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Recognition of Rail Car Retroreflective Patterns for Improving Nighttime Conspicuity

**Office of Research
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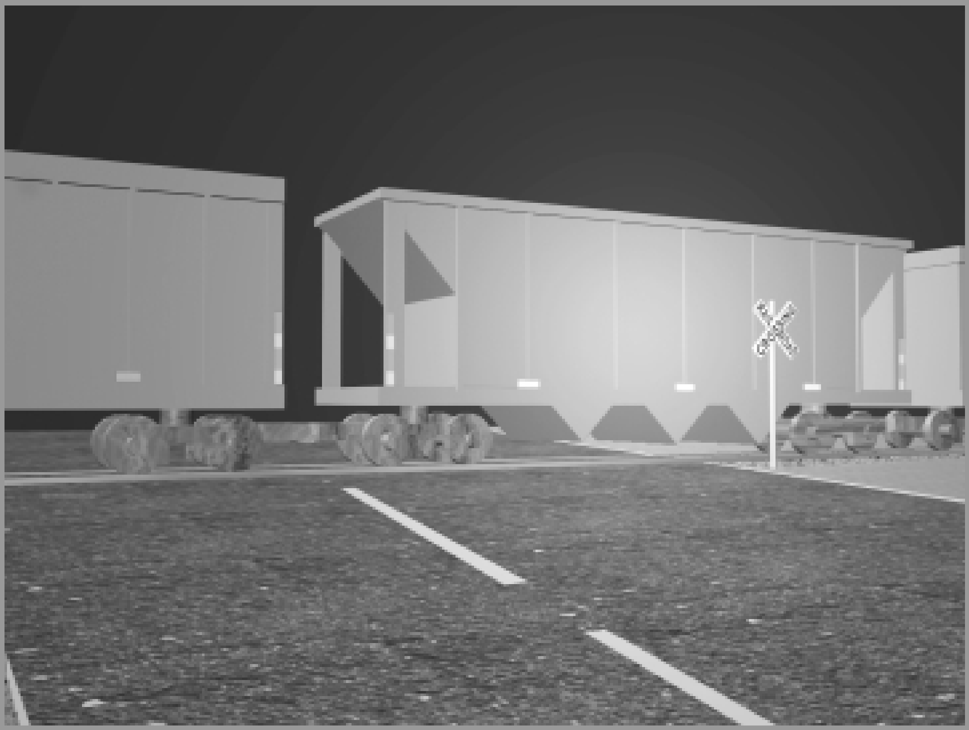
U. S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093



Safety of Highway-Railroad Grade Crossings

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always expect a train

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13. ABSTRACT (Maximum 200 words)

Every year in the United States, accidents at highway-railroad grade crossings take place where the motorist hits the side of the train at night. In a portion of these nighttime accidents, the motorist fails to see the train in the grade crossing. One proposed solution to prevent such accidents is to mount retroreflective material on the sides of rail cars to make them more conspicuous.

The objective of this research was to evaluate the effectiveness of several train-mounted reflector patterns to improve recognition of the train. Four patterns were evaluated in two experiments, using a human-in-the-loop driving simulator. In the first experiment, participants, located at a fixed position from a highway-railroad grade crossing and parallel roadway, viewed over a thousand scenes showing one of three items: a moving train, a moving motor vehicle, or nothing. The participants' recognition of different reflector patterns was recorded and analyzed using the Receiver Operating Characteristic (ROC) based on Signal Detection Theory (SDT). In the second experiment, participants drove the simulator and reported all objects on the roadway, some of which were trains. The recognition distance from the participants' position to the train was recorded and analyzed.

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PREFACE

In 1981, the Federal Railroad Administration (FRA) began an effort to evaluate the effectiveness of placing retroreflective materials on the sides of freight cars in reducing accidents at highway-railroad grade crossings. Retroreflective materials were proposed as a method for increasing the visibility of freight cars as they passed through the grade crossing by returning light from the approaching motor vehicles headlights back to the motorist. This initial study found that the materials available at the time were not effective enough due to the harsh environmental conditions. Dirt accumulated on the retroreflective materials and degraded the detectability to the point where they provided an insufficient benefit to the motorist.

Since that initial study, manufacturers have created a new generation of retroreflective materials that raise the level of light returned to the motorist compared to the earlier generation of materials and increased their durability. Federal regulations now require the use of retroreflective materials on truck trailers wider than 80 inches and weighing more than 10,000 lbs., to increase their conspicuity and to aid motorists in judging their proximity to these moving vehicles.

In 1990, the FRA initiated a new research program to address the following issues:

- determine whether these materials can withstand the environmental conditions in which they would be placed;
- establish the minimum intensity level required to attract the motorist's attention; and
- assess the effectiveness of pattern placement on freight car detectability.

The current research program is described in the report *Safety of Highway-Railroad Grade Crossings: Freight Car Reflectorization*. The authors found that the current generation of materials is durable enough to provide the minimum intensity levels to aid detection of freight cars in the grade crossing. In evaluating the ability of motorists to detect freight cars with different patterns, the results indicated that all patterns were effective in improving detectability compared to an unreflectorized freight car.

With retroreflective materials in common use on the nation's highways, the opportunity exists for motorists to confuse freight cars with truck trailers and respond inappropriately. Because trucks are shorter in length and pass through an intersection more quickly than the average train, the motorist may only need to slow the vehicle to avoid a collision instead of stopping prior to reaching the intersection. Conversely, because the average train is longer than the average truck, it spends a greater amount of time in the intersection. For motorists approaching a grade crossing, the greater amount of time the train spends in the intersection means the more likely the motorist will need to stop at the intersection.

In selecting a pattern for placing retroreflective materials on freight cars, an effective design may minimize confusion, while an ineffective design may contribute to confusion. However, it is not clear, how the placement of these materials affects the ability of motorists to discriminate freight cars from truck trailers. The current study examines several patterns to determine how placement affects the ability of motorists to recognize freight cars at a highway-railroad intersection.

ACKNOWLEDGMENTS

This research was made possible by the efforts of many people. We would like to thank our colleagues, friends and families in supporting our efforts to make this research a success.

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We would like to thank Anya A. Carroll, principal investigator for Highway-Rail Grade Crossing Safety Research and Debra Williams Chappell for their expertise in helping to make the simulation as realistic as possible and their helpful comments.

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Thanks go out to our MIT colleagues, Santanu Basu, Jay Einhorn, Steve Landry, Helias Marinakos, Nicholas Malsch, Shinsuk Park, Jim Thompson and Steven Villareal who helped in many ways to make the driving simulator what it is today.

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We are appreciative of Dan Morin’s efforts to turn our crude drawings into clear, easy to read graphics.

Finally, we are grateful to the many people who participated in this study, and whose support made this study possible.

TABLE OF CONTENTS

Section **Page**

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The typical freight car presents a poor target at night and is difficult to detect by headlight illumination. The painted surface of the freight car is frequently dirty and painted in dark colors. Consequently, much of the light from the motor vehicle's headlights is absorbed by the freight car instead of being reflected back toward the motorist. Retroreflective materials have been proposed as an aid to improve the visibility of freight cars. Retroreflective materials work by returning the light from the headlights to the motorist. A similar problem with trucks was addressed in federal regulations (49 CFR Part 571.108) requiring the use of retroreflective materials.

As more roadway hazards benefit from the addition of reflectorization, the potential for motorist confusion increases. The problem of recognition becomes more difficult in visually complex or noisy environments. For example, an observer can easily detect a single flashing light in a background of stationary lights. However, as the number of flashing lights in the background increases, detecting the target (flashing) light becomes harder. Current federal regulation requires truckers to reflectorize their vehicles (49 CFR Part 571.108) if it is more than 80 inches wide and weighs more than 10,000 lbs.

A standard marking design that could fit on all types of freight cars from flat cars to tank cars would facilitate freight car recognition. Olson and his colleagues (Olson et al, 1992) found that a design that outlines the truck improves the driver's recognition. However, the limited surface area of the flat car constrains the variety of patterns than can be constructed. As the freight car with the smallest surface area, any pattern would be limited to relatively small horizontal band 4 to 18 inches in height. The result may be a pattern that is similar to that found on truck trailers.

Given the abundance of reflectorized trucks on the road as well as on trains, the question arises whether the motorist can discriminate freight cars from a truck trailers. Correctly identifying a roadway hazard is important so that the motorist can respond appropriately.

The current study attempted to determine whether the motorist is likely to confuse trains with trucks at night when relying upon retroreflective patterns for identification. Four patterns were evaluated: an outline, a horizontal strip, a vertical strip and a variable height vertical strip. The patterns were placed on two types of freight cars, a hopper car and a flat car. The study measured the degree to which drivers recognized reflectorized freight cars in the grade crossing, when both the motor vehicle and the train were in motion and the driver's ability to discriminate reflectorized freight cars from other objects in the intersection.

In the first experiment, the observer remained stationary, at a fixed distance from the grade crossing. The study used a signal detection paradigm to assess observers' abilities to recognize trains with four patterns in two background conditions. One background modeled a rural environment where the amount of visual noise as indicated by the number of lights was relatively low. The second background modeled an urban environment, where the amount of visual noise, as indicated by the number of lights, is higher. A series of trials were presented in which the observer viewed a grade crossing for a brief duration and indicated whether there was a train in the grade crossing. The experimenter measured the accuracy of the observer's decisions and the confidence of those decisions.

In the second experiment, both the observer and the train were in motion. The observer drove a simulated passenger car along a route and encountered a variety of objects. These objects included a train, truck, cars, traffic signals, and traffic signs. The observer was asked to report the objects as soon as they were recognized. The experimenter measured the distance at which the objects were recognized.

Signal Detection Experiment

The results of the current experiment uncovered no differences in discriminating between trains and trucks as a function of pattern. Differences were found as a function of the environment and were attributed to the participants greater difficulty in detecting unreflectorized freight cars in the rural environment compared to the urban environment. The lack of differences between patterns may have been due to visual cues in the environment that enabled participants to use context to discriminate between trains and trucks.

Recognition Distance Experiment

Overall, participants were able to recognize all four patterns at far greater distances than the unreflectorized patterns. This was expected given the previous research (Ford et al. 1998; Olson et al. 1992; Ziedman et al. 1981) showing the effectiveness of retroreflective materials in aiding detectability. In general, participants recognized patterns on the hopper car farther away from the grade crossing than the flat car. This result was attributed to the greater amount of material that increased the amount of light returning to the motorist and the larger visual angle associated with those patterns.

While the average recognition distance for the flat car was lower than the hopper car, it may still be practical to use the smaller amount of material found in the flat car patterns. Field tests conducted on truck trailers (Olson et al. 1992) suggest these values may be a reasonable approximation of the results from this laboratory study.

Among the four reflectorized patterns, recognition distance varied with car type. While performance with the vertical bar, horizontal bar, and variable vertical bar was relatively consistent across car types, the outline showed a significant performance difference between the two car types. Performance suffered in the flat car condition, but it is not clear why. The outline was also one of two patterns in which participants made errors. Given the small vertical height of the typical flat car (between 4 and 18 inches), this car type makes displaying an outline shape difficult.

In contrast to the outline pattern, the horizontal bar pattern showed better performance in the flat car condition than in the hopper condition. This finding was unexpected. Since the horizontal bar was the pattern most similar to the truck patterns, participants were expected to take longer to identify the freight car than for the other three patterns. However, the horizontal bar was the other pattern for which participants made recognition errors. Although the number of errors was statistically insignificant, in every case, the train was confused with a truck. This confusion was expected given its similarity with the truck patterns. By contrast, the outline pattern was confused with both the truck and car.

