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Human Factors Evaluation of Design Ideas for Prevention of Vehicles Entrapment on Railroad Tracks due to Improper Left Turns

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Submitted by

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16. Abstract

The purpose of this project was to investigate the problem of vehicle entrapment at grade crossings due to attempts of making left turns to roadways which are parallel to the railroad. This project investigated selected highway-rail grade crossing on NJ TRANSIT's lines in New Jersey. Possible design ideas for solving such vehicle entrapment problems were examined using human subjects in the lab and observations in the field. The projects involved data analyses of accident records, development of an in-lab experiment for studying effect of design solutions to the performance of driver's roadway vs. railroad judgment, conducting the experiment, data analyses of the experiment, recommendations to the field validation study, selection of field study sites, conducting the field study using video cameras, data analyses for the field study, and recommendations to conclude the project.

Results from the laboratory experiment suggest that confusion of the drivers attempting to make left-turns at railroad crossings can be reduced by delineating the track crossing limits, including pavement and center line marking and coloring the road-rail track intersection area with reflective painting. A field study was conducted to validate design ideas suggested in the laboratory experiment. Three railroad crossings were selected at Hackensack, NJ for the field study. Video recordings were taken before and after the treatments were applied. Results of the field study showed that the grade crossing being treated with both grade crossing area painting and pavement marking showed significantly safer vehicular movements in terms of reduction of unsafe left turn and reduction of stop on track cases**.** Although it showed some reduction of unsafe driving behaviors, no statistical difference was found between pre-treatment and post-treatment conditions for the railroad crossing which was only treated with grade crossing area painting. Similarly, no significant reduction of unsafe driving behaviors was observed at the grade crossing where the recommended pavement marking was applied. Based on the current project, combining the two treatments showed the best results of minimizing potentially unsafe left turns at railroad crossings where roadways run parallel rail tracks.

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SUMMARY

The purpose of this project was to investigate the problem of vehicle entrapment at grade crossings due to attempts of making left turns to roadways which are parallel to the railroad. This project investigated selected highway-rail grade crossing on NJ TRANSIT's lines in New Jersey. Possible design ideas for solving such vehicle entrapment problems were examined using human subjects both in the lab and in the field.

The projects involved data analyses of accident records, development of an in-lab experiment for studying effect of design solutions to the performance of driver's roadway vs. railroad judgment, conducting the experiment, data analyses of the experiment, recommendations to the field validation study, selection of field study sites, conducting the field study using video cameras, data analyses for the field study, and recommendations to conclude the project.

Results from the laboratory experiment suggest that confusion of the drivers attempting to make left-turns at railroad crossings can be reduced by highlighting the grade area, including pavement and center line marking and coloring the road-rail track intersection area with reflective painting. A field study was conducted to validate design ideas suggested in the laboratory experiment. Three railroad crossings were selected at Hackensack, NJ for the field study. Video recordings were taken before and after the treatments were applied. The video recordings were taken place between October, 2002 and April, 2003.

Results of the field study showed that the grade crossing at Clinton Place had a superior performance comparing to the other two locations. Clinton Avenue, being treated with both grade crossing area painting and pavement marking, showed significantly safer vehicular movements in terms of reduction of unsafe left turn and reduction of stop on track cases. Although it showed some reduction in unsafe driving behaviors, no significant difference was observed between pre-treatment and post-treatment conditions for the Central Avenue grade crossing (treated with grade crossing area painting). Similarly, no significant reduction in unsafe driving behaviors was observed after the treatment was applied to the Euclid Avenue grade crossing (treated with pavement marking). Based on the current project, combining the two treatments showed the best results as evidenced by observations at Clinton Place and grade crossing areas painting alone (Central Avenue) or pavement marking only (Euclid Avenue). In order for the research team to expedite evaluating the effectiveness of the above mentioned treatments, reflective paint was applied to highlight railroad crossing surfaces in two locations. Although reflective paint on surfaces is believed to have equivalent effectiveness as compared with surface materials dyed with reflective paint, the latter is recommended by the research team for minimizing maintenance efforts.

The frequency and duration of observations are considered adequate for a typical field study. However, due to the low occurrence rate of unsafe left turn driving behaviors or its surrogate measures, the results of the current project should be interpreted carefully without overstating the outcome.

In addition to the potential risk of vehicles turning onto railroad tracks, the specific roadway/railroad configurations being investigated in the current project put a heavy mental workload on drivers of both roadway directions (perpendicular to the railroad tracks and parallel to the tracks). Drivers need to make quick and accurate decisions upon approaching and crossing the grade crossing. Although the problem of vehicle-to-vehicle collisions is not in the scope of this project, it is believed that there is a high incident rate of vehicle-to-vehicle or vehicle-to-pedestrian collisions in the specific roadway/railroad configurations. The assessment is evidenced by near misses of collision and many failure-to-yield cases observed in our field study. Based on the experience learned from the current project, the research team would suggest installing traffic lights at those grade crossings if eliminating those grade crossings is not feasible. The traffic lights should be installed throughout the entire section in order to ensure consistency of traffic controls in similar roadway/railroad configurations. Consistency and standardization is always beneficial to human users of any human-system interface, such as traffic controls being studied in this project.

INTRODUCTION

This project investigated the risk of vehicles turned onto tracks and were physically trapped on the tracks which occur at grade crossing where streets run parallel to railroad tracks and motorists make left turns across the tracks. The numbers of accidents at railroad grade crossings are found to be particularly high at places where streets run parallel to the railroad tracks. Motorists who make turns across the tracks to enter the road parallel to the tracks are sometimes confused and found entrapped on tracks. Research was needed in order to determine the perception of drivers upon driving through the intersection of the roadway parallel to the railroad tracks and the grade crossing and to investigate useful design solutions in order to minimize the potential risk of vehicles' entrapment on railroad tracks due to Improper left turns. Human factors research methods are suitable for the current project since the problem is related to human-system interface design issues. An in-lab experiment for investigating design solution and a field study for validating results from the in-lab experiment were conducted for the project.

BACKGROUND

Railroad crossings in urban areas in general pose a potential hazard for drivers on the road, even under the presence of warning signs and devices. NJ TRANSIT recorded a total of 91 accidents at railroad crossings in New Jersey between 1994 and 1998. All the crossings are equipped with either active or passive devices or a combination of both. The numbers of accidents at railroad grade crossings are found to be particularly high at places where streets run parallel to the railroad tracks. Motorists who make turns across the tracks to enter the road parallel to the tracks are sometimes confused and found entrapped on tracks. Existing railroad grade crossings on selected highway-rail grade crossings on NJ TRANSIT's lines in New Jersey were investigated for potential problems and studied for design solutions.

