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Research

# Effectiveness of Marketing Campaigns for Grade Crossing Safety

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# **Effectiveness of Marketing Campaigns for Grade Crossing Safety**

**Final Report**

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The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Minnesota Department of Transportation.



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## Executive Summary

This is the final report for this project which examined grade crossing safety and human factors through focus groups, a telephone survey, a literature review and, in this report, an analysis based chiefly on a new approach stated by Neil Lerner [1]. Lerner noted that drivers should not be treated as reckless, inattentive speeders. Instead they should be thought of as *decision makers* who are using information of limited quantity and quality against a background of knowledge shaped primarily by the experience that trains are only very rarely at grade crossings when the driver is also at the grade crossing.

We found no evidence that additional education programs or public awareness campaigns had any lasting effect on the frequency of grade crossing accidents. We found no evidence suggesting that bigger or brighter or other modifications of traditional signs or signals led to favorable changes in drivers' behaviors at grade crossings.

We concluded that using available sensor-processor-message display technology, configured in a way to promote improved driver decision making, offers the potential for grade crossing accident reduction. Our recommendation is to support additional research to investigate this potential for grade crossing accident reduction implicit in our conclusion.



# Introduction

This is the final report from the Human Factors Research Laboratory (HFRL) for the project “Effectiveness of Marketing Campaigns for Grade Crossing Safety.” Previous reports for this Project were a Literature Review And Analysis, the results of focus group studies and the results of a telephone survey. The focus group and survey reports were prepared and submitted by C.J. Olson, Market Research Inc. This report focuses on one finding in the literature review of Task 1. That finding was suggested by Neil Lerner in a lengthy analysis of grade crossing safety published in 1991 [1].

## ***Objective And Scope***

The object of this report is to explore the meaning and consequences of drivers’ expectations about the safety of grade crossings which they approach. This report focuses on aspects of drivers’ *decision making behavior* related to signs, signals, gates, crossing geometries and visibility distances, vehicle malfunctions and the like rather than the purely engineering aspects of these factors. For example, the round **RXR** warning sign simply states that there is a grade crossing ahead. There is no information about the distance from the crossing or the presence or approach of a train, or whether there is an active warning device at the crossing, or the visibility of the crossing. There are many obvious engineering implications of the foregoing. However, in this report we are concerned with how such factors affect drivers decision making abilities. In addition we are concerned with drivers’ behaviors with respect to grade crossings which are not determined or altered by intoxication, greatly reduced visibility or other extreme and unusual conditions. We are primarily concerned with drivers’ decision making behavior with respect to grade crossings. We only consider typical drivers in typical circumstances. The findings from the literature related to such issues are discussed in Appendix A which includes references added since the Task 1 report was submitted.

## ***Problem Description And Background***

The problem underlying this project was the large number of accidents which occurred at grade crossings. In 1995 there were more than 600 deaths at grade crossings in the US. There is a collision between a car and a train about every 90 minutes. There seemed to be no single reason for the large number of accidents. Post and Lumenfeld [2] developed the Positive Guidance Model which suggested factors which might, to various extents, impose demands on drivers which could contribute to grade crossing accidents. These demands were categorized as: perceptual and cognitive involving seeing, comprehending and decision making. This model

focused on the driver's process of acquiring and using needed information. Five information handling zones were defined: The advance zone which preceded the demands of the hazard; the approach zone which was defined by the decision sight distance, the non-recovery zone which was primarily defined by the stopping distance, the hazard zone (about 15 feet from the nearest track) and the downstream zone which was beyond the hazard.

In an excellent review of grade crossing safety studies Lerner [1] stated that the commonly accepted reasons for drivers' involvement in grade crossing accidents were inattention, inappropriate speed, unnecessary risk-taking, and disregard of signs and signals. Thus accidents were completely assignable to avoidable driver error. Lerner [1] presented a different view. In his view drivers are reasonable and rational, if imperfect, decision makers who are trying to optimize their situation based on prior knowledge and the facts at hand. Drivers bring to this decision making task a body of valid experience so they are not completely relying on information provided at or near the crossing. Drivers are usually familiar with all aspects of the crossing such as geometry, sight distances, signs and signals. In spite of this familiarity, and occasionally because of familiarity, the driver's decision making task is complex and subject to many sources of error.