Summary and Conclusions

Taken together, the two experiments suggest that motorists can discriminate between freight cars and truck trailers for any of the four patterns tested here. In both experiments, performance differences between the four patterns were small. In the first experiment, differences in the patterns were not statistically significant. In the second experiment, differences between the patterns were found as a function of car type. While the performance of the vertical bar and variable vertical bar was consistent across car type, the horizontal bar and outline varied by car type. Recognition distance for the outline pattern was better with the hopper car than with the flat car, while the opposite was true for the horizontal bar pattern. The horizontal bar pattern and outline both exhibited a small number of recognition errors. Participants made no recognition errors with the other two patterns. The outline pattern was confused with both the truck and car, while the horizontal pattern was confused with the truck pattern only. Considering the two measures together (recognition distance and number of errors), performance is likely to be more variable with the outline and horizontal bar patterns.

From a practical standpoint, the significance of these differences depends upon the stopping distance criterion selected. Assuming the recognition distance found in this study are representative of real world performance, 85 percent of the driving population would recognize the train for all four patterns in time to stop safely at 45 mph. At 55 mph, only three of the four patterns would provide adequate safety margin. The outline pattern would be unacceptable in this situation. By contrast, the unreflectorized rail car would be significantly more difficult to recognize under these experimental conditions, at speeds above 25 mph.

In terms of confusing the freight cars with truck trailers, the likelihood of these confusions is quite small. However, using similar patterns that could be confused increase the probability of an accident compared to the patterns that are not easily confused. Choosing a pattern that is dissimilar to the horizontally oriented patterns found on truck trailers will minimize the opportunity for these confusions. A vertically oriented pattern is preferable.

This study also demonstrated the importance of context in participants’ behavior. In the signal detection experiment, unreflectorized freight cars were more difficult to recognize in the rural environment than the urban environment due the lower illumination levels. The use of retroreflective materials eliminated this difficulty. This performance improvement did not vary with the type of pattern. For both car types, participants were able to discriminate between trains and trucks.

The findings from this study are summarized in bullet form below:

- Participants discriminated between freight cars and truck trailers for all of the four patterns evaluated.
- Vertically oriented patterns were recommended over outline and horizontally oriented patterns because they were less likely to be confused with the horizontally oriented truck patterns.
- Unreflectorized rail cars were more difficult to discriminate from trucks as illumination level declines.

1. INTRODUCTION

1.1 FREIGHT CARS ARE HARD TO SEE

One category of nighttime accidents at highway-railroad grade crossings takes place when the motor vehicle hits the train as it passes through the crossing. Many of these accidents take place at passively protected crossings where the motorist receives no information from warning devices at the crossing whether a train is approaching. Most crossings have only a crossbuck to warn of a hazardous intersection. The crossbuck indicates the presence of the grade crossing intersection. It does not alert the motorist when a train approaches or is in the grade crossing.

Passive crossings typically are located in rural areas where the accident exposure, as measured by the amount of highway traffic and train traffic, is low. These crossings frequently provide no illumination. Combined with the low ambient light levels in rural areas at night, the driver must rely upon his headlights to illuminate and detect the train.

However, the typical freight car presents a poor target at night and is difficult to detect by headlight illumination. The painted surface of the freight car is frequently dirty and painted in dark colors. Consequently, much of the light from the motor vehicle’s headlights is absorbed by the freight car, instead of being reflected back toward the motorist. Generally, the dirt accumulation is greatest near the ground and decreases the higher the surface is above the ground (Carroll, Multer, Williams, and Yaffee, 1999). The fact that much of the surface of the freight car is above the mounting height of the headlamps decreases the likelihood of detection with low beam illumination (Appendix H in Carroll, Multer, Williams, and Yaffee, 1999).

Retroreflective materials have been proposed as an aid to improve the visibility of freight cars. Retroreflective materials work by returning the light from the headlights to the motorist. A similar problem with trucks was addressed with the use of retroreflective materials. Current regulations require trucks to place retroreflective materials on their rear and sides (49 CFR Part 571.108, 1996). Current generations of materials are more effective in terms of durability and detectability than previous generations.

1.2 REFLECTORIZATION CAN INCREASE CONSPICUITY

A body of research suggests that retroreflective materials can increase the conspicuity of objects to which they are attached (Lauer and Suhr, 1956; McGinnis, 1975; Olson, 1988; Olson et al. 1992; Stalder and Lauer, 1965). However, previous generations of retroreflective materials reflected less light and lacked the durability to survive the harsh environment to which freight cars are regularly exposed (Poage, Pomfret, and Hopkins, 1982; Carroll, Multer, Williams, and Yaffee; 1999). The prismatic (cube corner) retroreflective markings currently available overcome these limitations.

Little research suggests how retroreflective materials should be displayed on the freight cars to maximize freight car conspicuity for the approaching motorist. Studies devoted exclusively to the problem of displaying retroreflective markings on freight cars were performed with the previous generation of retroreflective materials (enclosed lens or encapsulated lens). Lauer and Suhr (1956) tested four different configurations using the same amount of material for each pattern. They discovered that the massed applications (concentrating the material in one or two locations) were more effective than applications that were distributed over a wider area. By contrast, studies assessing the effectiveness of retroreflective markings on trucks, (Olson, 1992; Ziedman et al. 1981) using the prismatic materials available today, concluded that providing a design that outlined the shape of the vehicle increased conspicuity. The recommendation to use an outline shape was based in part on the need to estimate closing distance when following behind a truck. However, the motorists interaction with trains is different from trucks. Their task is to detect whether a train is in the grade crossing in time to stop.

While much of the research investigating the effectiveness of retroreflective markings for trucks are relevant to freight cars, there is a lack of knowledge about the optimal design of freight car retroreflective markings. The primary concern here is with developing a retroreflective marking design that is detectable in time for the motorist to recognize a train in the grade crossing and respond in time to avoid an accident.

The FRA recently supported research examining the effectiveness of the latest generation of retroreflective materials. In this effort, the Volpe Center looked at the durability of the newest retroreflective materials to withstand the harsh environment in which these materials would be placed (Carroll, Multer, Williams, and Yaffee, 1999). As part of this research, the Volpe Center sponsored a study, performed by the University of Tennessee, to measure the detectability of several patterns and colors of retroreflective materials on freight cars (Ford, Richards, and Hungerford 1998). In this evaluation, participants viewed static images of freight cars, with and without reflectorization. This study examined the detectability of three retroreflective patterns in three color combinations for a total of nine designs and found that even the poorest design was considerably better than an unreflectorized car. The average detection distance was 160 feet for the unreflectorized car compared to 1245 feet for the worst of the reflectorized patterns. These results were consistent with the findings of Ziedman et al. (1981) and Olson et al. (1992) showing that adding retroreflective materials to roadway hazards significantly increases their conspicuity.

As more roadway hazards benefit from the addition of reflectorization, the potential for motorist confusion increases. The problem of recognition becomes more difficult in visually complex or noisy environments. For example, an observer can easily detect a single flashing light in a background of stationary lights. However, as the number of flashing lights in the background increases, detecting the target (flashing) light becomes harder. Current federal regulation requires truckers to reflectorize their vehicles (49 CFR Part 571.108). The regulation requires the use of a strip (2 to 4 inches or 50 to 100 mm wide) in alternating colors (red and white) and covering at least 50 percent of the length of the trailer. The colors red and white were selected for several reasons (Olson, 1988). White returns the greatest amount of light to the driver compared to other colors, while red has a long association with danger. The use of two contrasting colors increases internal contrast and contributes to conspicuity during the daytime, as well as night. The combination of red and white is frequently used in the driving environment (i.e., stop signs, gates at highway-railroad grade crossing) to identify hazards. The logic behind the use of red and white retroreflective markings for trucks applies equally well to the development of a retroreflective marking for freight cars.

A standard marking design that could fit on all types of freight cars from flat cars to tank cars would facilitate freight car recognition. Olson and his colleagues found that a design that outlines the vehicle improves the driver's recognition of the object. However, the limited surface area of the railroad flat car constrains the variety of patterns than can be constructed. As the car type with the smallest surface area, any pattern would be limited to a relatively small horizontal band 4 to 18 inches in height. The result may be a pattern that is similar to that found on truck trailers.

Given the abundance of reflectorized trucks on the road, the question arises whether the motorist can discriminate freight cars from truck trailers. Correctly identifying a roadway hazard is important so that the motorist can respond appropriately. A motorist may respond differently to both types of hazards. Because a truck moving through an intersection is likely to clear the intersection much more quickly than a train (with its greater length), the motorist's response may differ for the two objects. Upon seeing a truck, the motorist may avoid a collision by slowing, but not stopping at an intersection. However, when encountering a train, the motorist may need to stop before reaching the intersection to avoid a collision, due to the long clearance time.

The current study attempted to determine whether the motorist is likely to confuse trains with trucks at night when relying upon retroreflective patterns for identification. Four patterns were evaluated: an outline, a horizontal strip, a vertical strip and a variable height vertical strip. The outline pattern was selected because previous research (Olson et al. 1988; Lauer and Suhr, 1956) indicates that outline patterns are effective in fostering object recognition. The horizontal bar pattern was selected because of its similarity to the pattern found on the sides of truck trailers and its ability to fit on freight cars with little surface area. The vertical and variable vertical patterns were selected because they are distributed patterns like the horizontal bar, but may enable the motorist to more easily discriminate a train from a truck. The vertical patterns should be less subject to the effects of dirt than horizontally oriented patterns (Carroll et al. 1999) and able to maintain their retroreflective properties longer.

1.3 GOAL OF CURRENT RESEARCH

The latest research examining retroreflective materials for use on freight cars did not provide a realistic environment in which to evaluate the detectability and recognition of these materials. In the University of Tennessee study, the retroreflective material on the freight car remained stationary. The observer did not see anything else in the scene that might be encountered in an actual driving environment, such as signs, other vehicles, lights, foliage, and buildings. In real world driving conditions, the driver and the freight car may be moving. In some cases, foliage, buildings, or other obstructions may block the motorist's view. In other cases, lights, signs and other visual clutter compete for the motorist's attention. In addition, the driver must be able to distinguish a moving train from a moving motor vehicle, since the appropriate response may be different. When the other vehicle approaching the intersection is a train, the driver is required to stop at the intersection, whereas when another motor vehicle approaches the intersection, the appropriate response will vary with the specific circumstances. Information is needed in this environment to determine how effectively drivers can recognize patterns of retroreflective materials as freight cars and whether they identify this situation as a roadway hazard requiring a timely response.

This study measured the degree to which drivers can recognize reflectorized freight cars in the grade crossing, when both the motor vehicle and the train are in motion and the driver's ability to discriminate reflectorized freight cars from other objects in the intersection. A variety of patterns was evaluated to see how the driver's recognition and discrimination performance varied. Two experiments were conducted using a human-in-the-loop driving simulator, developed for this purpose at the Volpe Center. Four patterns were evaluated against an unreflectorized freight car. The patterns were placed on two types of freight cars, a hopper car and a flat car.

In the first experiment, the observer remained stationary, at a fixed distance from the grade crossing. The study used a signal detection paradigm to assess the observer's abilities to recognize trains with four patterns in two background conditions. A series of trials were presented in which the observer viewed a grade crossing for a brief duration and indicated whether there was a train in the grade crossing. The experimenter measured the accuracy of the observer's decisions and the confidence of those decisions.

In the second experiment, both the observer and the train were in motion. The observer drove a simulated passenger car along a route and encountered a variety of objects. These objects included a train, truck, cars, traffic signals, and traffic signs. The observer was asked to report the objects as soon as they were recognized. The experimenter measured the distance at which the objects were recognized.