Basically, two types of devices exist for reducing the probability of vehicle accidents occurring at the grade crossings, namely active and passive devices. [(1)] Typical active devices are two-quadrant gate systems with flashing-light signals and bells [(2-4)]. Devices that use sensors [(5)] or video monitoring [(2)] for detecting vehicles being trapped at the grade crossing and applying a tolerable deceleration to the train are also considered as active devices. In terms of the cost of the devices themselves only, active devices were found to be more expensive than the passive devices in their initial cost and cost for maintenance. The Los Angeles Metro Blue Line investigated the feasibility of using four-quadrant gate systems, video graphics systems [(6)], and several other safety measures to minimize accidents. [(3)]

Computer simulation has been frequently used in laboratory experiments in transportation research. [7,8,9,10,11] Scenes are typically developed through 2D and 3D graphics in the simulation where the resolution and fidelity is limited. It is feasible to display scenes of the actual grade crossings in order to investigate problems of current display layouts and possible design solutions for such a unique rail-highway grade crossing configuration. The current research development is being considered in several other applications which also require evaluation and redesign of current display layouts.

The Los Angeles Metro Blue Line investigated the feasibility of using four-quadrant gate systems to minimize accidents. [3] The four-quadrant gate systems are used to prevent vehicles from attempting to pass through the grade crossing when the gates are activated. The idea is that there should be no chance for vehicles turning onto the railroad if the vehicles can not pass through the grade crossing when the train is passing. However, as soon as the train leaves and the gates are lifted, errors of being confused with the railroad and roadway can still exist. Besides, the high cost of installing and maintaining a four-quadrant gate system makes it unfavorable to be considered for solving the problem of vehicles entrapment on railroad tracks. [3]

Such accidents can happen when the drivers are confused between the railroad and the roadway, or that they try to go around the gate systems when they are already activated. [12] The former type of human error is related to incorrect human information processing [13], whereas the latter type is related to mainly aggressive driving behaviors and to a less degree of inability of controlling the vehicle under a high time pressure condition [14]. Solutions to these two types of error can be quite different. [15] It is important to investigate accident records [16] in the state of New Jersey to determine which type of errors attribute to the accidents of vehicles making left turn at the crossing.

IN-LAB EXPERIMENT

This project involves both in-lab and field experiments to evaluate design solutions for minimizing the risk of vehicle entrapment occurrence on railroad tracks where roadways are closely parallel to the railroad. An in-lab experiment was conducted to investigate possible design solutions to be implemented in the field study.

Methods

Human subjects, namely the vehicle drivers, were tested for identifying design solution(s). Computer simulation was used in the laboratory experiments similar to other studies. [7, 8, 9, 10, 11]

An extensive review of literature and railroad accident reports was conducted to identify possible direct and indirect causes of those accidents that involved vehicle entrapment on the railroad crossings due to left turns. The review helped to generate design ideas for solving technical problems and modifying driver behavior patterns.

A simulation was developed using real images retouched in Adobe Photoshop® and controlled by Java® programming as shown in Figure 1. The background images of the simulation were taken from different railroad crossings in Long Branch, Asbury Park, Belmar (North Jersey Coast Line at Monmouth County), and Hackensack (Pascack Valley Line at Bergen County). An In-lab experiment was conducted for identifying effective design solutions.

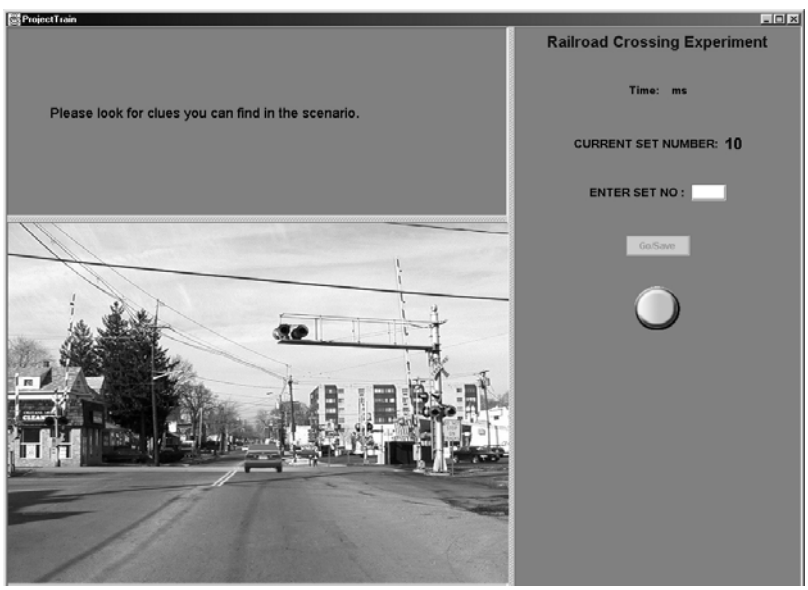


Figure 1. A view of Simulation developed in Java.

Development of Design Ideas

Based on accident records, critical factors were identified for directing design guidelines. Possible design ideas were then selected from existing research studies [17, 18, 19, 20, 21, 22] and were also generated by brainstorming of the research team. The design ideas were strictly scrutinized to check if the ideas answer the effects described above. Existing standards and issues in standardization were also reviewed in order to integrate the developed design ideas into the overall NJ Transit standards. [23] The selected design ideas were combined in various ways based on the experimental design and the geographical conditions of the selected crossings.

Development of Visual Presentation

Still images were taken from four different cities in New Jersey namely, Asbury Park, Belmar, Hackensack and Long Branch. Those cities were selected based on the frequency of reported vehicle entrapment records from NJ Transit. The images were taken at every interval of 10 meters (from 10 meters up to 150 meters) using a 3-CCD Sony® digital camera (640 x 480 resolution). Three images from the appropriate distance of each location were selected for the in-lab experiment. The first image selected was 120 meters from the grade crossing (the farthest one); the second image was either 80 or 90 meters from the grade crossing depending on the background settings and on the appropriateness of the images. The last image was either 20 or 30 meters, depending on the perspective of the pictures, from the grade crossing.

Images selected for the experiment were processed in great detail to incorporate the generated design ideas. Firstly, the selected images were treated as backgrounds and some changes were made to get the overall effect desired. Secondly, each design idea was individually created in layers for each image in Photoshop. The original background and the superimposed design ideas were compressed to a single layer. Images taken during daytime were also processed separately as mentioned above to get the nighttime images.

The images taken from actual railroad crossings are processed digitally using Photoshop® to achieve similar brightness and contrast. The images are later superimposed by design ideas and used as background in the experiment. The design ideas are saved as layers in Photoshop® and then merged as needed for producing backgrounds. The final images are converted to “jpeg” format in order to reduce the size of images. For example, the image in Figure 2 shows an original image followed by an image superimposed with the surface treatment design idea (see Figure 3).

The in-lab experiment uses a static background-moving vehicle display mode and records subject’s reaction time and error rate while watching the simulated car movement. The approach was decided mainly due to practical constraints of recording video footages from a moving vehicle and subsequent video editing for superimposing design features.

Figure 2. A background image taken from an actual railroad crossing without design features superimposed.

Figure 3. The same background as in Figure 2 now it is retouched by superimposing a distinctive surface treatment to the grade crossing.

