

# Visibility of Tractor Trailer Reflective Strips at Small Viewing Angles in Collision Reconstruction

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In collision reconstruction of nighttime accidents, the conspicuity of hazards from a driver's perspective is a critical factor. When the collision involves large commercial vehicles, the visibility of the reflective strips is essential in assessing avoidance. Reflective strips on commercial vehicles are generally consistent from vehicle to vehicle and are highly reflective between perpendicular and 45° viewing angles. However, at shallower viewing angles (closer to parallel viewing), which occurs when trailers begin turns, the reflective strips may not be effective. In this initial study, the effectiveness of reflective strips at shallow viewing angles ('entrance angles' of 45° to 90°) was examined under a variety of test conditions including high beams and viewing distances of up to 150 m. The results indicated that at entrance angles of less than 70°, reflective strips are highly effective warnings from a human factors perspective. At entrance angles of more than 75°, reflective strips are ineffective. From 70° to 75°, the results were sensitive to the test parameters. This study does not address the visibility of the tractor or other aspects of nighttime visibility. Further research is recommended to extend this study to greater viewing distances, xenon headlights, 'dirty' vs. 'cleaned' reflective strips, and wet roads, with attention to entrance angles of 70° to 75°.

## INTRODUCTION

In collision reconstruction of nighttime accidents, the conspicuity of the hazard from the driver's perspective is a critical factor to consider. When a nighttime collision involves tractor-trailers or other large commercial vehicles with reflective strips, the visibility of the reflective strips from a distance is essential in helping to determine whether or not the collision was avoidable.

The design and placement of reflective strips on commercial vehicles are regulated by federal motor vehicle standards in the United States (FMVSS 108, 2004) and Canada (CMVSS 108, 1995; TSD 108, 2007). These reflective strips must meet standardized performance requirements (ASTM D4956-90, 1990; SAE J594, 1995) and in practice, are generally consistent from vehicle to vehicle. These standards specify the minimum amount of light that a new reflective strip must reflect at specific 'entrance angles' and 'observation angles'.

The 'entrance angle' is the angle between the light beam and the perpendicular to the reflective surface. For example, if a northbound car approaches a stopped trailer that is oriented exactly northwest (with a reflective strip along its side), then the entrance angle of the light from the car's headlights is approximately 45°. If that trailer was parked perpendicular to the road, the entrance angle would be 0°.

The 'observation angle' is the angle between the light being shined onto the reflective surface and the light being reflected back to the observer. In the case of a motorist on a dark road, the observation angle would be less than 1° for objects in the distance, due to the headlights being slightly below and almost aligned with the line of sight of the driver.

The reflective properties of reflective strips for trailers are typically listed in their product specifications for entrance angles ranging from 0 to 30° (sometimes up to 45°) and

observation angles of 0.2° to 0.5°. There are no performance requirements for reflective strips on commercial vehicles at entrance angles of greater than 45°.

In our experience, if a trailer is oriented at a sharp angle to the road (entrance angle of 0 to 45°), the reflective strip is highly effective in warning drivers of the upcoming hazard in advance, even with low beam headlights (see Figure 1).



**Figure 1: Copy of our calibrated exposure photo of a trailer across a road, viewed from 175 m away (low beam headlights, entrance angle of 0°).**

Similarly, if a trailer is parked on the shoulder, parallel to the road, a series of reflective strips on the back of the trailer will be highly effective in warning motorists in advance due to the 0° entrance angle for that reflective surface (see Figure 2).

However, in collision reconstruction it is often necessary to consider the conspicuity of the trailer for entrance angles above 45°. As well, that angle will often change during the pre-collision sequence as the vehicles move relative to each other. Reflective strips are not as effective at viewing angles

above 45° (Sutphen, 2003), since the reflected amount of light continues to decrease as the entrance angle increases.



**Figure 2:** Copy of our calibrated exposure photo of a trailer parked on the shoulder with reflective strips at the rear, viewed from 100 m away (low beams, entrance angle of 0°).

Nevertheless, the reflective strip will still be noticeable to a motorist until some point that the entrance angle becomes high enough. To our knowledge, no real-world studies have been published in the collision reconstruction community regarding the effectiveness of reflective strips at entrance angles of 45° to 90°.