The two experiments will be discussed separately in Sections 2 and 3. Then, the results of both experiments will be summarized in Section 4.

2. SIGNAL DETECTION EXPERIMENT

2.1 METHOD

2.1.1 Overview

Participants viewed briefly a series of scenes each containing the same intersection. Each intersection consisted of a roadway and a railroad track parallel to each other and located perpendicular to the roadway where the participant was positioned. A vehicle could cross the intersection perpendicular to the participant. The participant's task was to identify what was in the intersection: a train, a truck or nothing.

2.1.2 Participants

Eleven licensed drivers were recruited from the Massachusetts Institute of Technology (MIT) and the Volpe Center. All participants possessed visual acuity of 20/30 or better as measured by the Snellen visual acuity test. Some participants' vision was corrected with eyeglasses. Seven of the participants were women and four were men. The participants ranged in age from 20 to 47 with a mean age of 26. Participants recruited from MIT were paid $10.00 per hour while employees of the Volpe Center participated as a part of their work duties.

2.1.3 Experimental Design

During the experiment, participants were exposed to one of three events on each trial. The participant could see one of two signals (train or truck) or noise (no train or truck). The experiment was designed as a 2 x 2 x 5 repeated measure design, in which each participant was exposed to all possible conditions. The three independent variables manipulated were environment, freight car type and pattern. Environment represents the amount of visual distraction in the background. There were two levels: a rural condition and an urban condition. The rural condition had no visual distractions. The urban environment had street lighting and lights from nearby buildings that served as visual clutter competing for the motorist's attention. For freight car type, two types of freight cars were shown: a hopper car and a flat car. Pattern referred to the type of retroreflective pattern and represented the placement of retroreflective materials on the freight car. There were four patterns plus an unreflectorized condition. The four patterns: outline, horizontal bars, vertical bars and a variable length vertical bar are shown in Figure 1. Each pattern has an equal percentage of red and white material. However, the flat car patterns used half as much material (144 sq. in.) as the hopper car patterns (288 sq. in.).

In addition to the freight cars, one type of truck was shown, a tractor trailer truck. There were four truck patterns designed to meet the requirements in the U.S. Federal regulations for truck conspicuity (49 CFR 571.108) and an unreflectorized truck. The truck patterns are shown in Figure 2. Current regulations for truck trailers require at least 50 percent of the length of the trailer be covered, with the material being distributed as evenly as practical. The material is arranged in alternating strips of red and white. The patterns were representative of patterns found in revenue service. Each truck pattern used the same amount of material.

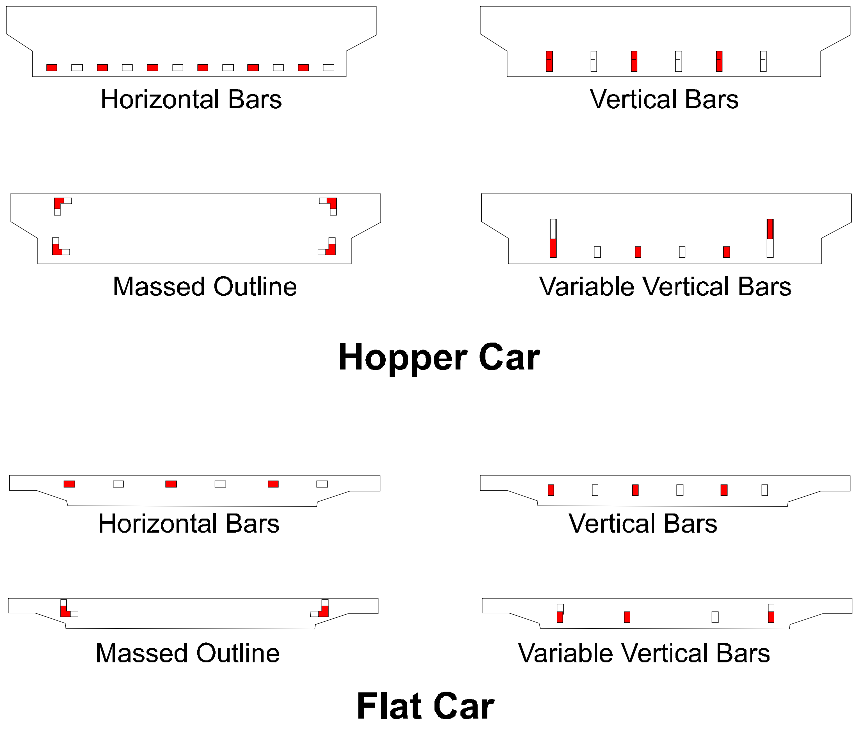


Figure 1. Freight Car Retroreflective Patterns

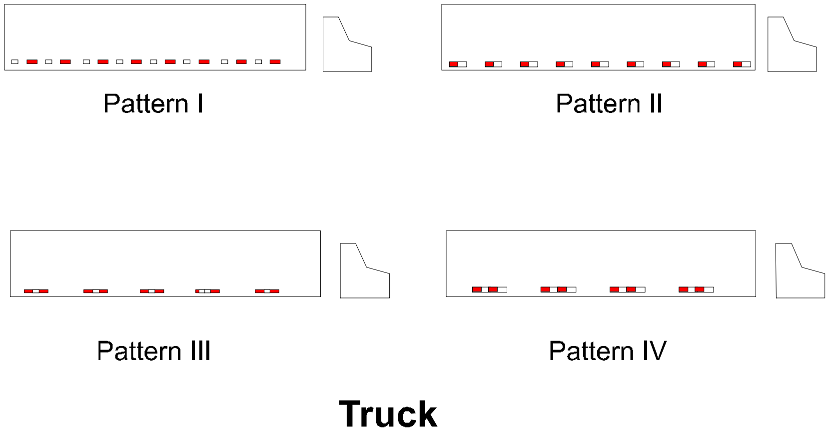


Figure 2. Truck Retroreflective Patterns

Table 1 shows the 20 conditions in which a freight car signal was present. In addition to the freight car signal, there were conditions in which a truck signal was present and conditions in which no signal was present. Each participant was exposed to the three event types (train, truck, or nothing) equally. On any given trial, the participant had a 33 percent chance of receiving a particular event. To calculate the number of false alarms, trials were blocked by train condition (environment x freight-car type x pattern). False alarms occurred when the participant said a signal was present (i.e., a train is present) when in fact it was not present. The trials were blocked together to associate false alarms with the appropriate train signal condition (i.e., an outline pattern on a flat car in the urban environment). Within a block of trials, participants' saw each event (train, truck or nothing) 20 times for a total of 60 trials. The order in which the blocks were administered was randomized between subjects.

Table 1. Experiment 1 Conditions

Environment	Freight car	Pattern
Rural	Flat	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None
	Hopper	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None
Urban	Flat	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None
	Hopper	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None

Performance was measured by recording hits, false alarms and confidence estimates of the participants on each trial. The meaning of the terms hits and false alarms is described in the section on signal detection theory that begins on page 10. The confidence estimates were used to construct receiver operator curves (ROC) showing the relationship between hits and false alarms for each condition.

2.1.4 Scenario Description

The basic scenario showed a single two-lane road intersecting a single railroad track and adjacent two-lane road at a 90-degree angle as shown in Figure 3. The grade crossing intersection was located approximately 500 feet from the position where the participant began the scenario. Obstructions blocked the view on either side of the roadway. The participant was only able to see the two lanes of the roadway directly ahead. A moving vehicle consisting of either a group of the same type of freight cars or a series of trucks passed through the intersection, in front of the participant. The dimensions of the two freight cars and the truck were modeled after vehicles found operating in revenue service. Figure 4 shows the horizontal and vertical dimensions of all three vehicles. The crossbuck sign normally found on either side of the road at the grade crossing was omitted to prevent the participant from using the sign as a cue to identify the object. In the urban scenario, stationary lights were visible and competed with the moving objects for the participant's attention as shown in Figure 5. The rural scenario lacked these lights, but otherwise was identical to the urban scene.