The analysis of accident data found that the number of accidents was significantly higher at nighttime than during daytime, even without trying to normalize the accident rate with the traffic volume. Therefore the study addresses the nighttime visibility issues. Some design solutions like the delineators and surface treatment for example, gave the driver an idea of where the road was located and assist the drivers in making proper decisions as shown in Figure 4. The number of accidents during winter months was significantly higher than the rest of the year. It suggests that weather conditions like snow, frost and fog may hinder the visibility of driver leading to miss the grade crossing boundary.

Figure 4. A nighttime background image superimposed with reflective delineators.

Computer Programming

The virtual railroad crossing was simulated in Java as an application. Each trial contains 30 images of the car in different coordinates and sizes. The images were displayed at a rate of 10 frames per second, which depicted a moving car on the road. The car can go straight or make a proper or an improper turn. Subjects responded by pressing a “green button” if they felt that the car had passed the crossing properly or responded by pressing the “red” button if they detected the car made an improper turn. The experiment includes “catch trials” which are normal intersections without any grade crossing or specific features to ensure that subjects do not attempt to guess.

Apparatus

The equipment utilized for the experiment was a PC (Pentium III 1000 MHz) along with a standard keyboard, mouse and loudspeakers. The images were displayed on a screen using a computer projector (Epson Powerlite 7250). The projected image on a screen was 72 inches diagonal in size. The subject was positioned 9 feet from the screen.

Subjects

There were 28 subjects, 14 males and 14 females, recruited for this experiment. All subjects were New Jersey residents with a valid driver's license. Other demographic factors such as educational background, driving experience, and driving records, although not analyzed in the current study, were obtained in the in-lab experiments for future data analyses.

Procedure

Subjects were given practice trials prior to the experiment and the order of trial sets were counter-balanced between subjects. The first scene showed an image taken from 80-90 meters away from railroad crossing for 3 seconds. The second scene showed an image taken from 60-70 meters away from the crossing depending on the surroundings and road. The second image had possible design ideas that might indicate a railroad crossing. Subjects looked carefully and identified any clues or no clue can be found that might indicate a railroad crossing. After six seconds the second image disappeared and a list of possible clues were presented for subjects to choose.

In the next step, subject can start the simulation by pressing space bar of the keyboard. The car can take any one of the following three possible routes. First, the car can go straight which is a proper pass. Second, the car can make a turn to the road parallel to the tracks, which was also a proper pass. Lastly, the car can turn on to the tracks, which represents an improper pass. Subjects gave their responses (proper and improper passes) by pressing either the red or green button indicating improper and proper turn respectively. Figure 5 depicts the flow of the experiment.

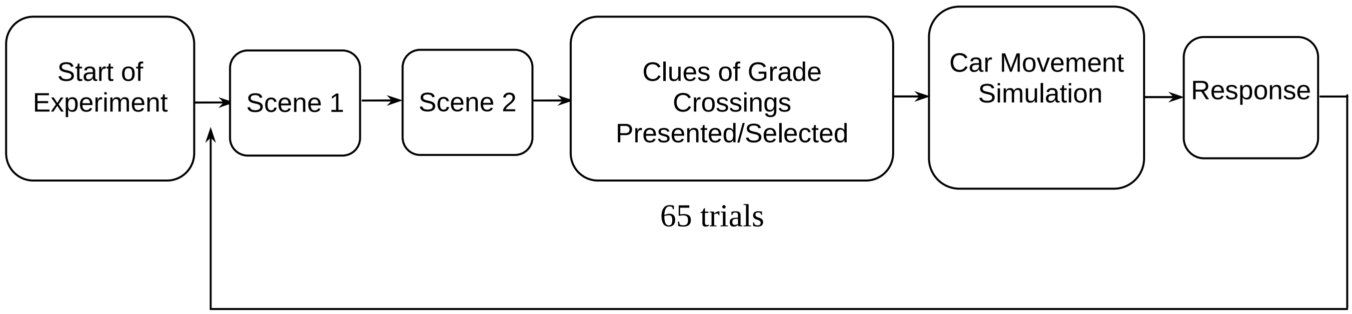


Figure 5. Experiment procedure in sequence of steps

Experimental Design

Each subject performs trials of the simulated task in different orders to counterbalance and cancel out transfer effects. The data is recorded while subjects perform the task and no feedback is provided to the subjects regarding their performance. The data recorded are errors and reaction times where misjudgment or misidentification of clues indicating railroad crossings is defined as an error. Reaction time is the time it takes to hit the response key after either the car safely passes all railroad tracks or turns over to the tracks.

Results and Discussion

The accident records from the NJ Transit provided information about year of the accident, date and time of the incident, incident finish time, time taken to remove the vehicle from tracks, location of the accident (street) and the town where the accident occurred. It showed that there were a total of 91 accidents in the four-year period. Some data in the records are found to be missing resulting in inconsistent totals in individual analysis discussed below.

The accident data indicated that four locations out of the 30 odd locations contributed approximately 40 percent of the total accidents as shown in Table 1. The Chi-square analysis revealed that the average number of accidents in the four cities were significantly higher than the average of other cities in New Jersey ($\chi^2 = 71.15$, $p < .01$). Records of the accidents indicated another critical factor, the visibility effect. Data indicated that 55 out of 90 accidents occurred during the night (5:30 pm to 6:30 am from October to March and 7:30 pm to 6:30 am from April to September months) as shown in Table 1. The difference between the numbers of accidents occurred during the day and during the night is significant ($\chi^2 = 4.4$, $p < .05$). It also showed that the winter season (December, January, and February) had a higher percentage (42.7%) of such accidents than the rest of the year. Accident rate (number of accidents per month) during the winter was found to be significantly higher than the rest of the year ($\chi^2 = 14.87$, $p < .01$) as shown in Table 1. On the other hand, no significant difference was found between the accident occurred during the peak hour period (6am - 9am and 4pm - 7pm) and during the rest of the day based on a Chi-square analysis ($\chi^2 = 0.02$, $p > .05$). Data indicated that 22 accidents out 86 accidents occurred during the six hours of peak time, comparing to 64 accidents occurred during the other 18 hours.

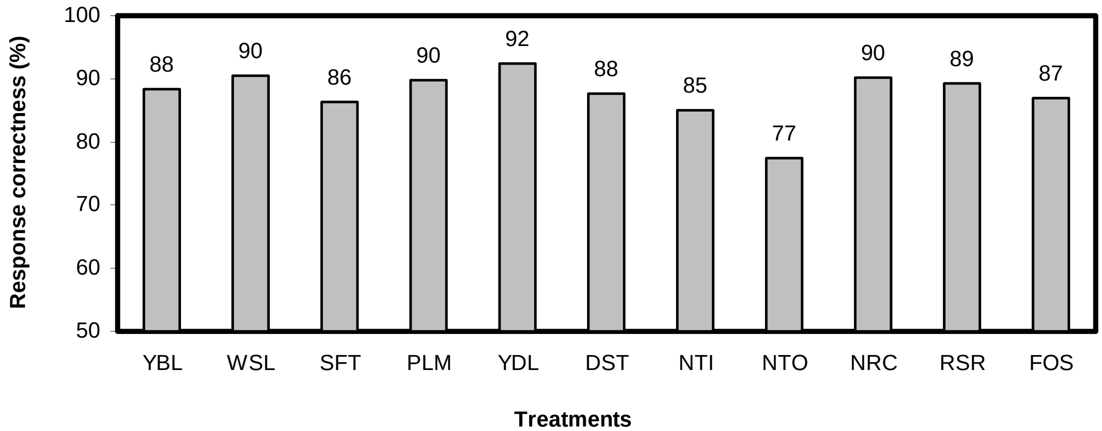
Table 1. Comparisons of Number of accidents for (a) the four cities and the rest of the cities, (b) daytime and nighttime, (c) winter and rest of year, (d) peak hours and rest of day. The numbers of accidents are adjusted proportionally. For example, the four cities account for 12% of total number of cities but had 40% of total number of accidents.

