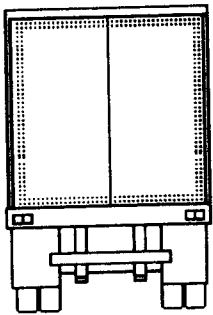
## METHODOLOGY

This study endeavoured to evaluate different tape configurations on the basis of (1). recognition threshold determination, and (2). a subjective configuration evaluation. A total of 120 test participants reviewed video recordings of field trials and the results were subsequently analyzed. In order to minimize biases, the sample was stratified on the basis of an age/gender profile of drivers licensed in the Province of New Brunswick.

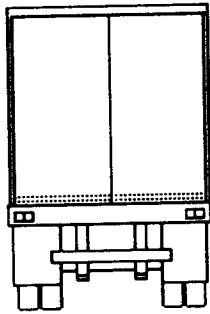
The field data collection took place at an abandoned airstrip in Pennfield, New Brunswick. An actual tractor semi-trailer was used as the target vehicle. The semi-trailer was a basic 48 foot aluminum box van. The combination unit was placed at one end of the asphalt surfaced runway. An observation vehicle, complete with video recording equipment, would approach the target vehicle from the opposite end of the runway some 800 metres away. Longer approach distances could not be provided, however, distances in excess of 800 metres would be irrelevant for stopping or decision sight purposes. Small markers were placed adjacent to the runway at 100 metre intervals to allow calibration of recognition distances in the laboratory. The only means of illumination were provided by the low beam headlights of the observation vehicle. Careful attention was given to the settings used on the video recorder so that the recorded image was as close to that viewed by the human eye as possible. Increased aperture settings can make the images appear brighter on a monitor than those actually perceived in the field.

As previously noted, nine rear and five side configurations (including 'no treatment' which was needed as a benchmark) were evaluated under four basic weather conditions. Therefore, a total of 56 approach runs were videotaped. The tractor semi-trailer would be positioned either end on, or perpendicular to the approaching vehicle depending on the scenario being tested.

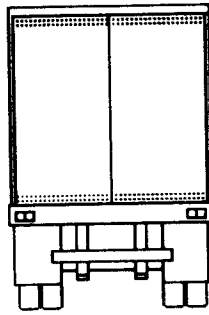
The retro-reflective tape configurations were applied to sheet metal strips, which, in turn, were attached to the trailer surfaces using velcro for easy removal/modification. All 2-inch wide tape used was manufactured to meet DOT-C2 grade certification as required by NHTSA legislation. The one exception was the *Metalcore* scenario which used ½ inch stripes to represent an application to the door seals of the trailer. The different tape configurations which were evaluated are depicted in Figure 2. The patterns and colours tested were selected, in part, on the basis of advice solicited from Transport Canada.