Without a noticeable reflective strip, it has been our experience that one would not recognize the presence of the trailer in time to avoid a collision, even though the standard side light markers lamps are on. Although the side light markers on a trailer are clearly visible on a dark road at night from 750 m away (see Figure 3), they do not convey the message that a trailer is present. In our experience, these small markers could be easily mistaken for background lights, unless the four-way flashers are activated.



**Figure 3:** Copy of our calibrated exposure photo of a tractor-trailer across a road, viewed from 750 m away. The headlights and side light markers of the tractor-trailer are visible but are not identifiable as a vehicle.

Due to the lack of research in this area, it is typically desirable to attempt a case-by-case re-enactment of these

collisions. However, conducting these re-enactments is complex, expensive, and dangerous. A large amount of coordination, strategy, and creativity is required to correctly position the vehicles throughout the sequence, match the lighting and weather conditions, and provide adequate safety measures such as traffic control. Furthermore, the safety measures must not compromise the desired amount of lighting.

The purpose of this research was therefore to study the effectiveness of trailer reflective strips at high entrance angles, so that some baseline data will be available for cases where a full re-enactment is not possible. The results of this initial study are hereby being made available to the human factors forensic community to assist in understanding tractor-trailer nighttime collisions.

## METHOD

In this initial study, we conducted three sets of tests to assess the visibility of in-service (i.e. used) reflective strips on trailers during full nighttime conditions from a motorist's perspective for entrance angles above 45°. All visibility observations were documented using calibrated nighttime photography techniques. Multiple exposure 'bracketed' photographs were taken using no flash, with the correct exposure setting validated on-site using either a multi-shade grey board or a pre-calibrated view screen (adapted from Holohan, 1989 and Klein, 1992).

In the first set of tests, stationary semi-trailers were viewed in an industrial area in Toronto, Ontario using a range of entrance angles from 60° to 90° with low and high beam headlights. There was no moonlight at the time. The weather was clear and the roads were dry. Some street lighting was present in the vicinity but it did not shine upon the side of the trailers in question. The trailers were standard '53-foot' van semi-trailers. The red-and-white 'DOT approved' reflective strips on the trailers were in good working condition (not torn or muddy) and were not wiped or cleaned prior to testing. The observation vehicle was a 1996 Honda Civic. The headlights on the observation vehicle were in good condition and were not wiped or cleaned prior to testing. The viewing distance from the observer to the centre of the reflective strip ranged from 25 to 50 m. The observation angle was estimated to range from 0.9° to 1.9°.

In the second set of tests, we arranged for a tractor-trailer operator to conduct a typical 'backing up' manoeuvre across a two-lane rural road into a residential driveway, north of Dunnville, Ontario. There was no moonlight at the time and no street lighting. The weather was clear and the roads were dry. Traffic was detoured away from the test site. The tractor-trailer was a conventional cab tractor and a standard '53-foot' van semi-trailer. The red-and-white 'DOT approved' reflective strip on the trailer was in good working condition (not torn or muddy) and was not wiped or cleaned prior to testing. The visibility of the reflective strip was documented from the perspective of a stationary 'oncoming' vehicle with low beam headlights, located 125 m from the target driveway (1998 Nissan Maxima, headlights in good

condition, not wiped or cleaned prior to testing). Observations were made for entrance angles ranging from 45° to 90°. The backing-up manoeuvre had been previously practiced and documented during daytime hours in order to establish the trailer angle at various points during the manoeuvre. The observation angle was estimated to range from 0.3° to 0.5° for this set of tests.

In the third set of tests, the same tractor-trailer was parked in a stationary position midway along its 'backing up' manoeuvre, blocking the road (same site, vehicles and test conditions as noted above in the second set of tests). Visibility observations were made from the observation vehicle using low beam headlights from 45 to 150 m away. The entrance angle for this set of tests was 63° (since the trailer at this point during the backing up manoeuvre was oriented at a 27° angle to the road). The observation angle was estimated to range from 0.3° to 0.9° for this set of tests.