Comparisons	Number of Accidents	Theoretical Value	Total	χ^2 value	*p* value
Four Cities	36	45.5	91	71.14	$p < .01$
Rest of Cities	55	45.5			
Daytime	35	45.0	90	4.44	$p < .05$
Nighttime	55	45.0			
Winter	38	22.3	89	14.87	$p < .01$
Rest of Year	51	66.7			
Peak Hours	22	21.5	86	0.02	$p > .05$
Rest of Day	64	64.5			

Fourteen locations from four cities were identified and used in the study based on the maximum number of accidents for a location. Photographs and video shots of the locations were taken and the driver behavior as well as the crossing traffic was studied. The photo images were carefully analyzed and the design ideas were superimposed on the original images according to the experimental design.

A total of 65 sets of background images were generated based on the 14 locations. They included 52 sets of daytime conditions and 13 nighttime scenarios. There were 6 sets which were images taken from the actual locations without any additional treatment superimposed. Eight sets of backgrounds which contained no railroad crossings were used as catch trials for discouraging subjects from guessing. The design ideas or treatments include *yellow full barrier line, white solid line* for road boundary, grade crossing *surface treatment, pavement left turn intersection marking, reflective yellow delineators, "Do Not Stop On Tracks"* warning sign, *rumble strips,* and *flash/on-track sensors.*

Subjects' responses, in terms of percent correctness, to different treatments in the car movement judgment task were presented in Figure 6. There was a significant performance difference among the treatments ($F_{(10, 297)} = 2.18$, $p < .05$). A *post hoc* analysis using Duncan's multiple range test indicated that subject's performance in scenarios where original grade crossings were used was significantly lower than in scenarios where additional treatments were superimposed onto the original background (*p* < *.05*). Further analyses found that surface treatment, including yellow barrier line and the white solid line for defining road boundaries, and grade crossing surface treatment were particularly superior comparing to the rest of the treatments.



YBL-	Yellow Barrier Line	WSL-	White Solid Line
SFT-	Surface Treatment	PLM-	Pavement Left Turn Marking
YDL-	Reflective Yellow Delineators	DST-	Do Not Stop On Tracks
NTI-	Night Time Images	NTO-	No Treatment (Original)
NRC-	No Railroad Crossing	RSR-	Rumble Strips on Road
FOS-	Flash/On-Track Sensors		

Figure 6. Percentage of Correct response for each treatment type

Results of the in-lab experiment indicate that use of actual images superimposed with possible design ideas is a feasible approach of evaluating and redesigning display layouts for existing transportation problems. A field study was conducted after the completion of the in-lab study, which reveals effective solutions to the unique vehicle entrapment problem that occurred at the railroad crossings.

FIELD VALIDATION STUDY

A field study was conducted in order to investigate the validity of those design solutions suggested from the laboratory experiment. Since there are two items, namely pavement and center line marking and railroad crossing highlighting, recommended for implementation, the research team discussed about candidate sites with Mr. Vogler of NJ Transit. Three grade crossings at Hackensack, NJ were chosen for the field study. They are locations on the NJ Transit Pascack Valley Line at Central Avenue, Euclid Avenue, and Clinton Place (see Figure 7.). At each crossing at least one side of the road runs parallel to the railroad tracks.