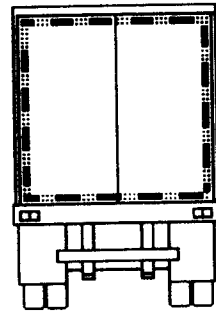
**Full White Outline**



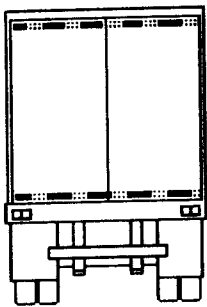
**White Bottom Stripe**



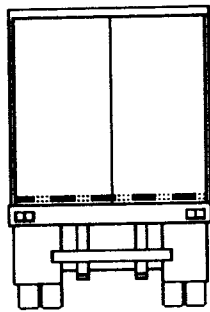
**White Horizontals**



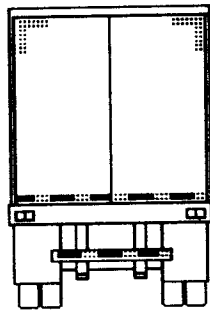
**Red/White Outline**



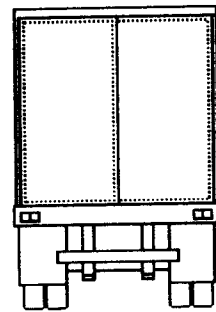
**Red/White Horizontals**



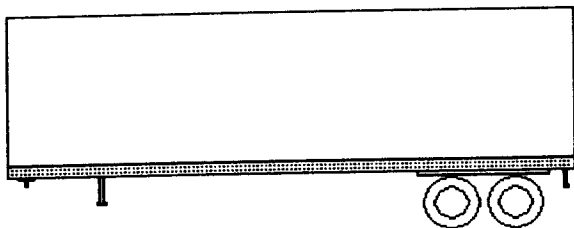
**Red/White Bottom**



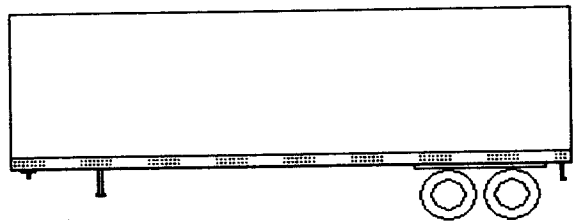
**NHTSA**



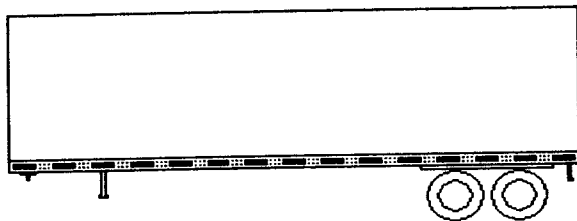
**Metalcore**



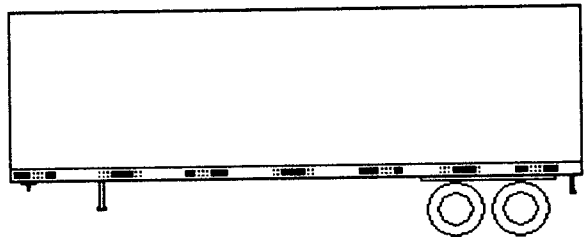
**Solid White Stripe**



**Staggered White Stripe**



**Solid Red/White Stripe**



**Staggered Red/White Stripe**

**Figure 2. Rear and Side Tape Configurations Evaluated**

Using the field data, two separate experiments were conducted which were designed to differentiate the effectiveness of the different taping schemes. The first experiment, *Recognition Threshold Determination*, had the test subjects identify the point at which an object was first noticed, where it was recognized as being 'large and potentially hazardous', and finally, where the object could be positively identified as a semi-trailer. The second experiment, *Subjective Configuration Evaluation*, asked test subjects to evaluate how effective the tape patterns were in identifying the truck as a hazard. A rating scale of 1 through 5 was employed.

## STUDY RESULTS

The first level of recognition tested, the *threshold of visibility*, is perhaps the most important when stopping sight considerations are considered. The variability between different taping schemes under different weather conditions did not vary statistically between the threshold of visibility and the second level tested, the *threshold of hazard identification*. The final level recorded, the *threshold of semi-trailer identification*, showed little variation between the different patterns or colour schemes evaluated. Therefore, the mean *threshold of visibility* is the primary focus of discussion throughout this paper.

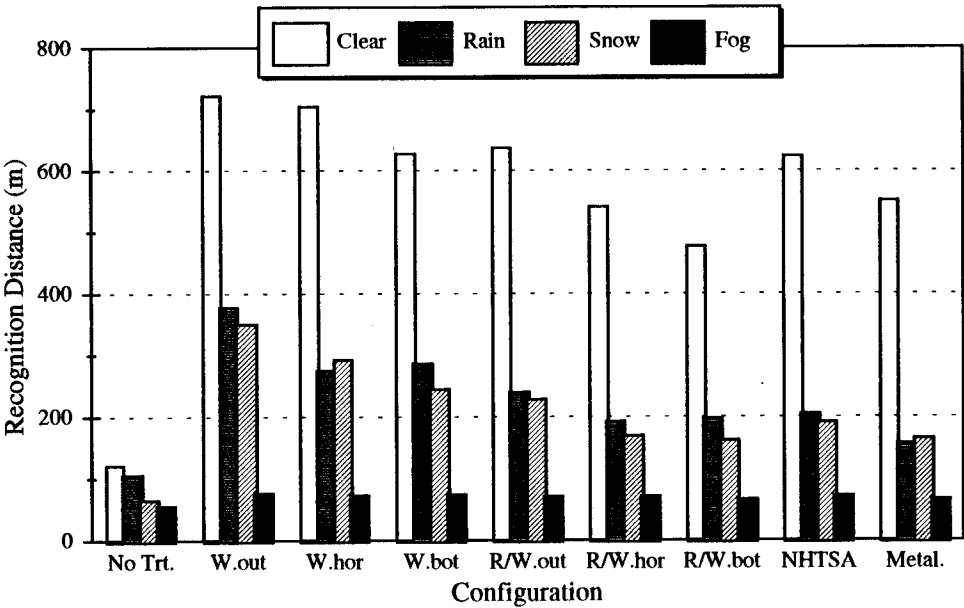
Figure 3 presents the different mean recognition distances for the rear of the trailer given the various treatments under all four weather conditions. As shown, the *solid white outline* provided the highest threshold of visibility for the rear configuration under all weather conditions. Not surprisingly, the *no treatment* configuration provided the lowest threshold. All retro-reflective tape treatments substantially increased the threshold of visibility for the rear of the trailer. Interestingly, the NHTSA configuration, only ranked fourth or fifth for the provision of visibility threshold, under the various weather conditions.