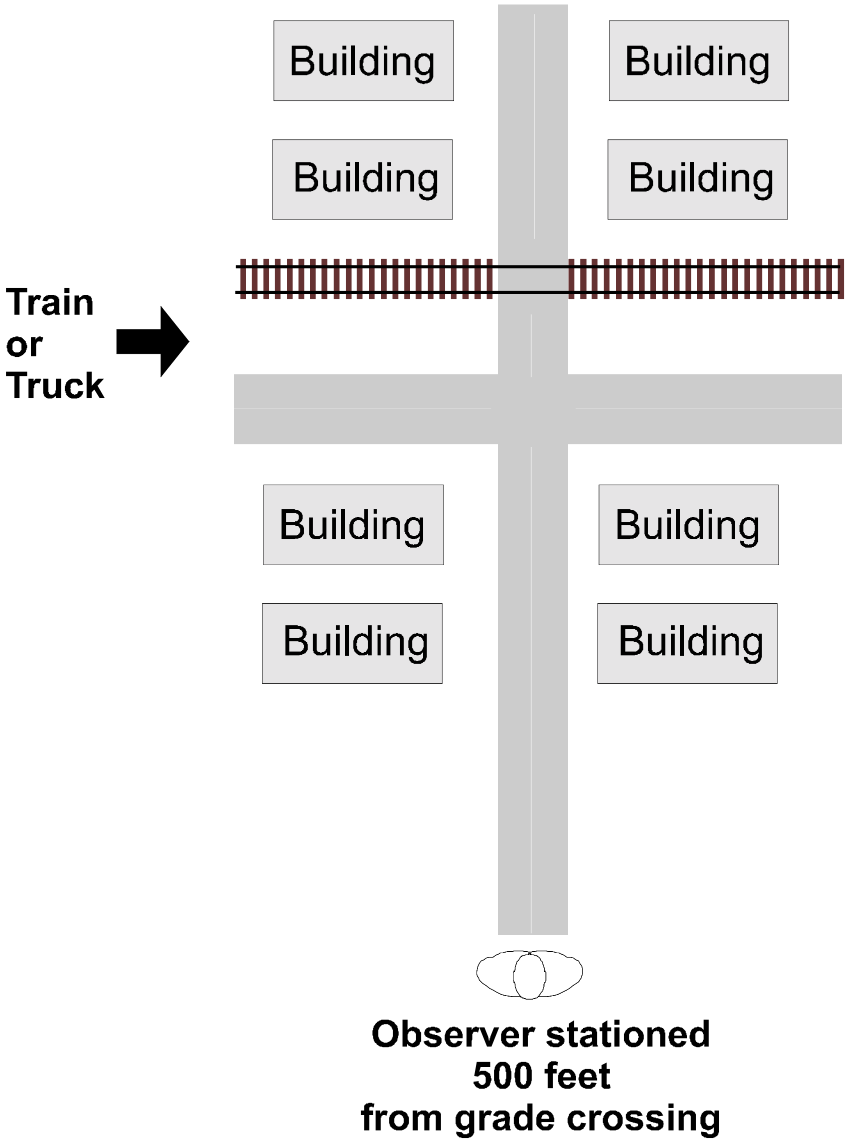


Figure 3. Plan View of the Basic Scenario

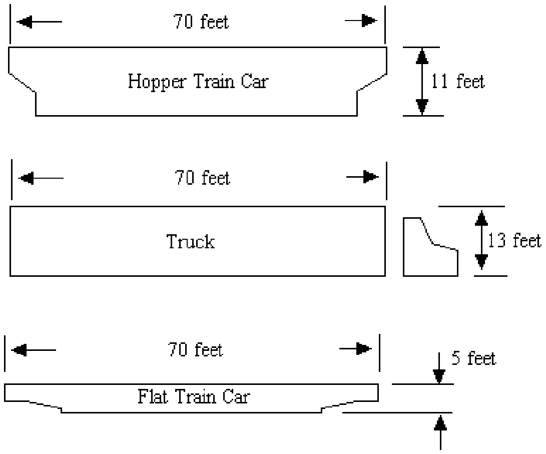


Figure 4. Vehicle Dimensions

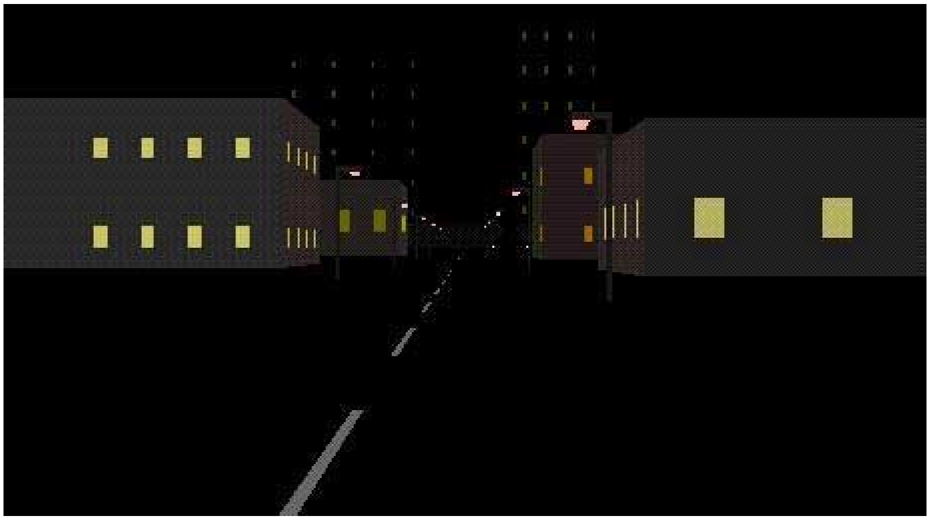


Figure 5. Forward Field of View for Stationary Observer

2.1.5 Apparatus

The visual scenes were created on a Silicon Graphics Indigo 2 workstation and displayed using a Barco 808S projector on a 6' x 8' screen. The participant sat 15 feet away from the display screen.

2.1.6 Procedures

For each participant, the experiment took place in two 1 1/2 hour sessions over 2 days. At least 15 minutes prior to beginning the experimental task, the overhead lights were turned off so the participant’s eyes were dark-adapted for nighttime driving conditions. The participant received 10 practice trials to become familiar with each of the objects. The trials were broken up into 20 blocks of 60 trials. After completing each block, the participant received a 30-second rest before beginning the next block. The participant received a 5-minute break approximately every 30 minutes.

The participant sat in front of a projection screen showing a blank screen. Each trial began with the display of a fixation point that lasted 1 second. The purpose of the fixation point was to direct all participants’ attention to the same area of the intersection. The intersection was displayed for 500 milliseconds during which time a train or truck may pass through the intersection. At the completion of the 500-millisecond interval, a response screen displayed one of four options: hopper car, flat car, truck, or nothing. The participant selected could take as much time as needed to select the appropriate response. The participant selected the appropriate response with a mouse to highlight the appropriate option and pressing the mouse button. If the participant selected “nothing,” a dimmed button labeled “next” was highlighted. Selecting the “next” button initiated the next trial. If the participant selected any of the other options, a different screen appeared. The new screen displayed a five-point rating scale for indicating the confidence of their decision. The participant responded by selecting the appropriate number and pressing the mouse button. After responding, the “next” button was highlighted. The participant selected the “next” button to begin the next trial. In each of the two experimental sessions, the participant repeated this procedure until 600 trials were completed for a total of 1200 trials.

2.2 RESULTS AND DISCUSSION

2.2.1 Signal Detection Theory

In this experiment, participants were shown a series of scenes. The participants’ task was to decide whether they saw a train, a truck, or nothing. Signal detection theory was used to measure the participant’s ability to discriminate trains from trucks. In signal detection theory, detection is a function of two processes: the observer’s perceptual sensitivity and response bias. This theory enables separation of the effects of perceptual sensitivity, in this case, the observer’s ability to discriminate trains from trucks, from response bias. Response bias represents the observer’s willingness to say “yes” or “no.” Does the observer adopt a conservative strategy or a liberal strategy? In this experiment, the concern is with the observer’s discrimination.

In a signal detection experiment, events can be categorized in a 2 x 2 matrix showing the event that occurred and the observer’s response to that event. Figure 6 shows the four possible categories. A hit occurs when a signal is present and the observer reports that the signal is present. A false alarm occurs when a signal is absent and the observer reports that the signal is present. A miss occurs when a signal is present and the observer reports that the signal is absent. A correct rejection occurs when a signal is absent and the observer reports that the signal is absent.

		State of the World	
		Signal	Noise
Observer's Response	Yes	Hit	False alarm
	No	Miss	Correct rejection

Figure 6. Four Outcomes of Signal Detection Theory

Figure 7 shows how signal detection theory characterizes the relationship between the observer's response for two hypothetical distributions. The distribution on the right represents the probability that "train" signal occurred. The distribution on the left represents a probability that the noise distribution occurred. In this experiment, this distribution is either a truck or "nothing." The observer's ability to discriminate trains from truck (sensitivity) is reflected by the amount of overlap in the two distributions. Sensitivity increases as the amount of overlap in the two distribution decreases. Response bias is represented by the vertical line showing the criterion selected by the observer to say "yes" or "no." When the value of the event is to the right of the criterion, the observer will say "yes." When the value of the event is to the left of the criterion, the observer will say "no." Moving the criterion to the left increases the likelihood that the observer will say "yes," while moving the criterion to the right increases the likelihood that the observer will say "no."

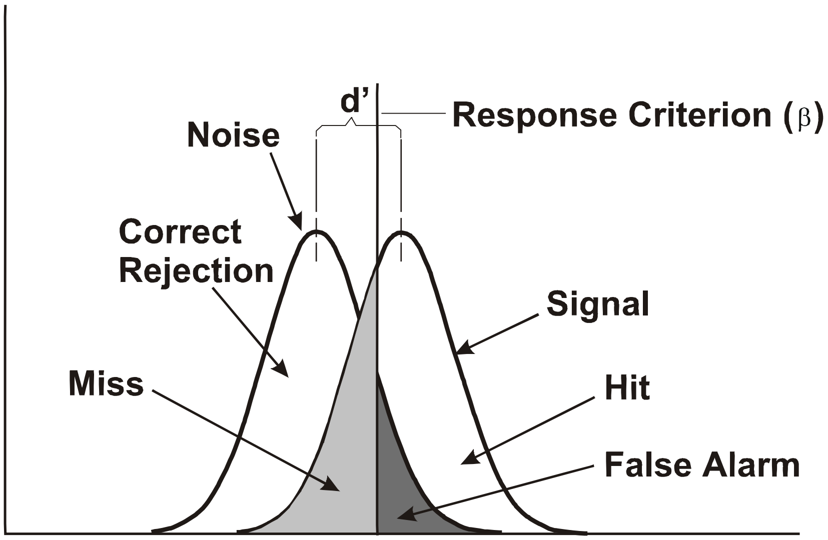


Figure 7. Graphical Depiction of Signal Detection Theory

To evaluate participants' ability to discriminate trains from trucks the number of hits and false alarms were recorded. As shown in Figure 7, the two distributions can be characterized from knowledge of the number of hits and false alarms. This relationship is frequently described graphically by an ROC curve. This curve shows the relationship between probability of hits and the probability of false alarms for different levels of response bias. To calculate ROC curves for each pattern by type of freight car and environment, the confidence level of each participant's decision was also recorded on a five-point scale. Figure 8 shows the ROC curves for each pattern by type of freight car and environment. The vertical axis shows the probability of hits and the horizontal axis shows the probability of false alarms. Sensitivity increases as points on the curve move from the lower right-hand corner to the upper left-hand corner of the chart. Sensitivity is measured typically by an index called d' and response bias is measured by an index called beta (β). D prime (d') corresponds to the separation of the mean of two distributions expressed in units of their standard deviations as shown in Figure 7. The response critierion, beta is measured by the ratio of the probability of saying "yes" when the signal is present to the probability of saying "yes" when only noise is present. For the reader interested in learning more about signal detection theory, refer to books by Green and Swets (1988) or Egan (1975).

In this experiment an alternative measure A prime (A') was used rather than d'. D prime cannot be calculated if either hits or false alarms equal 100 percent, as was the case for several conditions. Therefore, a nonparametric measure of sensitivity, A prime (A'), was used (Grier, 1971) instead. A' measures the area under the ROC for the measured data point. Beta corresponds to the ratio of hits to false alarms for a given event state. In Figure 7, the value of beta is represented by the ratio of hits to false alarms where the vertical line intersects the horizontal axis. To determine statistical significance, analysis of variance (ANOVA) and Student-Newman-Keuls multiple comparison tests were performed on the percent correct for hits (PC_h) in each condition.

2.2.2 Sensitivity

To compare the four reflectorized patterns and one unreflectorized pattern, the data were analyzed by environment and car type. For each of the environment-by-car-type conditions, a similar pattern emerged. Participants showed a high level of sensitivity across all levels of response bias for all reflectorized patterns as shown in Figure 8. For all four of the reflectorized patterns, the probability of detecting the signal when it was present was over 85 percent or higher across all false alarms probabilities. By contrast, for the unreflectorized freight car in each condition, participants exhibited a guessing strategy. The probability of hits and false alarms were approximately equal across all levels of response bias.

A similar picture emerged from an analysis of A'. Figure 9 shows A' values for each pattern by environment and car type. A' has a range from zero to one where zero represents an inability to detect and one represent perfect detection. For all conditions, discrimination was better when the patterns were reflectorized than when they were not. The ANOVA for PC_h indicates there was a statistically significant main effect for pattern, F (1,40) = 21.0, p = .0001. Student-Newman-Keuls multiple comparison tests indicate that the differences are attributed to the much lower sensitivity of the unreflectorized car compared to all the reflectorized cars (CR_t (5, 40 = .051, p, < .05). However, the differences among the four reflectorized patterns were not statistically significant. No one pattern was better than another in supporting rail car detection. This situation