## RESULTS

The results for the 3 sets of tests were generally consistent. At entrance angles of less than 70°, the reflective strips were highly effective and conspicuous, even from 100 m away with low beam headlights and no other ambient light (examples illustrated in Figures 4 & 5). At entrance angles of more than 75°, the reflective strips were ineffective, even from only 30 m away with high beam headlights and some ambient light. At those angles, the reflective strips were either not visible at all, or were faintly visible and were considered to be not noticeable (examples illustrated in Figures 6 & 7).

For entrance angles of approximately 70° to 75°, the results varied from test to test and were sensitive to the viewing distance, the type of headlights used (low vs. high beam), and the presence of ambient light. This range of entrance angles represented a type of transitional zone where the reflective strips started to become noticeable. Tests conducted in this range with high beam headlights tended to result in the reflective strips being noticeable.



**Figure 4:** Calibrated exposure photo taken 90 m from a trailer with low beam headlights at an entrance angle of 63°. The reflective strip is clearly visible and effective at this angle.



**Figure 5:** Calibrated exposure photo taken 25 m from a trailer with low beam headlights at an entrance angle of 60°. The reflective strip is clearly visible and effective at this angle.



**Figure 6:** Calibrated exposure photo taken 35 m from a trailer (centre of photo) with high beam headlights at an entrance angle of 79°. The reflective strip is barely visible and is ineffective at this angle.



**Figure 7:** Calibrated exposure photo taken 30 m from a trailer with low beam headlights at an entrance angle of 76°. The reflective strip is barely visible and is ineffective at this angle.

During the second set of tests (i.e. the 'backing up' manoeuvre), the entrance angle between the semi-trailer and the headlights was more than 75° for a continuous period of over 30 seconds during the first half of the manoeuvre.

## DISCUSSION

The results of our initial study demonstrate that if the entrance angle between the reflective strip and the approaching driver's headlights is less than 70°, the reflective strip can be assumed to be fully effective from the perspective of a human factors analysis. That is, when assessing a nighttime collision involving tractor-trailers, the reflective strip provides a strong and effective warning to approaching motorists, even at entrance angles of 60° or 65°. This result may seem surprising, given the reduced amount of light being reflected back to the observer at such angles. Nevertheless, this result was consistently observed under a variety of test conditions. Therefore, in real-world scenarios, reflective strips continue to be effective at angles well above 45°.

Once the entrance angle between the reflective strip and the approaching driver's headlights becomes more than 75°, the reflective strip can be assumed to be ineffective from a human factors perspective. That is, the reflective strip will not provide an effective warning to approaching motorists in such cases and will likely be missed, ignored or misunderstood.

We note that during the second set of tests (the 'backing up' manoeuvre from the rural road onto the driveway), the entrance angle between the semi-trailer and the headlights was more than 75° for at least 30 seconds near the beginning of the manoeuvre. During this time, the trailer was partially blocking the oncoming lane but would not be noticeable by an oncoming driver. Therefore, when investigating a nighttime collision involving a turning trailer, a daytime re-enactment of the manoeuvre or use of a computer simulation tool such as PC-Crash<sup>TM</sup> is recommended to confirm the pre-impact timeline of the trailer position.

For entrance angles between 70° and 75°, a case-by-case assessment of the effectiveness of the reflective strip will be required by the investigator, since our results in this range were sensitive to the test conditions.

In general, it would be expected in all cases that ambient lighting from street lights or other headlights facing the trailer would increase the conspicuity of the reflective strips. As well, the trailer will be more conspicuous in all cases if the four-way flashers are activated, or if a row of supplementary marker lights are present on the upper outline of the box.

The results of this study do not negate the need to assess all other aspects of nighttime collisions. For example, tractors typically do not have reflective strips and may not be conspicuous when viewed at night from behind or from the side. Poor weather conditions or glare will affect the visibility of hazards at night. Background lighting clutter or masking will also affect nighttime visibility.

Further research is recommended to extend this initial study to further viewing distances and other headlight types such as xenon headlights. Further research is also recommended to assess the effect of 'dirty' vs. 'cleaned'

reflective strips, and the potential effects of glare on wet roads. Particular attention should be given to entrance angles near the range of 70° to 75°.

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