If a train is seen in the distance, drivers must use the information at hand in deciding whether or not to cross the tracks. Drivers must estimate their distance and the train's distance from the crossing, the train's speed and time to arrival at the crossing, and their own time to arrival. This perceptual estimation problem can be aggravated by darkness, road-track geometries, sight distances and visibility conditions. The problem is made even more difficult by the looming phenomenon and the large object illusion. The problem can be alleviated by devices such as two quadrant gates (or even better, four quadrant gates), and active signals or electronically presented information (active advance warning devices) on roadside or in-vehicle displays. Based on such information of uncertain quality and limited quantity, drivers decide whether or not to risk crossing the track. (We assume that drivers understand the undesirability of the consequences of colliding with a train.) Predictably, some drivers fail to perform this difficult decision making task adequately.

# **Analysis of Driver Expectations of Grade Crossing Safety**

## ***Expectations Based on Prior Grade Crossing Experience***

This analysis addresses the remarkable fact that typical drivers in typical conditions collide with trains or allow trains to collide with them. It is reasonable to assume that drivers understand the serious and perhaps fatal outcome of such encounters. However, drivers explicitly or tacitly, realize that an accident at any particular crossing of the tracks is extremely unlikely. In fact Lerner pointed out that for an average level crossing, a driver could cross safely twice a day for fifteen years even if the driver was deaf and blind to everything but the pavement immediately in front of the car. Lerner [1] summarized: "At a personal level the relative importance of some benefits or costs may not be weighted the same as they would be from the perspective of a highway safety specialist; 'wrong' actions could thus result not from errors as much as from different decision criteria. Viewing the driver in this way, one can place potential safety treatments in the full context of the driver's decision making task."

This concept does not ignore factors such as inattention, inappropriate speed, unnecessary risk-taking, intoxication, and disregard of signs and signals but rather places them in the context of impairments to decision making. The alternative to Lerner's version of the causes of accidents at grade crossings is to admit and accept that each year hundreds of drivers will be inattentive, speed, take unnecessary risks and disregard signs and signals and have accidents involving trains. Until many more safety ideas have been tested, it is unwise to accept this fatalistic alternative.

If we accept Lerner's conclusion, then we can partially redefine the traffic engineers task. That is we must take whatever steps we can to suggest to drivers that the cost of an incorrect decision (an accident) far outweighs the benefit of a few minutes saved by not waiting for a train to vacate a crossing. We should do what we can to make the driver an extremely conservative decision maker.

The foregoing might seem to suggest that increased education on the hazards of grade crossings might improve drivers' decision making with respect to grade crossings. We could find no data to support the idea that increased education would cause drivers to become more conservative decision makers. However, in the focus groups which were a part of this project, many participants felt more formal education might be beneficial. Another possibility suggested by Lerner's conclusion, is that campaigns to increase public awareness of the dangers inherent in grade crossings might reduce accidents. However, Iowa studies [3], [4], showed that public awareness campaigns had only a briefly beneficial effect (for less than six months) in improving drivers' performance at grade crossings.

The issue we are addressing is how to improve drivers' decision making regarding grade crossing behavior. In general we know that decision making is enhanced by improving the timeliness, quality and quantity of information relevant to the decision making environment. The majority of information which most drivers have about grade crossings comes from prior experience with grade crossings. Most drivers are familiar with all aspects of grade crossings and in general they are especially familiar with those crossings which they use frequently. Advance warning signs, the round **RXR** signs, as well as the cross buck at the crossing, both signs with or without flashing yellow or red lights are completely familiar to drivers as are gates. We could speculate that these devices provide decision making drivers with an adequate quantity and quality of information. We could also speculate that adding more such signs and lights would not improve drivers' decision making. Indeed, in research discussed by Lerner [1] more signs or lights or modified versions of the familiar signs and lights provided little or no benefit. Perhaps we should depart from the familiar signing and lighting and venture one or more new concepts.

### ***Driver Expectancies Based on Grade Crossing Familiarity***

Drivers can be familiar with grade crossings in either a general or a particular sense. In general drivers are familiar with the signs, signals and gates associated with all grade crossings. In particular a driver may be familiar with a grade crossing because the driver crosses these tracks at least twice a day.

### **General Familiarity with Grade Crossings**

While it is difficult accept that drivers do not understand the meaning of the standard signs and signals which denote a grade crossing, some investigators have examined this question. In general drivers understand that the usual signs and signals mean that there is crossing nearby and that there may be a train present or approaching. However, detailed understanding is often lacking. Drivers may interpret the lack of an active signal at a crossing as meaning that it is safe to cross. Sanders et al. [5] interviewed over one thousand drivers just after they had driven over a grade crossing. At active crossings, 23% of drivers thought that all crossings had signals or gates. At passive crossings 15% also thought this. Tidwell and Humphreys' survey [6] at a license renewal site found that when applicants were shown a picture of a flashing signal array for a grade crossing, over half stated that the signal was rarely or never used. In a later study, Richards and Heatherington [7] found this figure to be 23%. In both these studies almost all drivers understood that flashing lights meant that a train was coming.