It is interesting to note the significant reduction in visibility thresholds for the rear of the trailer which accompany the changes in weather. Obviously, the intensity of adverse weather will directly influence results, however, relative to clear conditions, the presence of rain or snow reduced thresholds by approximately 50 to 70 percent, while fog decreased visibility by as much as 90 percent. Furthermore, note how little variation there is between visibility thresholds in the presence of fog. Retro-reflective tape seems to have little value for increasing conspicuity when weather conditions are foggy.

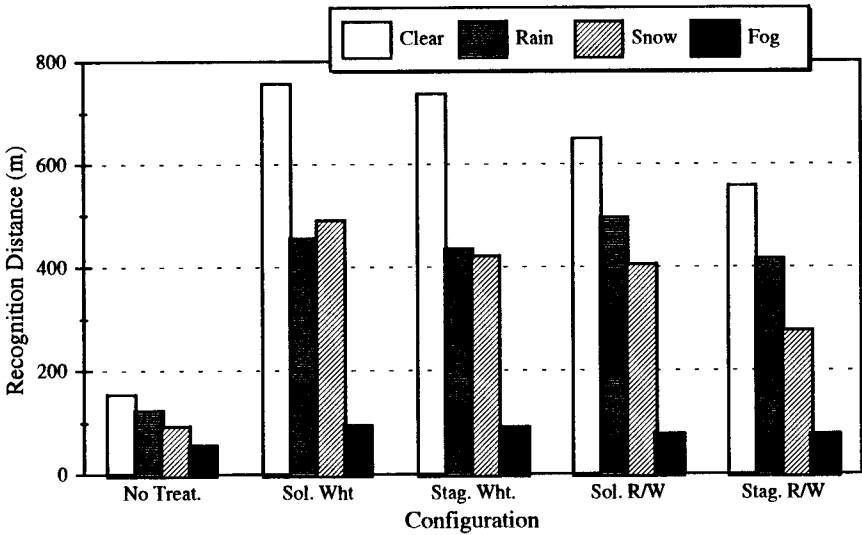
Figure 4 depicts the different mean *thresholds of visibility* developed for the different side treatments under the four weather conditions. Again, all retro-reflective tape treatments provided significantly greater recognition distances relative to an untreated scenario. There were no statistically significant differences found between the solid white, staggered white, and solid red/white treatment configurations. The staggered red/white (the NHTSA standard) showed markedly reduced visibility thresholds under both clear and snowing conditions.

Interestingly, for the side of the trailer, there is less of a reduction in visibility when the weather changes from clear to either rain or snow relative to the rear scenarios. Generally, the visibility thresholds were reduced by only 30 to 45 percent when weather conditions changed from clear to

either rain or snow. The results indicate that retro-reflective tape treatments provide a more effective counter-measure under adverse weather conditions than for the rear of the trailer. It is unclear why this effect exists, however, it may be attributed to the *width* of target created by taping the full length of the trailer (rather than simply the area of retro-reflective tape). It appears from the plot that the *solid red/white* stripe is more effective than the other tape configurations under rain conditions, however, this difference is not statistically significant. Under foggy conditions, retro-reflective tape again seems ineffective at increasing visibility thresholds.



**Figure 3. Mean Recognition Distances (Rear): *Threshold of Visibility***



**Figure 4. Mean Recognition Distances (Side): *Threshold of Visibility***

Table 1 quantifies the increases in visibility thresholds, beyond the *no treatment* scenario, provided by the NHTSA standard and the use of solid white retro-reflective tape. These values naturally have a degree of variance, however, point estimators are presented for clarity. As shown, there are some relatively significant gains which can be achieved by using solid white striping rather than the NHTSA prescribed alternating red/white retro-reflective tape.