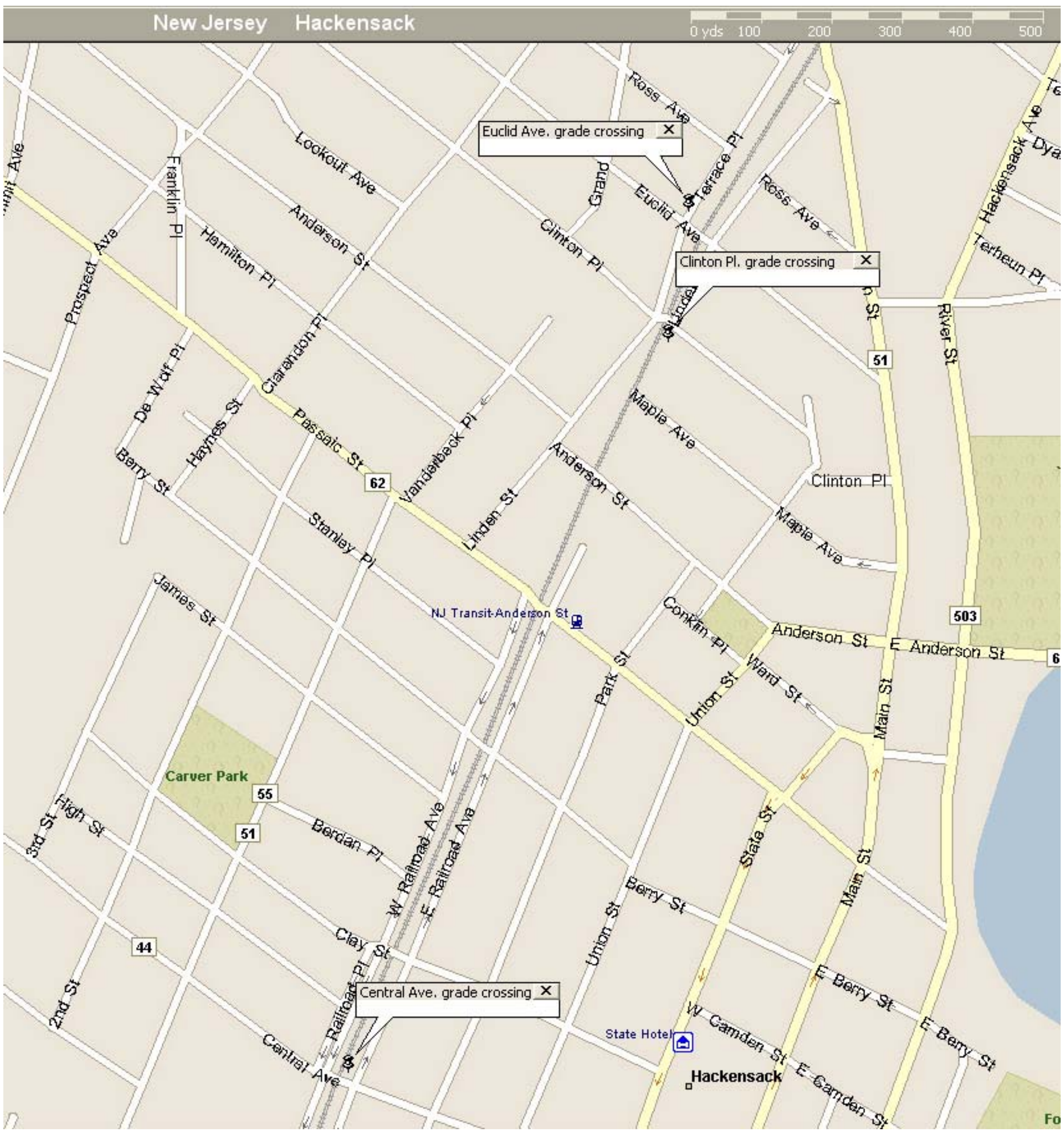


Figure 7. Ariel view of the three grad crossings at Hackensack, NJ for the filed evaluation study.

Methods

The research team conducted a field study, using video cameras to record vehicular movement behavior, for comparing treatment effects before and after the treatments were implemented.

Apparatus

A SONY PD-100A 3-CCD digital camcorder and a Ricoh R18-H Hi-8 camcorder were used for the field study. The video tapes were transferred to standard VHS tapes for review.

Procedure

Each of the three grade crossings is applied with different treatments for subsequent comparisons and contrasts about the treatment effects (See Table 2). The treatments on the three grade crossings are

(1) Central Avenue- railroad tracks/road intersection painting (*Area Painting*) (see Figure 8 for a plan view and Figure 9 for actual photos of before and after treatments),

(2) Euclid Avenue- Pavement and center line marking (*Pavement Marking*) (see Figure 10 for a plan view and Figure 11 for actual photos of before and after treatments), and

(3) Clinton Place- both *Area Painting* and *Pavement Marking* (see Figure 12 for a plan view and Figure 13 for actual photos of before and after treatments).

Table 2. Treatments for the three grade crossings at Hackensack, NJ.

Location	**Treatments**
Central Avenue	Area Painting
Euclid Avenue	Pavement Marking
Clinton Place	Area Painting + Pavement Marking

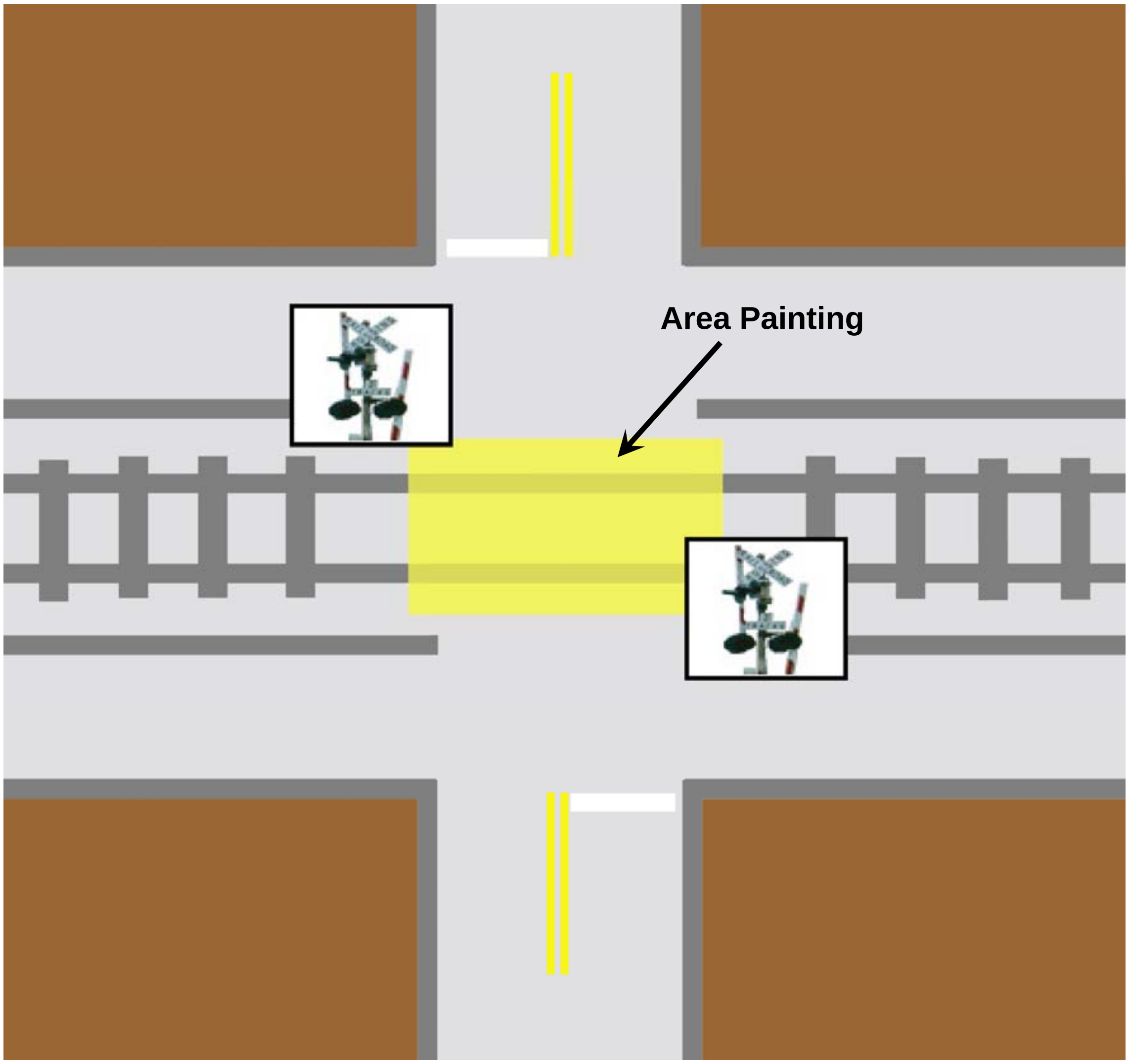


Figure 8. Plan view of treatments (area painting) at the Central Avenue grade crossing.

(a) Central Avenue- Before Treatment

(b) Central Avenue- After Treatment

Figure 9. Photos taken at the Central Avenue grade crossing.