In spite of many studies related to detection and recognition of grade crossing signs and signals there was no evidence to show a clear correlation between drivers' understanding of signs

and signals and accident frequencies. For example, there was no evidence to show that just because many drivers incorrectly believe that the cross buck means “stop, look and listen” that these same drivers have more crossing-related accidents. We can only speculate that lack of understanding of the meaning of grade crossing signs and signals may contribute to accident occurrence.

We can also speculate that failure to understand that trains cannot make sudden collision avoidance maneuvers may contribute to accidents. In the Richards and Heatherington survey [7] 45% of respondents felt that when the train driver saw cars crossing the track, the train driver should slow or stop the train. About 10% of drivers did not know whether it took a greater distance to stop a train or a large truck. Based on such information it is not unreasonable to assume that drivers’ inability to estimate the time available to cross the tracks could lead to accidents.

The evidence shows that more and bigger, brighter signs and signals will not reduce grade crossing accidents. Unfortunately, the only proven methods for eliminating grade crossing accidents are to close the crossing or to use grade separation.

### **Familiarity with Particular Grade Crossings**

As noted above a driver paying no attention to a grade crossing, would be safe from a train collision for about 15 years when crossing twice a day. Presumably, if drivers devoted even a minimal amount of attention to safety at familiar grade crossings, their chances for survival beyond 15 years would be greatly increased. If we accept this assumption then we can state the familiarity problem as one of attracting the attention of frequent users of the grade crossing to the low but finite probability of vehicle-train collisions. Stated slightly differently, we need to identify methods which will alter drivers’ expectancies from not expecting a train to be coincident with their arrival at the crossing to an expectancy that there just might be a train at the crossing.

### ***Potential Aids to Decision Making***

To improve decision making not only must the quality, quantity and timeliness of the information be improved but the information must be presented in ways which attract the attention of even drivers who are completely familiar with the grade crossing and who know that trains are rarely at the crossing.

#### **Advance Warnings**

The round **RXR** warning sign is believable (the tracks in fact exist) but of very little value to the decision making driver. To drivers familiar with the particular intersection this sign is

especially easy to ignore. Off the shelf sensor-processor-message display technology can present statements of fact which are of high value to the decision maker. Speeds, distances and times can be sensed and accurate and concise information can be computed and given to the driver such as: A TRAIN IS AT THE INTERSECTION. SLOW AND STOP or A TRAIN WILL BE AT THE CROSSING BEFORE YOU WILL. SLOW AND STOP. If we assume that such information is given far enough in advance of the crossing, and that the displays are attention getting then the decision making task becomes simple and the outcomes predictably correct. We should further assume that the false alarm rates are very low and that the information in the displayed message is accurate. If drivers who receive warnings such as the above arrive at the crossing and no train is in evidence, then the displayed advice will come to be ignored. Lamkin [8] discussed the undesirable effects of false alarms while Lerner [1] discussed perceived reasonableness pointing out that drivers are more likely to obey signs and signals if they think they are reasonable.

In the study by Sanders et al. [5] 23 percent of drivers who had driven across an active crossing thought all crossings were active. In the type of messaging display envisaged above the display should not be blank. There should always be some message so drivers do not believe that the display is broken. To the extent possible there should be redundant elements so the displays are always functional. A message such as IT IS SAFE TO CROSS THE TRACKS could be displayed as appropriate.

Messages should be attention getting. Longer messages are permissible if displays are large and have good luminance contrast. Several, separated, smaller displays could be used to convey a single message (the Burma Shave approach). The meaning of the messages may not change but the words used to convey the messages can be changed to promote novelty which would reduce the effect of familiarity. The wording of the messages should be such as to have high impact on drivers. The round, warning **RXR** sign besides conveying almost no useful information has little impact. Bolder and more explicit messages could have a high impact on drivers. A message such as TRAINS KILL. TRAIN TRACKS IN 1000 FEET would have much more impact than the **RXR** sign. Adding information about presence or absence of lights and gates would add even more usefulness to the message. In a study by Stackhouse and Dewing [9] drivers stated that they wanted signs to contain much information, quantitative information and advice as appropriate. Highway work zones are similar to grade crossings in that the number of accidents per mile is disproportionately high. In a study of work zone human factors [10] one of the findings from focus groups was that drivers wanted more and better information presented in a way that would attract drivers' attention.