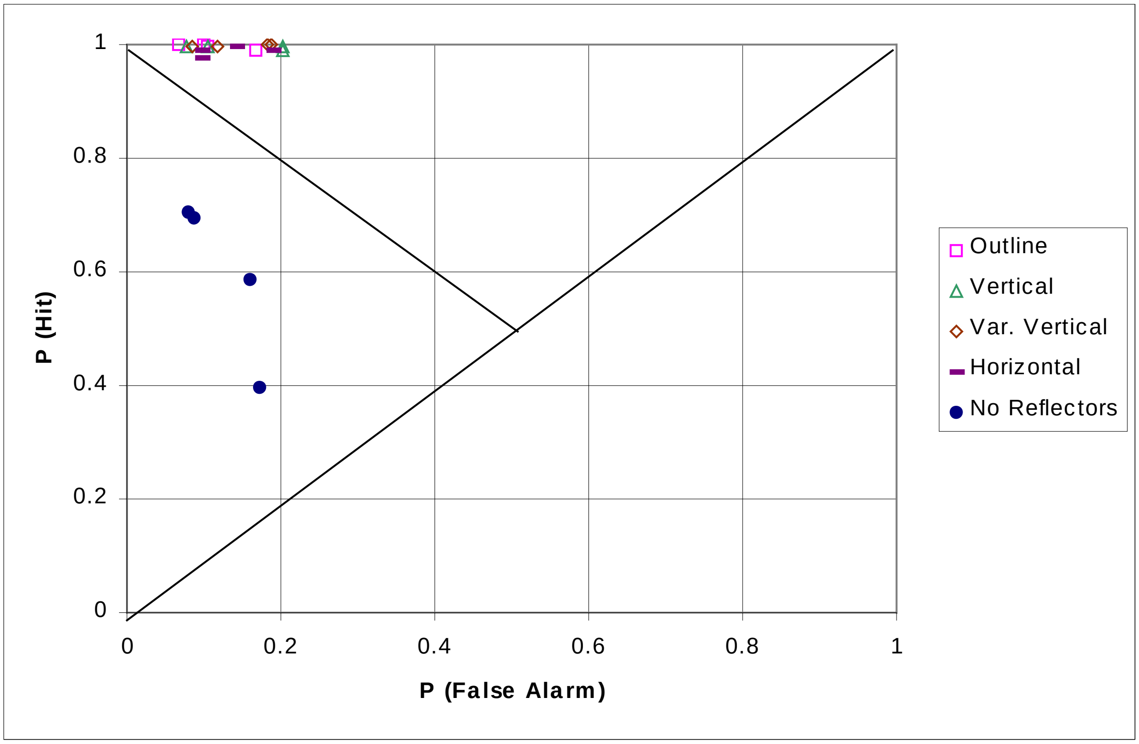


Figure 8. Probability of Hits Versus False Alarms by Car Type Based on Confidence Ratings

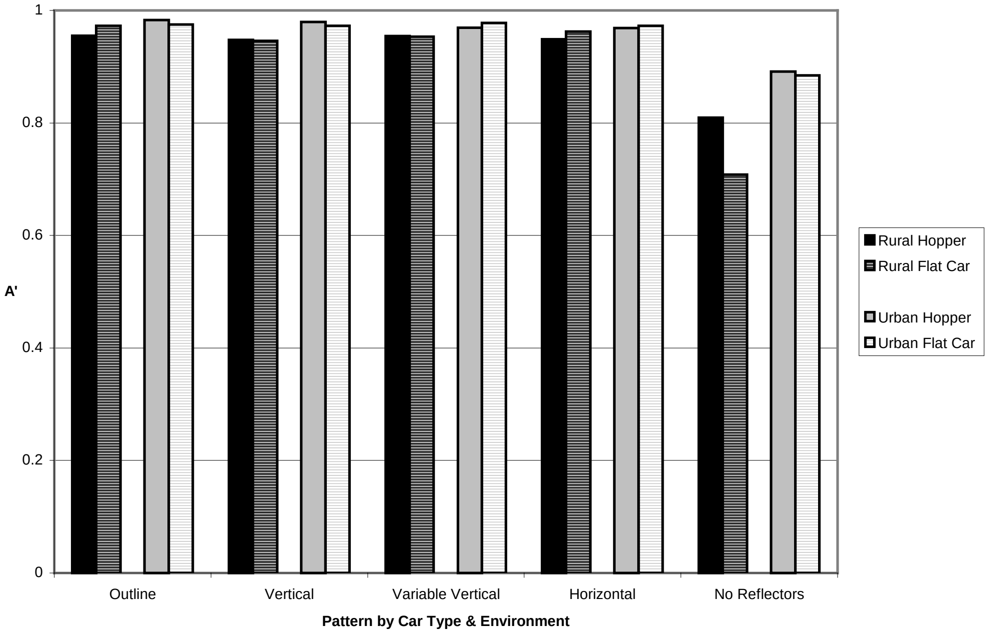


Figure 9. A' for Pattern by Car Type and Environment Based upon Confidence Ratings

applied for both types of freight cars. While there was no statistically significant effect for freight cars, there was a statistically significant effect as measured by PC_h, for environment, F (1,40) = 23.85, p = 0.0006. There was also a statistically significant interaction as measured by PC_h, between pattern and environment, F (4,40) = 5.58, p = 0.0012. Participants correctly identified trains at a higher rate in the urban condition (92 percent) than in the rural condition (85 percent).

The differences between the urban and rural environment as well as the interactions between pattern and environment can be attributed to the performance differences in the unreflectorized cars for the two environments. Table 2 shows the probability of hits and false alarms for unreflectorized cars by environment and car type. For both car types, the probability of hits in the urban condition are greater than in the rural condition while the opposite is true for false alarms. The task appears more difficult in the rural condition than in the urban condition. Table 3 showing false alarms by the type of signal present (truck or nothing), also illustrates the greater difficulty of the rural condition. The probability of false alarms occurring when the signal is a truck is almost the same in the rural condition. The equal distribution of false alarms suggests participants are guessing. In the urban condition, the number of false alarms is greater when the signal is a truck than when nothing is present.

Table 2. Probability of Hits and False Alarms for an Unreflectorized Freight Car by Environment and Car Type

	P(Hits)		P(False Alarms)	
Car Type	Rural	Urban	Rural	Urban
Hopper	.58	.70	.16	.08
Flat	.40	.70	.17	.09

Table 3. Probability of False Alarms for an Unreflectorized Car by Environment and Signal Present

	Rural		Urban	
	Truck	Nothing	Truck	Nothing
Hopper	.18	.17	.14	.03
Flat Car	.17	.18	.17	.02

The urban environment differed from the rural environment by exhibiting street lighting and lighting from surrounding buildings. These lights raised the illumination level near the grade crossing making it easier to detect the freight cars. Additionally, the illumination levels of both car types in the urban environment were somewhat higher than in the rural environment.

In discriminating trains from trucks, the unreflectorized rail car posed great difficulty for the participants. For different levels of hits and false alarms, participants were equally likely to say they saw a train when it was there or not. The linear relationship between hits and false alarms indicates chance performance. This means that the signal cannot be discriminated from noise.

By contrast, the higher A' values for the reflectorized patterns compared to the unreflectorized cars, suggest that participants had little difficulty discriminating trains from trucks. This finding was particularly surprising for the horizontal pattern, which because of its similarity with the horizontal patterns on the truck was expected to make discrimination more difficult than with the other patterns.

One reason this finding occurred may lay in the visual cues that enabled the participant to discriminate trains from trucks independent of the pattern. Streetlights, consisting of vertical poles with lights mounted on the top as shown in Figure 5, may have enabled the participant to use shape cues to discriminate between objects. As the reflectorized pattern crossed the intersection, different portions of the streetlights may have been obscured. For example, the smaller vertical height of the flat car would have obscured a smaller portion of the street lamps than the truck.

A second possibility in explaining the outcome of this experiment is that the patterns, themselves, enabled the participants to discriminate the train from the truck.

2.2.3 Response Bias

In addition to examining the participants' ability to discriminate trains from trucks based on different patterns, signal detection theory enables us to examine participants' response strategies in completing the task. One such strategy is presented graphically in Figure 10. The participant's task was to select among three options. The small number of options limited the participants' expectations about what they would see. This knowledge may have enabled them to approach the task by making two paired comparisons. In the first comparison, the participant decided whether an object was present in the intersection or absent. If the participant believed no object was present, the participant selected nothing. If an object was detected, then the participant made a second comparison between the train and the truck. For each decision, the participant had a 50 percent chance of correctly guessing what appeared on each trial.

Figure 11 shows response bias as measured by B" for each of the patterns. B" values range from –1 to +1. Negative values represent a willingness to say, "The object is a train." Positive values represent a willingness to say, "The object is not a train." A B" value of 0 indicates no bias; the participant is equally willing to say the train is present or absent. For each of the reflectorized patterns, participants exhibited a strong bias to say the train was present. Appendix A shows the B" values for each pattern by subject. For all four reflectorized patterns, the B" values ranged between –0.8 and –1.0, with one exception. In the urban hopper condition, several participants exhibited B" values around –0.5. One participant exhibited a B" value of +0.5. The four patterns showed no consistent trends in the β' values by environment and car type condition.

By contrast, for each unreflectorized pattern, participants exhibited a moderate bias to say the train was absent. Figure 12 shows the B" values for each of the unreflectorized conditions. Here, B" values ranged between -1.0 and +1.0. An examination of individual participant's B" values showed wide variability in willingness to report the train as present or absent in the unreflectorized conditions. Particularly in the urban condition, approximately 50 percent of participants were more willing to say the train was present, while the other 50 percent were more willing to say the train was absent. Given the greater difficulty in detecting the unreflectorized freight cars, this strategy seems reasonable. For the unreflectorized car, the greater willingness of participants to say the train was absent compared to the reflectorized cars, reflects the greater difficulty of the detection task. This negative response bias was smaller in the rural condition than in the urban condition, where the detection task was more difficult. Thus, as the discrimination task became more difficult, participants appeared to adopt a more neutral response bias.