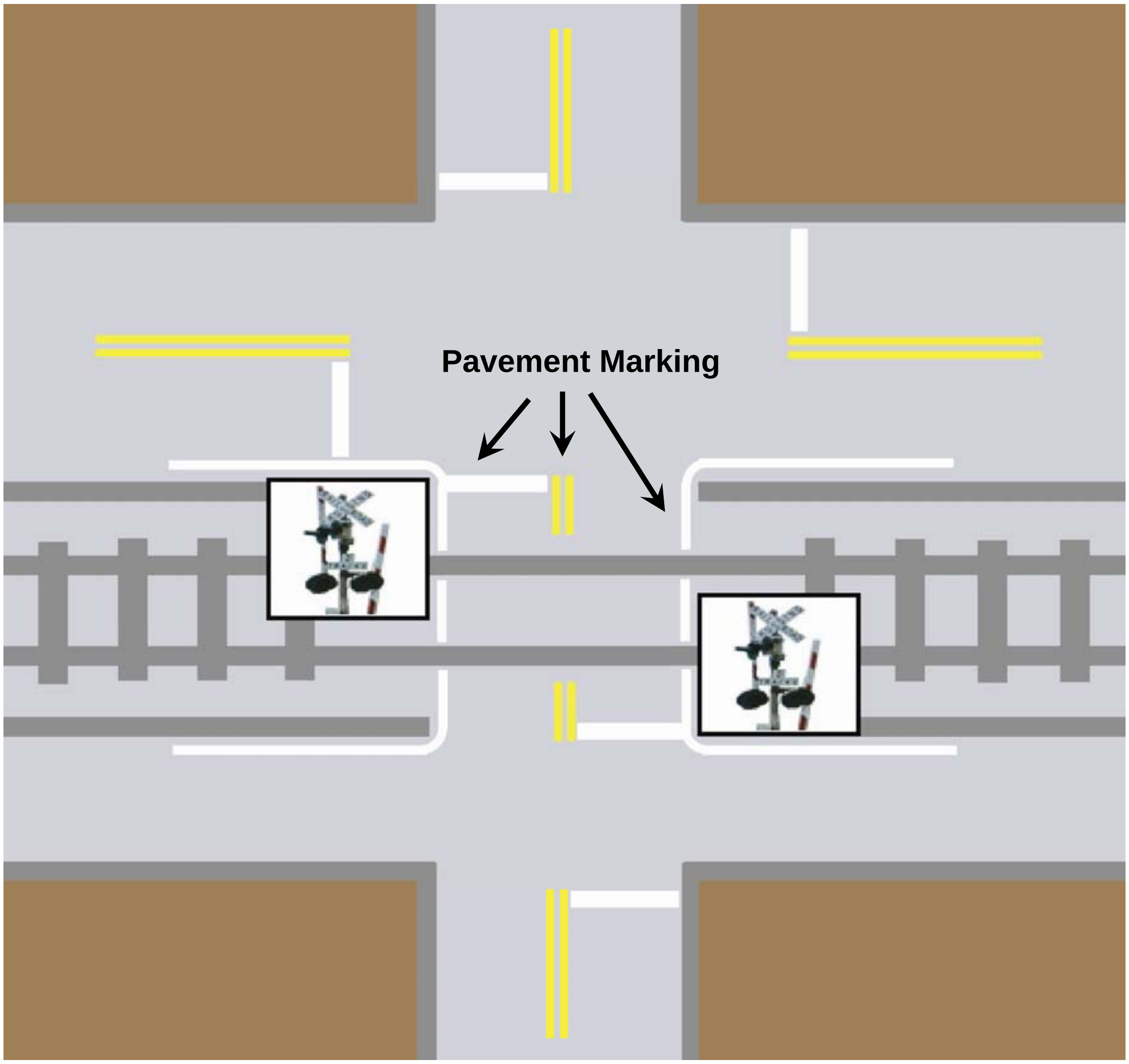


Figure 10. Plan view of treatments (pavement marking) at the Euclid Avenue grade crossing.

(a) Euclid Avenue- Before Treatment

(b) Euclid Avenue- After Treatment

Figure 11. Photos taken at the Euclid Avenue grade crossing.

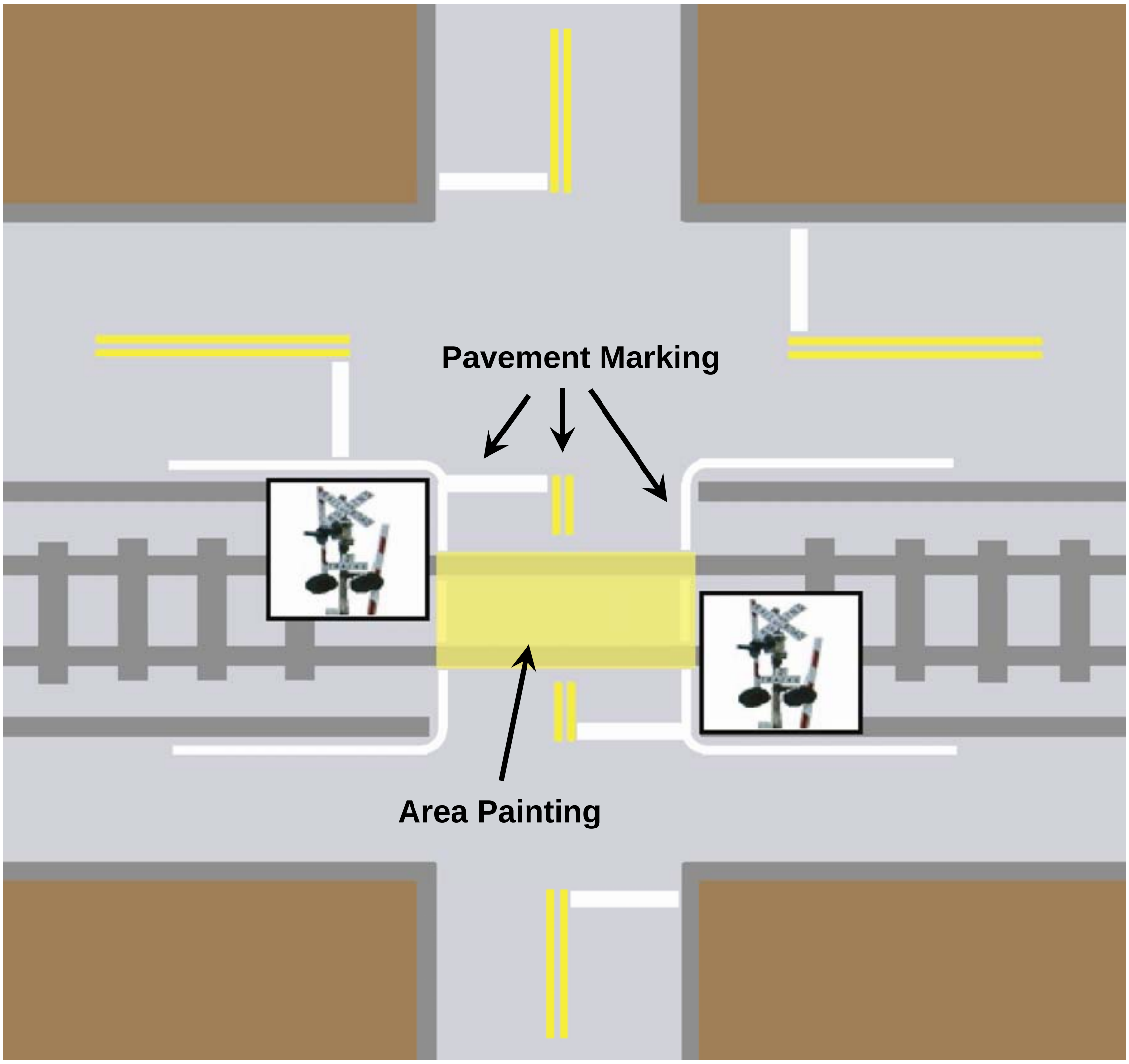


Figure 12. Plan view of treatments (area painting and pavement marking) at the Clinton Place grade crossing.