It requires only a fraction of a second for a vehicle to cross the tracks. Many drivers have shown that they are not willing to stop when the train is far enough away so that they believe they can easily beat the train to the crossing. That is, for continued compliance with the type of messages suggested above, it may be desirable to reduce the time interval considered to be safe between vehicle arrival and train arrival at the crossing. Drivers have shown that long periods of waiting before the actual arrival of the train led to ignoring flashing lights and driving around two quadrant gates. This is an example showing that erring on the “safe side” can actually promote risk-taking behavior.

Now that sensor-processor-message display devices are appearing, at least in prototype form, perhaps they can be used as an aide to driver decision making rather than just as a new way to put up a sign.



## Discussion of Liability Issues

The question of liability has been raised with regard to using any sort of sign message or signal which states or implies the imminent approach of a train. The concern is with equipment or power failure. If drivers who have become accustomed to an electronically presented message such as TRAIN APPROACHING, interpret the absence of this sign as meaning that there is no train in the vicinity, then a hazard has been created. There is a weak analogy between this case and the finding [5] that some drivers believe that there are signals at all grade crossings.

All mechanical and electrical systems fail from time to time. If the systems are critical, then there are two customary remedies. First, the system is able to detect its own failure or imminent failure and switch in a redundant element so that the system continues to operate. For example, when a flashing light is provided to warn of a highway intersection, two flashing lights may be supplied. If one fails, the other takes over. The second remedy is sometimes referred to as "fail safe." In fail safe mode the system continues to operate but in a degraded way. For example, during power failures, traffic signals may not operate in the usual manner but instead continuously flash red. Traffic flow is no longer maximized but the message that traffic is still moving in all directions following a stop, is still apparent. Redundancy and fail-safe solutions to the failure of the TRAIN APPROACHING sign could also be applied.

Another facet of the problem concerns the cost and magnitude of the benefit provided by the TRAIN APPROACHING sign. If the benefit is large, the decision might be made to undertake the cost of redundancy or fail safe operation. If the benefit is marginal, the slight improvement would probably not be implemented.

In-vehicle signing allows a message such as TRAIN APPROACHING to be presented only to vehicles willing to accept both the risks and benefits as well as a part of the cost. Some school buses may use this form of in-vehicle signing to warn of approaching trains at grade crossings.

In many cases of liability the issue is not whether the system failed but rather whether there were system design errors or whether there was negligence or whether there was sufficient diligence in performing tasks such as maintenance and inspection. For transportation systems, such as airlines, buses or commercial vehicle operations, we know in advance that there will be failures resulting in accidents. The fear of some form of legal liability does not cause us to abandon these systems; rather, it means that we should try to improve them by strengthening the weaknesses revealed by the accidents. Much the same case can be made for grade crossing systems of the kind discussed above

If the benefits of certain techniques such as the TRAIN APPROACHING sign were established through simulation and field trials, then such techniques could be bolstered with

redundancy or fail-safe measures and be widely deployed. We could anticipate that the liability issue would then fade to the same status prevailing for failed traffic signals. That is, if drivers are alerted to the fact that an unsafe condition exists, then drivers share a part of the responsibility for their own safety.

## **Conclusions And Recommendation**

It is unlikely that the problem of grade crossing accidents will be completely solved other than by closing the crossing or by grade separation. However, there is a possibility that the number of grade crossing accidents can be reduced.

In this report we concluded that one approach to reducing accidents begins by changing our perception of drivers. Generally we view drivers, particularly those involved in accidents, as inattentive, risk taking speeders. We should change our perspective and view drivers as decision makers with a strong set of expectations formed from long experience and familiarity with grade crossings. We should also consider the possibility that drivers approaching a grade crossing have only limited access to relevant information of adequate quantity and quality.

We found no evidence that additional education programs or public awareness campaigns have any lasting effect on the frequency of grade crossing accidents. We found no evidence suggesting that bigger or brighter or other modifications of traditional signs or signals led to favorable changes in drivers' behaviors at grade crossings.

We concluded that using available sensor-processor-message display technology, configured in a way to promote improved driver decision making, offers potential for grade crossing accident reduction. Our recommendation is to support additional research to investigate the implications of our conclusions.