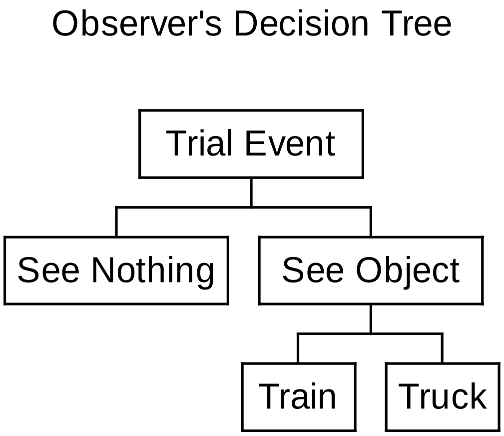


Figure 10. Observer's Decision Tree

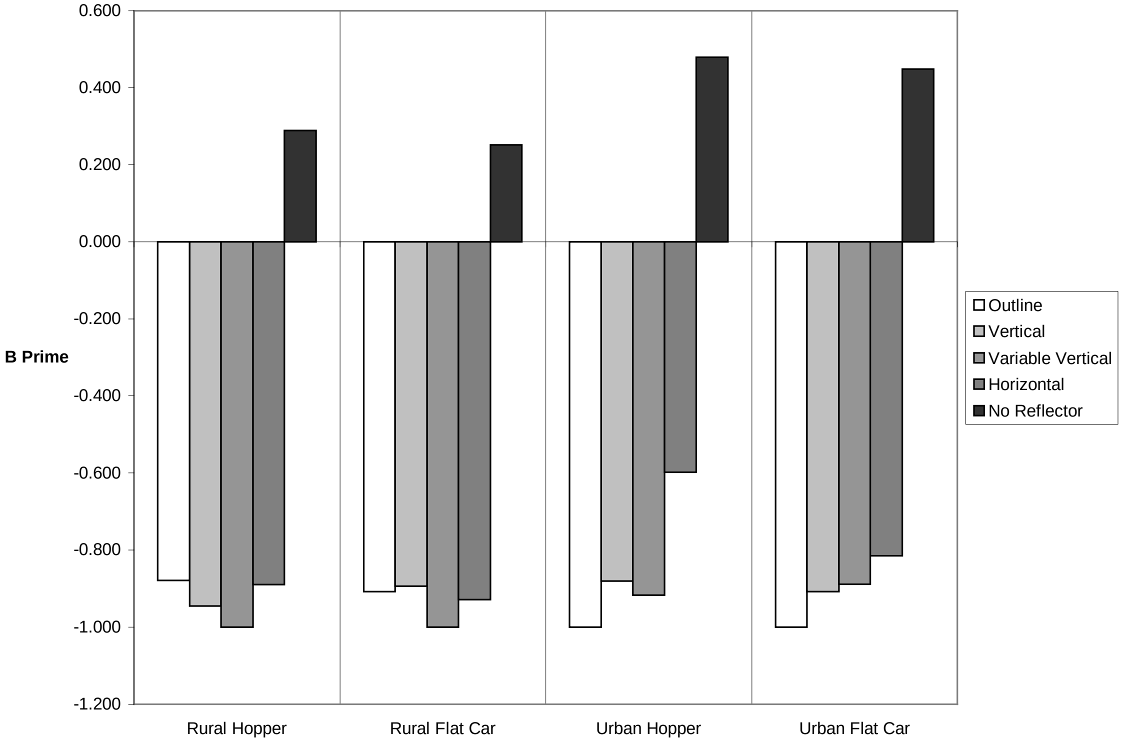
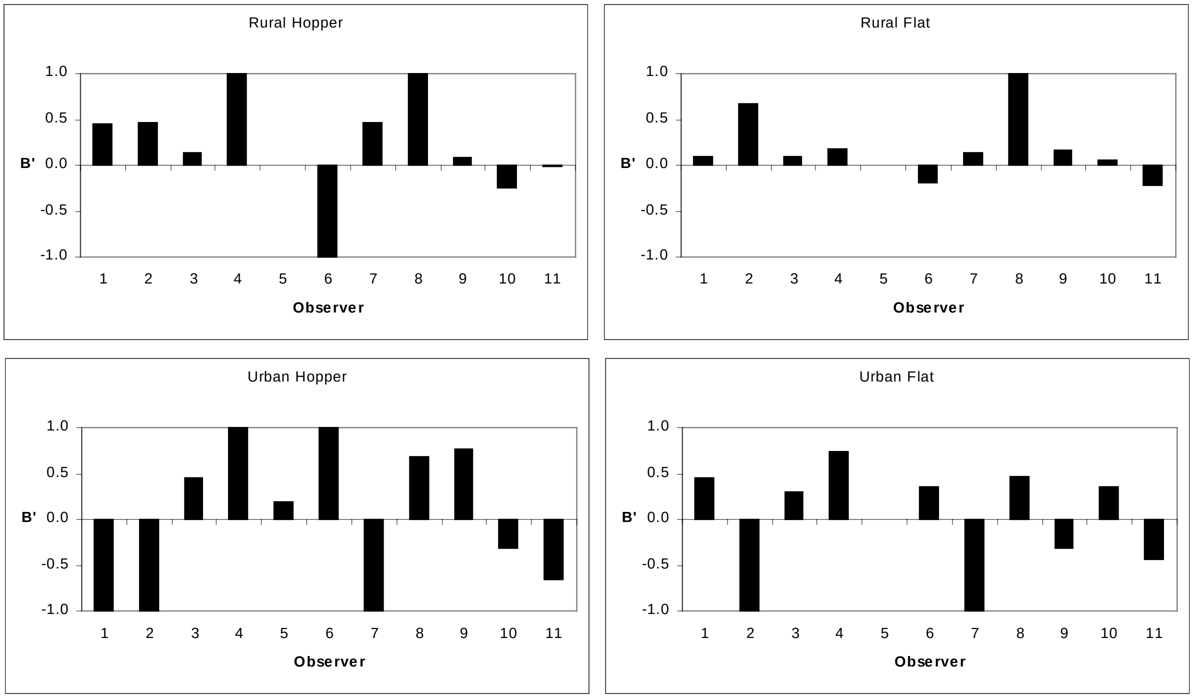


Figure 11. B" Values for Each Pattern by Car Type and Environment


Rural Hopper

Rural Flat

Urban Hopper

Urban Flat

Figure 12. B" Values by Observer for Unreflectorized Conditions

2.2.4 Summary

The results of the current experiment uncovered no differences in discriminating between trains and trucks as a function of pattern. Differences were found as a function of the environment and were attributed to the participants' greater difficulty in detecting unreflectorized freight cars in the rural environment compared to the urban environment. In the urban environment where visual cues were sufficient to assist in decision making, participants varied in their willingness to say a train was present or absent. In the rural environment, where the visual cues were insufficient to assist in decision making, participants adopted a neutral guessing strategy. The lack of differences between patterns may have been due to visual cues in the environment that enabled participants to use context to discriminate between trains and trucks.

The experiment described in Section 3 will attempt to resolve this question by looking at these patterns in a more naturalistic setting. To minimize the driver's expectations, the participant will drive a simulated motor vehicle without knowing explicitly what he or she is looking for. The participant will encounter objects that are found naturally in operating a motor vehicle and identify these objects. Identification of trains and trucks will be two of several objects encountered. Further, the participant will not be able to anticipate when a particular object will appear. Visual cues that may aid identification of trains and trucks at the intersection will be eliminated.

3. RECOGNITION DISTANCE EXPERIMENT

3.1 METHOD

3.1.1 Overview

Experiment 2 explored the relationship between recognition and retroreflective pattern in an environment more like that found in actual driving conditions. The same retroreflective patterns in experiment 1 were evaluated here. Using a low fidelity human-in-the-loop simulator, participants drove a simulated passenger car on a course containing a series of roadway intersections and highway-railroad grade crossings. The course also contained objects normally found in the highway-driving environment. These objects included traffic signs, traffic lights, trains, and motor vehicles. The participant's task was to drive the simulated passenger car and identify each object observed.

3.1.2 Participants

Twenty-two licensed drivers were recruited from MIT and the Volpe Center. All participants possessed visual acuity of 20/40 or better, as measured by the Snellen visual acuity test. Some participants' vision was corrected with eyeglasses. Eight of the participants were women and 14 were men. The participants ranged in age from 18 to 60 with a mean age of 37. Participants recruited from MIT were paid $10.00 per hour while employees of the Volpe Center participated as a part of their work duties.

3.1.3 Experimental Design

The experiment was designed as a 2 x 5 repeated-measure design, in which each participant was exposed to all possible conditions. The two independent variables manipulated were freight car type and pattern. Table 4 shows the 10 conditions. The two freight car types and four patterns were identical to those found in experiment 1. An unreflectorized freight car and truck were also used as control conditions.

Table 4. Experiment 2 Conditions

Freight car	Pattern
Flat	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None
Hopper	Outline Horizontal Bar Vertical Bar Variable Length Vertical Bar None

In addition to the freight cars, participants saw a truck (four patterns plus an unreflectorized truck), a car, several types of signs, and a traffic light. In total, there were five types of objects. Table 5 shows how many times that each object type was displayed. The order in which the rail patterns were given was randomized by participant. Within an experiment, participants saw each rail pattern twice for a total of 20 trials.

Table 5. Object Type Display Frequency

Object Type	Display Frequency
Car	40
Light	4
Sign	113
Train	20
Truck	20

Performance was measured by recording distance from each object when the participant spoke the name of the object and recognition errors. If the participant changed his or her response while moving closer to the object, only the last response was considered in calculating the recognition distance. If the driver made a recognition error, an error was recorded. Trials on which drivers made an error were excluded from the calculation of recognition distance.

3.1.4 Scenario Description

Figure 13 shows the course participants drove. The course was 17 miles long and contained 11 grade crossings and 10 highway intersections. Each driver completed the course twice. Thus, each driver passed through 22 grade crossings and 20 highway intersections. The letters in Figure 13 represent the highway intersections and the numbers represent the grade crossings. All road markings, signs, and traffic lights were designed according to the regulations set forth in the Manual on Uniform Traffic Control Devices (FHWA, 1988). The posted speed limit was 50 mph. The approach to every grade crossing contained an advanced warning sign, railroad warning sign, and a crossbuck sign. The out-the-window view always displayed a forest of trees on both sides of the road to prevent participants from using peripheral vision to detect vehicles approaching an intersection. The design of the trains and trucks and the patterns evaluated in this experiment were identical to those found in Experiment 1. The background illumination level was comparable to the rural condition in Experiment 1.

As the driver approached intersections where a vehicle would appear, the vehicle would begin crossing the path when the participant was 2,000 feet from the intersection. For trains, a group of the same type of freight cars moved continuously through the intersection until the driver was 375 feet from the intersection. For trucks and cars, a convoy of the same type of vehicles separated by fixed intervals would cross through the intersection until the driver was 375 feet from the intersection. The interval for trucks was 5 seconds. The interval for passenger cars was 4 seconds.

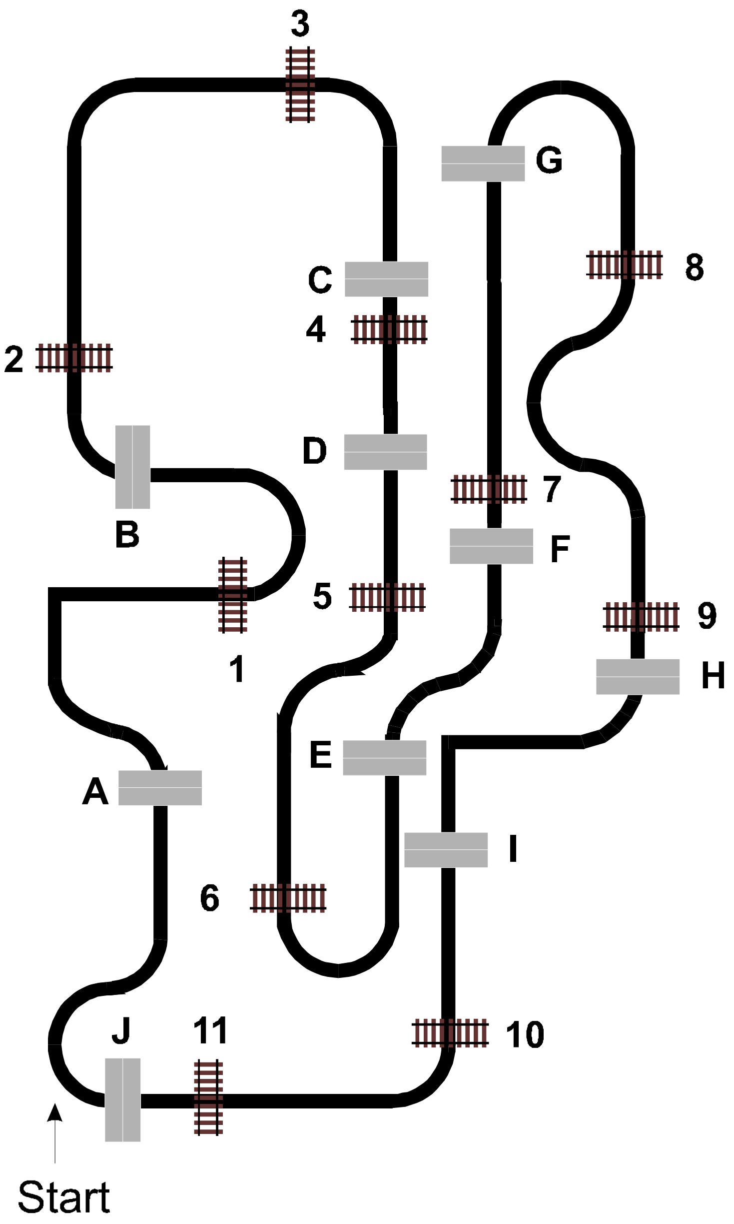


Figure 13. Simulator Course

3.1.5 Apparatus

A low fidelity, fixed-based driving simulator was created with a Silicon Graphics Indigo 2 workstation, using the C++ programming language. The visual scenes were displayed using a Barco 808S projector on a 6' x 8' wall-mounted screen. The vehicle's motion was modeled after a Volkswagon Rabbit. The participant sat 15 feet away from the projection screen and controlled the vehicle with a desktop steering wheel and an accelerator and brake pedal located on the floor. The projection screen displayed three items: the out-the-window view, a speedometer, and six text labels to aid data collection. Figure 14 shows an example of what the participant saw.