(a) Clinton Place- Before Treatment

(b) Clinton Place- After Treatment

Figure 13. Photos taken at the Clinton Place grade crossing.

The before-treatment video recordings were taken from October 24 to November 15. 2003. Due to inclement weather in the winter of 2002-2003, the painting at railroad crossing and pavement marking was delayed. NJ Transit hired a contractor in early January, 2003 to do the painting. The temperature continued to stay below 40 degrees Fahrenheit until March. In order to avoid potential risks of equipment damage due to low temperature and/or precipitation, the after-treatment video recording was not started until mid March. The post-treatment video recordings started on March 19 and completed on April 25, 2003. Each grade crossing site was video taped four times, each last two hours, for the before-treatment condition as well as for the after-treatment condition. Both day time and night time recordings were obtained for each site.

Five trained reviewers participated in reviewing the video tapes. The reviewers were trained by the principal investigator who instructed them what to observe in the tape. Each videotape was reviewed by two reviewers for observation reliability. The videotapes were first reviewed by the reviewers to determine the total traffic volume of vehicles traveling across the grade crossing, across the intersection next to the grade crossing from either directions where the road is parallel to the railroad tracks, or making turns after passing the grade crossing.

After obtaining the traffic volume, the videotape was again reviewed for studying vehicular movement behaviors. Reviewers were instructed to focus on “surrogate measures” as oppose to observe near misses or actual vehicular entrapment on railroad tracks due to improper turns, due to low incident rate of such cases. Surrogate measures are commonly used in traffic safety research for predicting the severity of problems without obtaining actual accident cases. The surrogate measures used in the current project include abnormal turning curves, improper brakes-hesitation upon crossing railroad tracks, stop on railroad tracks. Other driving maneuvers were recorded which include inverse S turnings and failure to yield by vehicles running on the roads parallel to the railroad tracks. Inverse S turnings of vehicles occur when they initially run on the road parallel to the railroad track(s), turn at the grade crossings, then proceed with another turn onto the road parallel to the railroad tracks.

Results and Discussion

Since there are different traffic volumes at different grade crossings, the observations were normalized by the total traffic volume to become percentages for each of the three grade crossings. Summary results are shown in Table 3. There were four durations of observations on each of the three grade crossing locations. Two video recordings were taken during the day and two were at night for each location. It is obvious that the traffic volumes are dependent on the location and the time ($p<.05$).

Table 3. Summary results of unsafe driving behaviors (in percentage) observed in the field study-before and after treatment.

Location	Observations	Pre-Treatment Mean *(S.D.)*	Post-Treatment Mean *(S.D.)*	Changes (%)
Central Ave. †	Unsafe left turn	0.24 (*0.48*)	0.00 (*0.00*)	-100
	Improper brake- Hesitation	0.43 (*0.22*)	0.25 (*0.29*)	-42
	Stop on track(s)	2.39 (*1.22*)	1.91 (*0.60*)	-20
	Other vehicles failure to yield	1.97 (*1.21)*	2.19 (*0.96*)	11
Euclid Ave. †	Unsafe left turn	0.18 (*0.35*)	0.13 (*0.26*)	-26
	Improper brake- Hesitation	2.29 (*1.54*)	2.88 (*3.31*)	26
	Stop on track(s)	0.95 (*0.73*)	0.73 (*0.84*)	-23
	Other vehicles failure to yield	3.50 (*2.40*)	6.37 (*3.75*)	82*
Clinton Pl. †	Unsafe left turn	1.04 (*1.06*)	0.31 (*0.38*)	-70*
	Improper brake- Hesitation	4.41 (*2.25*)	4.18 (*1.71*)	-5
	Stop on track(s)	3.35 (*2.41*)	1.43 (*0.91*)	-57**
	Other vehicles failure to yield	7.42 (*7.00*)	6.86 (*3.90*)	-8

* $p < .05$; ** $p < .01$

† Central Avenue was treated with grade crossing area painting; Euclid Avenue was treated with pavement marking; Clinton Avenue was treated with both grade crossing area painting and pavement marking.

Using the Chi Square statistical analysis, the observations were tested for overall pre-and-post treatment effects, as well as the pre-and-post treatment effects for each grade crossing. There were 11 out of 3,187 vehicles making sharp (small radius) left turns at the grade crossings in the pre-treatment video recordings. For the post-treatment video recordings there were 4 out of 2,679 vehicles showing such improper left turns at the grade crossings. Chi Square statistics did not indicate an overall significant difference between pre-treatment and post-treatment observations (*p* was close to .1), despite a 69% reduction of unsafe left turns from pre-treatment to post-treatment observations. When tested each individual grade crossing area, Clinton Place showed a significant reduction of unsafe left turns from the pre-treatment observations to the post-treatment observations (p <.05). The unsafe left turns were reduced by 70%. The grade crossing area at Clinton Place was treated with railroad tracks/roadway area highlight (reflective paint) and pavement marking (see Figure 13). There were no significant differences observed between pre-treatment and post-treatment observations pertaining to unsafe left turns at the Central Ave. or the Euclid Ave.

crossings. The results that no significant differences were observed should be interpreted carefully since the occurrence of unsafe left turns was less than 0.25% before and after the treatment at both locations.

Since the objective of the current project was to investigate design solutions for reducing the problem of vehicular entrapment at the railroad crossings due to improper left turns, it was hypothesized that signs of driver confusion can be surrogate measures before vehicles actually turn onto the railroad tracks. From a system safety point of view, signs of confusion before actual accidents are such as when drivers: (1) make sharp (improperly small radius) left turns, (2) change vehicle turning directions abruptly, or (3) do not know the exact location of the railroad tracks therefore apply brakes and hesitate upon crossing the railroad tracks.

It is a common problem of vehicles stopping on tracks at grade crossings where roadways run parallel to railroad tracks. Although no extra "Do Not Stop on Track" signs were installed for the current project, comparisons were made between pre-treatment and post-treatment observations on occurrence of vehicles stopping on tracks. There was a significant reduction of vehicle stop on track cases in the post-treatment observations than in the pre-treatment observations for the overall three grade crossings ($p<.05$). The percentage of vehicles stopping on tracks dropped from 2.23% in the pre-treatment observations to 1.53% in the post-treatment observations. The percent reduction was 31%. In terms of individual grade crossing, Clinton Place showed a significant reduction of vehicle stopped on track cases ($p<.01$), down from 3.35% in the pre-treatment observations to 1.49% in the post-treatment observations. Neither Central Avenue nor Euclid Avenue had significant difference between pre and post treatment observations on their vehicle stop on track cases ($p>.05$).