## References

1. **Lerner, N. (1990).** *Driver behavior at rail-highway crossings.* Prepared by the Comsis Corp., Report No. FHWA-SA-90-008, Washington, D.C., Department of Transportation, Federal Highway Administration.
2. **Post, T.J. and Lumenfeld, H. (1981).** *A Users' Guide to Positive Guidance.* (2nd Ed.) Report No. FHWA-TO-81-1, Washington, D.C., Department of Transportation, Federal Highway Administration.
3. **Brewer, K. (1991).** *Drivers' behavior at railroad grade crossings: Before and after safety campaign.* Report on Iowa Department of Transportation Project HR-355, 27 pages.
4. **Iowa Department of Transportation. (1992).** Operation Lifesaver safety blitz follow-up study. Cerro Gordo County Iowa. Prepared by: Rail and Water Division, 12 pages.
5. **Sanders, J.H., Jr., Kolsrud, G.S. and Berger, W.G. (1973).** *Human factors countermeasures to improve highway-railway safety.* Report No. DOT-HS-800 888. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration..
6. **Tidwell, J.E., Jr., and Humphreys, J.B. (1981).** "Driver knowledge of grade-crossing information" (pp. 28-32). *Transportation Research Record*, 8d11. Washington, D.C.: Transportation Research Board.
7. **Richards, S.H. and Heatherington, K.W. (1988).** Motorists' understanding of railroad-highway grade crossing traffic control devices and associated traffic laws. Paper presented at the 67th annual meeting of The Transportation Research Board. Washington, D.C.
8. **Lamkin, J. (1985).** The Texas grade crossing signal notification program: Call 1-800. Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, MO, July 1985.
9. **Stackhouse, S. and Dewing, W. (1993).** *Following advice from traffic advisories.* Minnesota Department of Transportation Contractor Report.
10. **Stackhouse, S. and Tan A. (1996).** *Effective speed reduction in work zones.* Minnesota Department of Transportation Contractor Report.



## **Appendix A**

### **Literature Review And Analysis**



## Literature Review and Analysis

### ***Introduction:***

The following are references and brief summaries of articles on grade crossing safety measures and their effectiveness. The summaries may use all or part of the summary provided by the original author. The summaries may also contain text from the report body which is not in quotation marks. This is the only attribution. The summaries may also have been prepared by the author of this report.

In 1990 Neil Lerner and the Comsis Corporation published a FHWA-sponsored report of nearly 200 pages which was a comprehensive review and analysis of the literature prior to 1991, "Driver Behavior at Rail-Highway Crossings." This report is summarized in this review and analysis. This review contains information which is primarily pertinent to human factors issues in grade crossing safety. Some of the more salient papers referenced by Lerner (1990) and several other recent papers neither included in our original review of the literature for the Work Plan nor in Lerner's review, are included following the summary of Lerner's review. Lerner's review is thorough and his analysis is insightful.

**Lerner, N. (1990).** Driver behavior at rail-highway crossings. Prepared by the Comsis Corp. Federal Highway Administration Report No. FHWA-SA-90-008.

### ***Contributing Factors***

Lerner organizes his analysis of the literature around the Positive Guidance model developed by Post, Alexander and Lunenfeld in 1981<sup>1</sup>. This is the model used to describe driver requirements in the "Railroad-Highway Grade Crossing Handbook" prepared by Tustin, Richards, McGee and Patterson in 1986<sup>2</sup>, as well as in other reports. This model provides a frame of reference for considering the demands that a rail-highway crossing imposes on the driver. These demands are perceptual and cognitive involving seeing, comprehending, and making decisions. The model focuses on the driver's process of acquiring and using the needed information.

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<sup>1</sup> Post, T.J. and Lunenfeld, H. (1981). A users' guide to positive guidance (2nd ed.) Report No. FHWA-TO-81-1, Washington, D.C., U.S. Department of Transportation, Federal Highway Administration.

<sup>2</sup> Tustin, B.H., Richards, H., McGee, H. and Patterson, R. (1986) Railroad-Highway Grade Crossing Handbook (2nd ed.), Report No. FHWA-TS-86-215). Washington, D.C., U.S. Department of Transportation, Federal Highway Administration

Five information handling zones are defined: the advance zone (precedes the demands of the hazard), approach zone (defined by the decision sight distance), non-recovery zone (defined by the stopping sight distance), hazard zone ( about 15 feet from the nearest track) and downstream zone (beyond the hazard). The engineering definition of these zones is arbitrary depending on how conservatively we define response time, braking distance, vehicle length, visibility conditions, sight distance and other conditions.