To identify an object, the driver spoke one of five signal words displayed on the screen that most closely matched the object. The driver spoke these words into a headset style microphone. The voice responses were then recorded on a personal computer using voice recognition software.

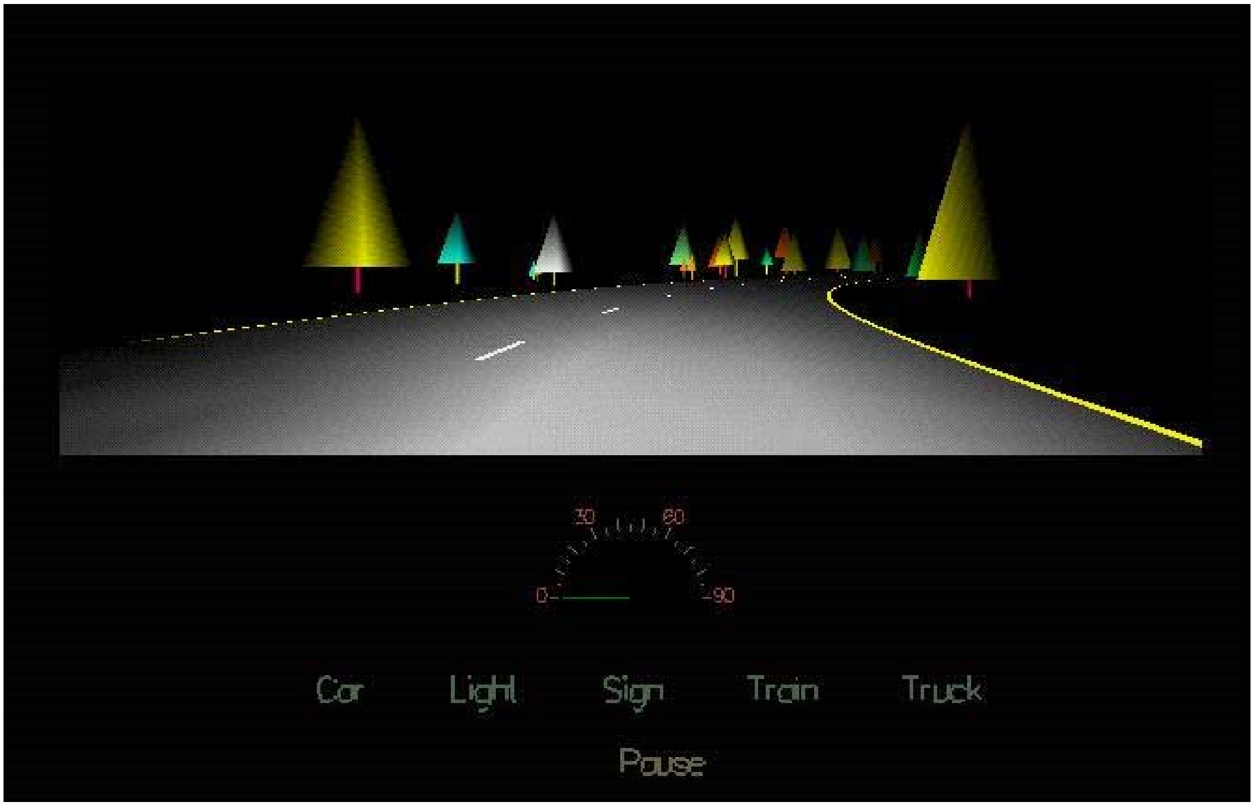


Figure 14. Driver's Forward Field of View

3.1.6 Procedures

The participant's task was to drive a simulated passenger car while identifying objects that appeared along the roadway. The experiment lasted approximately 2 hours. Each participant began by training the voice recognition software to recognize his or her voice. The participant repeated five signal words into a microphone for approximately 2 minutes. The signal words were: *car, light, sign, train,* and *truck*. The participant drove around an oval practice course to become familiar with the controls and to see the different objects that would appear on the experimental course. After seeing all the objects, the participant practiced saying the names of the objects observed while driving on the practice course. When the participant was comfortable driving the simulator and identifying objects on the road, the participant began the experimental course.

The experimenter instructed the participant to drive the vehicle while obeying all regulatory traffic signs (i.e., speed limits and stop signs) and traffic lights. The task was self-paced in that the participant could control the speed at which the vehicle traveled. However, the experimenter encouraged the participant to drive as close to the designated speed limit as possible. When it was necessary to turn at an intersection, arrow signs indicated the correct direction.

While driving, the participant encountered a series of objects. The participant was instructed to identify these objects in the order in which they were seen and as soon as they could be clearly recognized. The participant identified the name of the object by speaking the appropriate signal word shown on the projection screen below the speedometer. When a participant identified an object, a computer recorded the signal word, the distance of the vehicle from the object at that point, and the actual object name. If the participant changed his or her mind after giving a response, the participant could give another response. Only the last response was used in calculating recognition distance.

If the participant needed to interrupt the simulation to take a break or speak with the experimenter, speaking the word “pause” would suspend the simulation. Speaking the word “resume” continued the simulation from the same point where the simulation was suspended. The participant drove around the experimental course twice. At the conclusion of the experimental task, the participant completed a brief questionnaire.

3.2 RESULTS AND DISCUSSION

3.2.1 Recognition Distance

To compare the four reflectorized patterns and one unreflectorized pattern, the data were analyzed by car type. For each of the 10 conditions, mean recognition distance was calculated along with the number of recognition errors. Figure 15 shows the recognition distance for the four patterns plus the unreflectorized condition, by car type. An ANOVA for recognition distance indicates there was a statistically significant main effect for car type, $F(1,21) = 17.98$, $p = 0.0001$. The mean recognition distance was greater in the hopper car condition (1,026 ft) than in the flat car condition (947 ft). This outcome was expected since the patterns on the hopper car had twice as much material as the on the flat car.

An ANOVA for recognition distance showed a statistically significant effect for pattern, $F(4,21) = 193.67$, $p = 0.0001$. Since there was also a statistically significant interaction between pattern and car type, $F(4,21) = 12.17$, $p = 0.0001$, it is more appropriate to discuss the effects of pattern by how it varied with car type. For the hopper car, the patterns can be clustered into three groups according to whether the differences between the patterns were statistically significant using a Student-Newman-Keuls multiple comparison test (CR_{SNK} (5, 181 = 129.35, p, < .05). Table 6 shows how the different patterns were grouped according to whether the differences between them were statistically significant. Differences within a group were not statistically significant. Differences between groups were generally statistically significant. An exception occurred where one pattern belonged in more than one group.

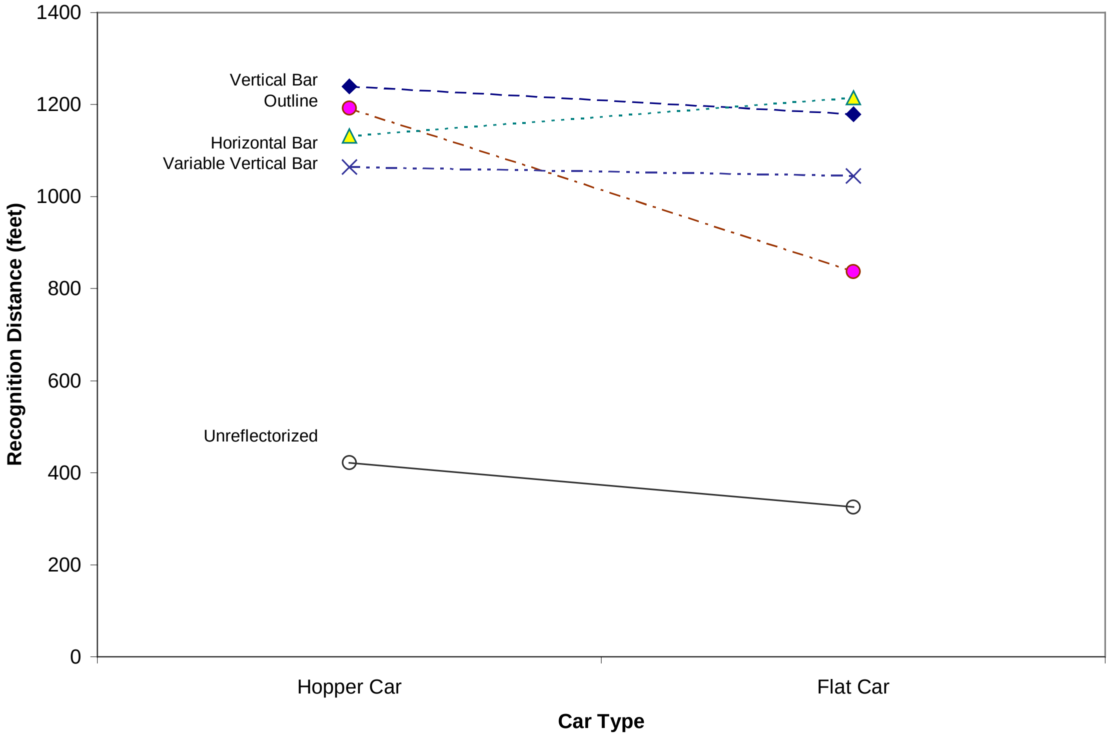


Figure 15. Effect of Pattern on Recognition Distance

Table 6. Pattern Grouped by Statistical Significance

Pattern	Recognition Distance (ft)	Grouping*
Hopper Car		
Vertical Bar	1240	A
Outline	1192	A
Horizontal Bar	1132	A,B
Variable Vertical	1064	B
Unreflectorized	422	C
Flat Car		
Horizontal Bar	1215	A
Vertical Bar	1179	A
Variable Vertical	1045	B
Outline	837	C
Unreflectorized	325	D

*Multiple letters indicate inclusion in more than one group. Statistical evaluations were made between all possible pairs of patterns. Differences in recognition distance between patterns with the same letter were not statistically significant. Differences between patterns with different letters were statistically significant ($p < 0.05$).

In the first group, the vertical bar, outline and horizontal bar performed similarly. Of the patterns in this group, the vertical bar and the outline were significantly better than the variable vertical and the unreflectorized pattern. The horizontal bar and variable vertical bar patterns formed a second group. Both these patterns were significantly better than the unreflectorized pattern. The third group consisted of the unreflectorized pattern alone. As expected, recognition performance was worst in this condition.

Recognition performance in the flat car condition showed a different trend. Multiple comparison tests using the Student-Newman-Keuls multiple comparison test (CR_{SNK} (5, 179 = 128.92, p, < .05) show four statistically significant groupings. Differences within a group were not statistically significant while differences between groups were statistically significant. From best to worst, the horizontal bar and vertical bar performed similarly followed by the variable vertical bar, the massed outline and finally, the unreflectorized car.

The only statistically significant result common to both types of rail cars was the better performance of the reflectorized patterns compared to the unreflectorized car. As expected, all patterns were better than the unreflectorized car.

Performance with the vertical bar pattern was among the best for both car types. It ranked first in the hopper car and second in the flat car. By contrast, the outline pattern performed well in the hopper car condition but suffered in the flat car condition. Mean recognition distance went from 1192 feet in the hopper car to 837 feet in the flat car. The poorer performance may be attributed to the fact that the outline pattern did not actually outline the shape of the freight car in the flat car. In creating this pattern, the small amount of surface area on the flat car resulted in only the lower half of the outline being displayed. Consequently, participants may have had more difficulty recognizing this pattern as the freight car than with the complete outline shown in the hopper car.