The roadway system at the field study site is configured such that vehicles on roadways which are perpendicular to the railroad tracks always have the right of way at the intersections as opposed to vehicles on the roadways which run parallel to the railroad tracks. Those intersections are adjacent to the grade crossings. The traffic is guided by stop signs for vehicles on the roadways running paralleled to the railroad tracks. A concern was raised whether the white pavement marking (parallel the rail track, see Fig. 11(b), 13(b)), which is used commonly in conjunction with stop signs and traffic lights, may have induced drivers to apply brakes unnecessarily, hence causing confusion although they have the right of way to the vehicles running on roadways parallel to the tracks. Neither the overall three grade crossing locations nor the individual location was found for any significant difference in driver's hesitation or stopping the vehicle upon passing the grade crossings before and after the treatments ($p>.05$). It should be noted that although no significant difference was found, Euclid Avenue showed some increase in driver's hesitation or stopping the vehicle, from 2.29% in the pre-treatment observations to 2.88% in the post-treatment observations.

In addition to focusing on vehicles traveling through the grade crossings, the research team also studied the driver's behaviors of vehicles running on the roadway parallel to the railroad tracks, i.e. perpendicular to the roadway intersecting the tracks. Throughout the entire project it was observed that vehicles running on the roadways parallel to the tracks frequently failed to yield to vehicles on the road perpendicular to rail tracks. Local residents and policemen had indicated to the research team that numerous vehicle-to-vehicle collisions, due to the failure-to-yield problem, had occurred at those intersections at Hackensack. It might be due to drivers who were traveling on the roadway next to the railroad perceived that driving on such a road was as continuous as the rail track without paying much attention to intersections and traffic signs- a misconception of the right-of-way. While trying to help driver's perception for vehicles crossing the grade crossings, the recommended treatments do not provide additional visual cues to drivers traveling on roadways parallel to the railroad tracks at the intersections next to the grade crossings.

Statistical comparisons were performed to investigate if there were differences in the frequency of *failure to yield* cases after the treatments were implemented. For Central Avenue and Clinton Place, there was no significant difference in frequencies of *failure to yield* cases observed between the pre-treatment and post-treatment observations ($p>.05$). The frequencies of *failure to yield* cases were around 2% at Central Avenue and 7% at Clinton Place. There is, however, a significant increase of frequency of *failure to yield* cases in the post-treatment observations. The frequency of *failure to yield* cases increased from 3.50% to 6.37% at Euclid Avenue ($p<.05$). Apparently it is unfavorable to implement a treatment which results in increasing risks of vehicle-to-vehicle collisions. Further investigation is needed to study why vehicles crossing the grade crossings were not observed with significant hesitations or stops after the treatments were implemented while vehicles running parallel to the railroad tracks more frequently failed to yield at the intersections adjacent to the Euclid Avenue grade crossing.

Based on the results of the field study, the three grade crossing locations which were treated differently showed some significant differences on the vehicular movement behaviors. Clinton Place, being treated with both grade crossing area painting and pavement marking, showed significantly safer vehicular movements in terms of reduction of unsafe left turn and reduction of stop on track cases. Although showed some reduction in unsafe driving behaviors, no statistical difference was observed between pre-treatment and post-treatment at the Central Avenue grade crossing (treated with grade crossing area painting). Similarly, no significant reduction of unsafe driving behaviors was observed at the Euclid Avenue grade crossings (treated with pavement marking). The cause of increased failure to yield cases in the post-treatment observations at Euclid Avenue is most likely due to the pavement marking (parallel to the rail track) on the roadway before the railroad tracks. The marking exists commonly at intersections where there are stop signs or traffic lights. It may have caused drivers to slow down or to stop when approach the grade crossing even thought they have the right of way at the intersection to vehicles from roadways parallel to the railroad tracks.

CONCLUSION AND RECOMMENDATIONS

The current project has demonstrated useful human factors research methods such as in-lab experiments and field observations in transportation safety research. Laboratory experiment resulted in two treatments recommended for the field study- grade crossing area painting and pavement marking. Although not tested in the field study, the pavement marking may be combined with reflective delineators to enhance the visibility at night. Field study proved to provide valuable validation information to the laboratory experiment.

Based on the results of the field study, Clinton Place showed a superior performance than the other two locations. Clinton Avenue, being treated with both grade crossing area painting and pavement marking, showed significantly safer vehicular movements in terms of reduction of unsafe left turn and reduction of stop on track cases. Although it showed some reduction in unsafe driving behaviors, no statistical difference was found between pre-treatment and post-treatment observations at the Central Avenue grade crossing (treated with grade crossing area painting). Similarly, no significant reduction of unsafe driving behaviors was observed at the Euclid Avenue grade crossing (treated with pavement marking) after the treatment was in place. The cause of increased failure to yield cases in the post-treatment observations at Euclid Avenue is most likely due to the pavement marking (parallel to the rail track) on the roadway before the railroad tracks (see Figure 13(b)). The marking commonly exists at intersections where there are stop signs or traffic lights. It may cause drivers to slow down or stop when approach the grade crossing even thought they have the right of way at the intersection. Consequently it may induce drivers on the roadways parallel to the railroad tracks fail to yield. Based on the current project, it is concluded that the white bar (parallel to the rail track) should be removed from the pavement marking recommendation. Combining the two treatments showed the best results, as evidenced by observations at Clinton Place, comparing to grade crossing area painting alone (Central Avenue) or pavement marking only (Euclid Avenue). In order for the research team to expedite evaluating the effectiveness of the above mentioned treatments, reflective paint was applied to highlight railroad crossing surfaces in two locations. Although reflective paint on surfaces is believed to have equivalent effectiveness as compared with surface materials dyed with reflective paint, the latter is recommended by the research team for minimizing maintenance efforts.

The frequency and duration of observations are considered adequate for a typical field study. However, due to the low occurrence rate of unsafe left turn driving behavior or its surrogate measures, the results of the current project should be interpreted carefully without overstating the outcome.

In addition to the potential risk of vehicles turning onto railroad tracks, the specific roadway/railroad configurations being investigated in the current project put a heavy mental workload on drivers of both roadway directions (perpendicular to the railroad tracks and parallel to the tracks). Drivers need to make quick and accurate decisions upon approaching and crossing the grade crossing. Although the problem of vehicle-to-vehicle collisions is not in the scope of this project, it is believed that there is a high incident rate of vehicle-to-vehicle or vehicle-to-pedestrian collisions in the specific roadway/railroad configurations. The assessment is evidenced by near misses of collision and many failure-to-yield cases observed in our field study. Based on the experience learned from the current project, the research team would suggest install traffic lights at those grade crossings. The traffic lights should be installed throughout the entire section in order to ensure consistency of traffic controls in similar roadway/railroad configurations. Consistency and standardization is always beneficial to human users of any human-system interface, including traffic controls.

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