Lerner's report's has main topics, each with subtopics. The main topics are: Contributing Factors, Driver Characteristics, Countermeasures, and Conclusions. Under Contributing Factors the first subtopic considered was Comprehension. This discussion considered Traffic Control Devices (TCDs), drivers' responsibilities and accident factors.

### **Comprehension**

In their investigation of causal factors in railroad-highway crossing accidents Berg, Knoblauch and Hucke, 1982<sup>3</sup>, found that both recognition errors and decision errors occurred frequently along the path to the crossing. However, there was no single error path that accounted for the majority of the accidents. Failures in perception and decision making occurred all along the path.

Driver expectancy is another important issue for understanding the causes of grade crossing accidents. Expectancy may be based on long-term experience with driving as in expecting freeway exits to be on the right. There are also short term expectancies. For example when driving on a winding road we come to expect the next curve but we would be surprised if this happened on a long, straight highway. Drivers' expectancies at a crossing can influence what they see and how they interpret what they see (likelihood that a train will be in the vicinity, the warning time provided by flashing signals, length of delay caused by the train, probability of being caught violating crossing laws, willingness to take risks, etc.).

There are many studies to show the extent to which people understand the meanings of the TCDs associated with rail-highway crossings. Results vary and there are many reasons for the variance; both content and method. In general drivers understand that the TCDs mean that there is crossing nearby and that there may be a train present or approaching. Detailed understanding is often lacking. Drivers may interpret the lack of an active signal at a crossing as meaning that it is

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<sup>3</sup> Berg, W.D., Knoblauch, K. and Hucke, W. (1982). Causal factors in railroad-highway grade crossing accidents. Transportation Research Record, 847, 47-54. Washington, D.C. Transportation Research Board.

safe to cross. Sanders et al. (1973)<sup>4</sup> interviewed over one thousand drivers just after they had driven over a grade crossing. At active crossings, 23% of drivers thought that all crossings had signals or gates. At passive crossings 15% also thought this. Tidwell and Humphreys' (1981)<sup>5</sup> survey at a license renewal site found that when applicants were shown a picture of a flashing signal array for a grade crossing, over half stated that the signal was rarely or never used. In a later study, Richards and Heatherington (1988)<sup>6</sup> found this figure to be 23%. In both these studies almost all drivers understood that flashing lights meant that a train was coming.

In spite of many studies related to detection and recognition of grade crossing TCDs there is no evidence to show a clear correlation between drivers' understanding of TCDs and accident frequencies. For example, there is no evidence to show that just because many drivers believe that the crossbuck means "stop, look and listen" that these same drivers have more crossing-related accidents. We can only speculate that lack of understanding of the meaning of TCDs or laws leads to accidents.

We can also speculate that failure to understand that trains cannot make sudden collision avoidance maneuvers. In the Richards and Heatherington survey (1988)<sup>7</sup> 45% of respondents felt that when the train driver saw cars crossing the track, the train driver should slow or stop the train. About 10% of drivers did not know whether it took a greater distance to stop a train or a large truck. Based on such information it is not unreasonable to assume that drivers' inability to estimate the time available to cross the tracks could lead to accidents. In making many judgments we get feedback about the correctness of our estimates. However, an exception may be that many drivers do not realize that one train is masking the second train and that when they attempt to cross after the first train has passed they collide with the second train. Lack of visibility due to geometry and sight-line obstructions has been documented as a contributor to accidents.

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<sup>4</sup> Sanders, J.H., Jr., Kolsrud, G.S. and Berger, W.G. (1973). Human factors countermeasures to improve highway-railway safety. Reprot No. DOT-HS-800 888. Washington, D.C.: U.S. Deparment of Transportation, National Highway Traffic Safety Administratioon..

<sup>5</sup> Tidwell, J.E., Jr., and Humphreys, J.B. (1981). Driver knowledge of grade-crossing information (pp. 28-32). Transportation Research Record, 8d11. Wahington, D.C.: Transportation Research Board.

<sup>6</sup> Ricgards, S.H. and Heatherington, K.W. (1988). Motorists' understanding of railroad-highway grade crossin traffic control devices and associated traffic laws. Paper presented at the 67th Annual meeting of The Transportation Research Board. Washington, D.C.

<sup>7</sup> Richards and Heatherington (1988) Op. Cit.