**Table 1. Comparative Increases in Visibility Thresholds <sup>1</sup>**

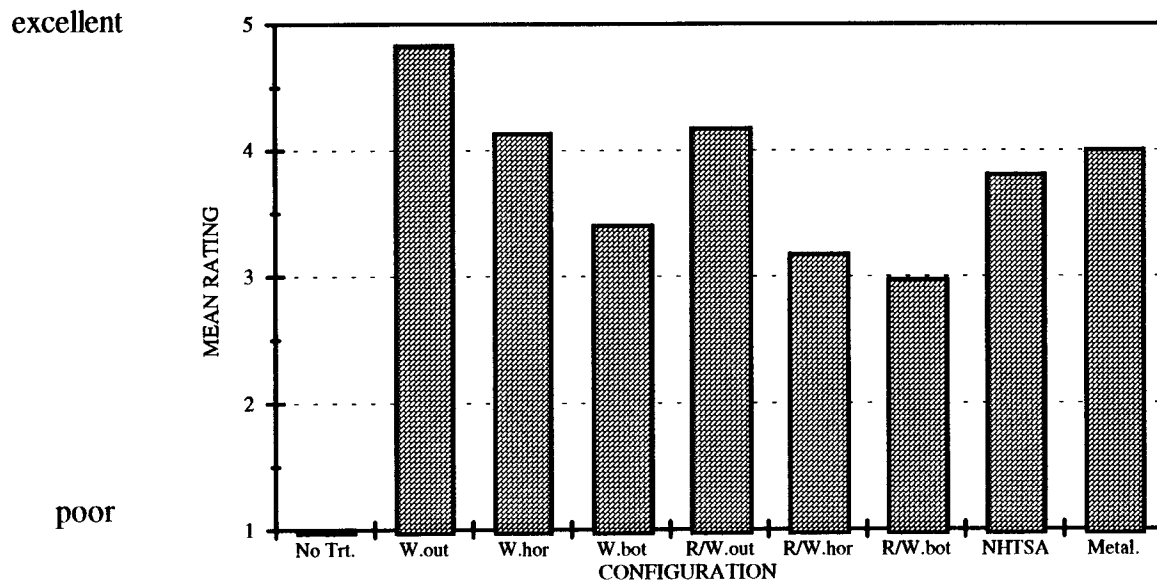
	Rear of Trailer		Side of Trailer	
	NHTSA (metres)	Solid White Outline (metres)	NHTSA (metres)	Solid White Line (metres)
clear	502	601	404	602
rain	160	284	292	333
snow	125	333	185	398
fog	16	21	21	39

<sup>1</sup> table distances are increases in the threshold of visibility beyond those provided by an untreated trailer.

When observers were asked to subjectively rate the effectiveness of the various configurations at identifying the tractor-trailer as a potential hazard, the *full white outline* provided a statistically significant higher mean rating relative to the other rear configurations (see Figure 5). The rating scale ranged from a value of 1 (‘poor’) to 5 (‘excellent’). Surprisingly, the NHTSA configuration received only the fifth highest mean rating of the eight scenarios utilizing retro-reflective tape (although the difference is not statistically significant than three of those found to be higher). One of the main reasons NHTSA chose to use alternating red/white tape was to facilitate hazard identification rather than focus solely on visibility thresholds. The results depicted in Figure 5 might suggest a strong relationship between hazard identification and visibility thresholds.

The side treatments were similarly evaluated on their ability to identify the trailer as a hazardous object. The *solid white stripe* configuration was rated significantly higher than the NHTSA and *no treatment* scenario, however, no other statistically significant differences could be established.





**Figure 5. Hazard Identification Mean Ratings (Rear)**

## CONCLUSIONS

All retro-reflective tape treatments which were tested provided significant increases in visibility thresholds relative to an untaped trailer under each weather condition except fog. The application of retro-reflective tape does little to increase the threshold of visibility under foggy conditions. The thresholds of visibility provided by any of the tested patterns/colours of retro-reflective tape were diminished by approximately 50 to 70 percent as the weather conditions change from clear to either rain or snow. The presence of fog decreased the visibility thresholds by as much as 90 percent for these field tests. The rear of the trailer seems to exhibit more of a relative reduction in visibility threshold than the side as weather conditions deteriorate. Nevertheless, even under rain and snowy weather conditions, a substantial benefit is derived by using retro-reflective tape..

The rear *full white outline* retro-reflective tape configuration was found to be the most effective to increase the visibility threshold under all weather conditions. No one pattern/colour was found to be more effective given specific weather conditions. The full white outline pattern provides significant increases in visibility thresholds beyond the NHTSA standard.

The *solid white stripe* configuration was found to be the most effective retro-reflective tape treatment of those tested for the side of the trailer under all weather conditions except rain. The tests showed that a solid red/white stripe slightly outperformed a white stripe in the rain, however, the difference was not statistically significant. Again, significant increases in visibility thresholds were observed relative to the NHTSA standard.

White tape treatments provided greater thresholds of visibility and hazard identification than the same patterns comprised of alternating red/white under all weather conditions. However, given the relatively small sample sizes, the differences could not be shown to be statistically significant in some cases.

## **RECOMMENDATIONS**

Canadian heavy truck operators should take advantage of their ability to deviate from the NHTSA standard for retro-reflective tape application. The Canadian standard allows the substitution of solid white in favour of the alternating red/white tape, for either the rear or sides, as stipulated by NHTSA. This study has shown that there are substantial advantages to using solid white retro-reflective tape.

The new Canadian legislation also permits the use of yellow and alternating yellow/white tape. The thresholds of visibility of these colours should also be tested under varying weather conditions so that they can be compared with other configurations.

Many critical issues need to be addressed regarding retro-reflective tape applications including the effect of wear and dirt on their performance, actual collision mitigation, retro-reflective corporate logos, inclusion of straight trucks, and the effectiveness of different colours/patterns during daylight operations.

## **ACKNOWLEDGEMENTS**

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