The horizontal bar was the only pattern to show a performance improvement in going from the hopper car to the flat car. This result was surprising, given the smaller amount of material in the flat car. Given the similarity between the truck patterns and the horizontal bar, it was also surprising that participants performed best with the horizontal bar in the flat car condition. Other visual cues in the environment may help the motorist to avoid confusing the two objects. For example, freight cars normally travel in closely spaced groups, while trucks generally consist of single trailers. In this experiment, trucks containing a single trailer crossed the intersection at 5-second intervals. The freight cars were separated by 4 feet and crossed the intersection continuously until the participant was 375 feet from the intersection. These differences may have been sufficient to enable the participant to discriminate between the train and the truck relatively quickly.

The variable vertical pattern showed consistent performance across the two car types. The difference in recognition distance between the two car types was less than 25 feet. For the hopper car, this pattern exhibited the worst performance of the four reflectorized patterns. For the flat car, this pattern exhibited the second lowest performance.

3.2.2 Recognition Errors

An analysis of recognition error shows the difficulty in recognizing the unreflectorized freight car compared to the reflectorized patterns. Table 7 shows the recognition errors for both car types by pattern. For both car types, more recognition errors occur for the unreflectorized cars than for the reflectorized cars. A test of the difference in proportions between these two groups was statistically significant ($z = 4.14$, $p < .05$). In the hopper condition, participants made seven recognition errors with the unreflectorized car and two errors with the reflectorized cars, out of 219 observations. In the flat car condition, participants made 10 recognition errors with the unreflectorized car and 4 errors with the reflectorized cars, out of 216 observations.

Table 7. Recognition Errors by Object in Grade Crossing

	Object Identified in Grade Crossing		
	Nothing	Car	Truck
Hopper car			
Unreflectorized [a]	4 (9%)	0 (0%)	3 (7%)
Reflectorized[b]	0 (0%)	0 (0%)	2 (1%)
Flat car			
Unreflectorized [a]	8 (18.2%)	1 (2.3%)	1 (2.3%)
Reflectorized[b]	0 (0%)	1 (0.6%)	3 (1.7%)

[a] Number in parentheses represents percent of errors for unreflectorized cars.
[b] Number in parentheses represents percent of errors for reflectorized cars.

Inspection of the recognition errors in reflectorized patterns shows participants made errors with only two patterns, the horizontal bar and the outline. Five out of six of the recognition errors involved confusing a train with a truck. In one instance, participants confused a train with a car. In the hopper car condition, participants confused a train with a truck twice with the horizontal bar pattern. In the flat car condition, participants confused a train with a truck twice with the outline and once with the horizontal bar pattern. The outline pattern was also confused with a car on one occasion with the flat car.

These results suggest that most of the time, motorists can discriminate between similar patterns on trains and trucks. Although the number of errors is too small to make statistical judgements, the fact that errors that did occur were predominantly in the horizontal bar condition, suggests that this pattern is more likely to be confused than the other patterns. In actual driving conditions, similar patterns are more likely to be confused when driving under less than ideal conditions (i.e., when weather reduces visibility or the motorist is distracted). Thus, when considering errors, the horizontal bar pattern may be less desirable than the other three patterns.

3.2.3 Summary

Overall, participants were able to recognize all four patterns at far greater distances than the unreflectorized patterns. This was expected given the previous research (Ford et al., 1998; Olson et al., 1992; Ziedman et al., 1981) showing the effectiveness of retroreflective materials in aiding detectability. In general, participants also recognized all patterns on the hopper car farther away from the grade crossing than the flat car. This result was attributed to the greater amount of material that increased the amount of light returning to the motorist and the larger visual angle associated with those patterns.

While the average recognition distance for the flat car was lower than the hopper car, it may still be effective to use the smaller amount of material found in the flat car patterns. Field tests conducted on truck trailers (Olson et al., 1992) suggest these values may be a reasonable approximation of the results from this laboratory study. In their experiment measuring detection distance, the mean detection distance was 1,461 feet with a standard deviation of 494 feet.

Among the four reflectorized patterns, recognition distance varied with car type. While performance with the vertical bar, horizontal bar, and variable vertical bar was relatively consistent across car types, the outline showed a significant performance difference between the two car types. Performance suffered in the flat car condition, but it is not clear why. The outline was also one of two patterns in which participants made errors. Given the small vertical height of the typical flat car (between 4 and 18 inches), this car type makes displaying an outline shape difficult.

In contrast to the outline pattern, the horizontal bar pattern showed better performance in the flat car condition than in the hopper condition. This finding was unexpected. Since the horizontal bar was the pattern most similar to the truck patterns, participants were expected to take longer to identify the freight car than for the other three patterns. However, the horizontal bar was the other pattern for which participants made recognition errors. Although the number of errors was quite small, in every case, the train was confused with a truck. This confusion was expected given its similarity with the truck patterns. By contrast, the outline pattern was confused with both the truck and car.

In selecting a standard pattern that could fit on all rail cars, the flat car becomes the limiting case, since it is the car with the smallest surface area. For 85 percent of motorists, three of the four patterns (horizontal bar, variable vertical bar, and vertical bar) would provide stopping distances adequate for operating at speeds up to 55 mph. All four patterns would be effective at speeds up to 45 mph. The unreflectorized cars would not provide adequate stopping distance at speeds above 25 mph.

Given that all four patterns are comparable at speeds up to 45 mph, recognition errors can serve as another criterion for selecting the optimal pattern. In this study, the horizontal bar pattern and outline pattern were more likely to be confused with truck patterns than the vertically oriented patterns. The number of recognition errors were lowest with the vertical bar pattern followed by the variable vertical bar pattern. While the number of errors made with the horizontal bar and outline patterns were small, selecting a vertically oriented pattern will minimize the likelihood of confusion.

4. SUMMARY AND CONCLUSIONS

The two experiments in this study examined the ability of observers to discriminate freight cars from truck trailers in an intersection at night, using retroreflective materials. Four patterns were evaluated. The four freight car patterns were compared to four retroreflective patterns currently found on truck trailers in revenue service. One experiment used a signal detection paradigm to evaluate the discriminability. The other experiment used a human-in-the-loop driving simulator to evaluate human performance in a more naturalistic setting.

Taken together, the two experiments suggest that motorists can discriminate between freight cars and truck trailers for any of the four patterns tested here. In both experiments, performance differences between the four patterns were small. In the first experiment, differences in the patterns were not statistically significant. In the second experiment, differences between the patterns were found as a function of car type.

From a practical standpoint, the significance of these differences depends upon the stopping distance criterion selected. Eighty-five percent of the driving population would recognize the train for all four patterns in time to stop safely at 45 mph. By contrast, 85 percent of motorists would not recognize an unreflectorized rail car in time to stop at speeds above 25 mph. At 55 mph, only three of the four patterns would provide adequate safety margin. The outline pattern would be unacceptable in this situation. In terms of confusing the freight cars with truck trailers, the likelihood of these confusions is quite small. However, using similar patterns that could be confused increases the probability of an accident compared to the patterns that are not easily confused. Choosing a pattern that is dissimilar to the horizontally oriented patterns found on trucks will minimize the opportunity for these confusions. Therefore, a vertically oriented pattern is preferred.

This study also demonstrated the important role context plays in understanding participants' behavior. In the signal detection experiment, unreflectorized freight cars were more difficult to recognize in the rural environment than the urban environment due the lower illumination levels. The use of retroreflective materials eliminated this difficulty. This performance improvement did not vary with the type of pattern. For both car types, participants were able to discriminate between trains and trucks.

For the reflectorized patterns, participants exhibited a strong willingness to say the train was present for all patterns with one exception. Participants were less willing to say the train was present for the horizontal bar pattern in the urban hopper car. This may have been due to the combined similarity of the patterns and the outline or shape of the two vehicles. The greater illumination level found in the urban environment may have enabled the observer to use this additional visual information in their decision-making. However, because, the additional information was similar between the two vehicles, it added to the difficulty of the discrimination task rather than making it easier. This may also explain why participants in the recognition distance experiment recognized the horizontal bar at greater distances than the hopper car. It is worth noting that the number of recognition errors for the horizontal bar was greater in the hopper car (2) than the flat car (2). Again, these data suggest that the horizontal bar pattern may be more likely to result in confusion between freight cars and truck trailers, than the other three patterns.

The findings from this study are summarized below:

- Participants discriminated between freight cars and truck trailers for all four patterns evaluated.
- Vertically oriented patterns were recommended over outline and horizontally oriented patterns because they were less likely to be confused with the horizontally oriented truck patterns.
- Unreflectorized rail cars were more difficult to discriminate from trucks as illumination level declines.

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APPENDIX

RESPONSE BIAS: B" VALUES FOR EACH PATTERN

Horizontal Bar

	Rural		Urban	
Observer	Hopper	Flat	Hopper	Flat
1	-0.097	-1.000	-1.000	0.000
2	-1.000	-1.000	0.574	-1.000
3	-1.000	-1.000	-0.457	-1.000
4	-1.000	-1.000	-0.542	-1.000
5	-1.000	1.000	-1.000	1.000
6	-1.000	-1.000	-1.000	-1.000
7	-1.000	-1.000	-	-
8	-1.000	-1.000	-1.000	-1.000
9	-1.000	-1.000	-0.394	-1.000
10	-1.000	-1.000	-1.000	-1.000
11	-1.000	-1.000	-1.000	-1.000

Outline

	Rural		Urban	
Observer	Hopper	Flat	Hopper	Flat
1	-1.000	-1.000	-1.000	-1.000
2	-1.000	-1.000	-	-
3	-1.000	-1.000	-1.000	-1.000
4	-1.000	-1.000	-	-
5	1.000	1.000	-1.000	-
6	-1.000	-1.000	-1.000	-1.000
7	-1.000	-1.000	-1.000	-
8	-1.000	-1.000	-	-1.000
9	-1.000	-1.000	-1.000	-1.000
10	-1.000	-1.000	-1.000	-1.000
11	-1.000	-1.000	-1.000	-1.000

Variable Vertical Bar

	Rural		Urban	
Observer	Hopper	Flat	Hopper	Flat
1	-1.000	-1.000	-1.000	-1.000
2	-1.000	-1.000	-1.000	-
3	-1.000	-1.000	-1.000	-1.000
4	-1.000	-1.000	-1.000	-1.000
5	-1.000	-	1.000	-
6	-1.000	-1.000	-1.000	-1.000
7	-1.000	-1.000	-1.000	-
8	-1.000	-1.000	-1.000	0.000
9	-1.000	-1.000	-1.000	-1.000
10	-1.000	-1.000	-1.000	-1.000
11	-1.000	-1.000	-1.000	-1.000

Vertical Bar

	Rural		Urban	
Observer	Hopper	Flat	Hopper	Flat
1	-0.505	-1.000	-1.000	-1.000
2	-1.000	-1.000	-	-
3	-1.000	-1.000	-1.000	-1.000
4	-1.000	-1.000	-	-1.000
5	-	1.000	-	1.000
6	-1.000	-1.000	-1.000	-1.000
7	-1.000	-1.000	-	-
8	-1.000	-1.000	-1.000	-1.000
9	-1.000	-1.000	-1.000	-1.000
10	-1.000	-1.000	-0.394	-1.000
11	-1.000	-1.000	-1.000	-1.000

Unreflectorized Car

	Rural		Urban	
Observer	Hopper	Flat	Hopper	Flat
1	0.455	0.092	-1.000	0.457
2	0.460	0.670	-1.000	-1.000
3	0.132	0.092	0.457	0.295
4	1.000	0.173	1.000	0.736
5	-	-	0.188	-
6	-1.000	-0.187	1.000	0.351
7	0.460	0.138	-1.000	-1.000
8	1.000	1.000	0.679	0.471
9	0.082	0.158	0.770	-0.309
10	-0.244	0.057	-0.309	0.351
11	-0.019	-0.220	-0.663	-0.445