Lerner summarizes this topic by stating that there are factors that are related to accident potential and drivers should be, but often are not, aware of these. Drivers should understand: 1) the meaning of information communicated by TCDs; 2) the responsibilities of drivers; and 3) the factors that can contribute to accidents at grade crossings. There is adequate evidence to show that some fraction of drivers fail on one or more of the above points. However, while there is speculation there is no evidence linking this failure to accident frequencies.

The next three subtopics considered in the Comprehension of rail-highway accidents context were detection and recognition, perception, and decision making.

### **Detection and Recognition**

The topic of detection and recognition is considered under the following headings:

- Dependent measures of detection. (The three common measures are head movements, characteristics of the vehicles speed profile on the approach to the crossing and perception-brake response time.)
- Conspicuity of TCDs (The characteristics of not just the sign but the sign in its environment.)
- Detection and recognition of: Advance warning devices, crossings, active warning devices, trains at the crossing, approaching trains.

Under this heading there are significant problems. A difficult problem for the driver is the recognition of the meaning of the round warning sign. This sign does not tell the motorist whether there is an active warning device at the crossing nor does it indicate distance from the crossing nor does it speak to the visibility of the crossing. If it is night, the intersection with a passive warning device but with an approaching train may first become visible in the non-recovery zone particularly if there is a difficult geometry.

One of the strategies might be to combine visual, tactile and auditory stimuli since such combinations are known to improve signal detectability. One could use rumble strips, the sounds from the train, and active or passive signals to ensure grade crossing detection. High intensity lamps or strobe lights could be added to increase detectability. Four quadrant gates decreased perceptual-braking response times compared two quadrant gates.

- Competing inputs near the crossing.

### **Perception**

After the crossing and the approaching train are detected, drivers still need to make higher order perceptual judgments which will form the basis of a decision about whether to cross the tracks.

The perceptual judgments are complex. For example these judgments involve estimating the time to arrival of the train based on the both the train's and the driver's vehicle's speeds, the distances to be traversed by both, the smoothness of the pavement, the grade of the road, the length of the vehicle, the number of tracks and other factors. Accident data makes it clear that not all drivers stop if there is any doubt about the outcome. Some drivers have been too willing to take risks.

The topic of perception was treated under the following headings:

- The perception problem.

The difficulty of the problem is increased by darkness, short site distances, and other factors which serve to decrease the time remaining to make a decision.

- Motion and gap problem.

There was no literature directly relevant to the grade crossing problem, however, there have been studies on the gap problem. Gap time is the time between two successive vehicles on a road. Lag time is a special case of gap time and is the time from the arrival of the driver's car at an intersection to the arrival of the first car on the intersecting road. Ebbesen and Haney (1973)<sup>8</sup> found that the probability of turning into traffic at an intersection (accepting the gap) was a normal function of the logarithm of the temporal distance. The OECD (1974)<sup>9</sup> found that gap acceptance corresponded to a lognormal distribution of gap times with a median value of 7.3 seconds; an 85th percentile of 10 seconds; and a 15th percentile of 4 seconds. As traffic volume increased, acceptable gap size decreased and this impatience factor might well operate at grade crossings.

When a vehicle is approaching (as in passing or as in viewing an on-coming train). the major visual cue is expansion of the retinal image, also called "looming." Because the size of the retinal image is a tangent function of its distance, the size of the image grows exponentially as the train or vehicle approaches at constant speed. As the distance halves, the visual angle subtended is doubled. As a train approaches from 5,000 feet away to 1000 feet away, the image size changes relatively little; but inside about 500 feet looming increases dramatically. Thus the difficulty in perceiving the rate of approach from a target at a distance is inherent in the geometry of the situation.

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<sup>9</sup> OECD Road Research Group (1974, November). Capacity of at-grade junctions. Organization for Economic Cooperation and Development.

In passing experiments Gordon and Mast (1976)<sup>10</sup> found that the percent of drivers underestimating the distance required to pass increased as speed increased. Judgments about passing, just as judgments made on an approach to a grade crossing, are subject to errors of estimation on each of the variables involved such as speeds and distances. The judgment of the perceived distance and motion of large trucks is related to the extent of patterning and delineation with a fully outlined pattern seen as much closer. Henderson, Zeidman, Burger and Cavey (1983)<sup>11</sup> have reviewed the literature relevant to this topic. Minimal patterning, particularly at night may be typical of trains where the outline of the approaching locomotive is not distinct. This could lead drivers to believe that the train is farther away than it actually is.

- Unique problems in the perception of trains.

The most serious of the unique problems in the perception trains are related to the large object illusion, Leibowitz (1985)<sup>12</sup>. In this illusion large objects seem to move more slowly than small objects. An example is large vs. small jet aircraft landings. The larger planes seem to be going much more slowly than the small planes when in fact they are landing at the same speeds. A classic effect in motion perception is “velocity transposition” which states that the perceived velocities of moving targets are related to the relative sizes of the targets and visual fields in which they move Brown (1931)<sup>13</sup>.

- Other sensory modalities.

Vision is the predominant modality with audition related to train whistles of much less importance.

## Decision Making

Under this subtopic decision making errors, risk perception and risk taking were discussed.

Knoblauch, Hucke and Berg (1982)<sup>14</sup> classified decision errors and gave their frequencies:

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<sup>10</sup> Gordon, D. and Mast, T.M. (1976). Driver’s judgment in overtaking and passing. *Human Factors*, 18, 53-62.

<sup>11</sup> Henderson, R.L., Zeidman, K., Burger, W.J. and Cavey, K.E. (1983) Motor vehicle conspicuity. In Crash Avoidance, SP-544 (pp 145-188). Warrendale, PA: Society of Automotive Engineers, Inc.

<sup>12</sup> Leibowitz, H.W. (1985). Grade crossing accidents and human factors engineering. *American Scientist*, 73, 558-562.

<sup>13</sup> Brown, J.F. (1931). The visual perception of velocity. *Psychologische Forschung*, 14, 199-232.

<sup>14</sup> Knoblauch, K., Hucke, W. and Berg, W. (1982). Rail highway crossing accident causation study. Vol. II: Technical report FHWA-RD-81-83. Washington D.C., U.S. Department of Transportation, Federal Highway Administration.

### Flashing Light Sites

Driver recognizes signal from approach zone, does not detect train. 18%

Driver recognizes signal from approach zone, does not stop, recognizes train from non-recovery zone, attempts to stop. 17%

Driver recognizes signal from approach zone, does not stop, recognizes train from non-recovery zone, does not stop. 22%

Driver recognizes signal from approach zone, brakes to stop, recognizes train, attempts to cross. 5%

### Crossbuck-Only Sites

Driver recognizes train from approach zone, does not stop. 7%

Driver recognizes train from approach zone, enters non-recovery zone, attempts to stop. 8%

Driver recognizes train from approach zone, brakes to stop, attempts to cross. 3%

About 20 % of the accidents did not fall into these categories and this included cases involving alcohol. Note that only 8% of the accidents occurred after the driver had stopped. The definition of a decision-making error was narrow and did not consider such factors as weather, pavement, other signs or markings or driver familiarity.

Risk taking refers to willingness to accept a potential for harm. Risk perception refers to a persons ability to perceive harm for whatever benefits might accrue. For a driver to take a risk means that the hazard must be detected, the degree of risk (probability and severity of consequence) perceived and the potential consequences of an action accepted. A special issue of the journal "Ergonomics" (April 1988, Volume 31, No. 4) was devoted to "Risky Decision-Making in Transport Operations."

Many surveys have shown that drivers are poor at estimating risks. Sight distances and approach speeds may be related to willingness to take risks. However, it could be that when sight distances are greater, drivers approach crossings at higher speeds.

Factors in decision making errors at crossings are discussed under the following heading: information limitations and ambiguity; information credibility; expectancies regarding trains; expectancies regarding crossings, costs of compliance; temporal constraints; competing inputs; decision making as a disruptive activity; recognition of capabilities and biases; conflicting messages; avoidance of effort; social influences; and emotional reactions.

## **Compliance**

This section deals with actions which the driver knows to be illegal and risky; that is, most cases of non-compliance are intentional. For example Knoblauch et al. (1982)<sup>15</sup> determined that in more than half the cases at flashing light crossings, the driver had seen the signal sufficiently in advance, but did not stop. Other studies were cited which confirmed this study. Drivers are sensitive to the length and reasonableness of the warning times and this influences compliance. Other factors which influence compliance are discussed under the heading of inconvenience; driver familiarity with the crossing; social behavior and norms, enforcement and conflicting concerns. (As an aside, “conflicting concerns” may well have been a factor in the 1995 crossing accident involving a school bus in Fox River Grove, IL.)

## **Impairment**

This section of Lerner’s report deals with alcohol, drugs and fatigue and these are not of interest in the context of this project.

## ***Driver Characteristics***

For our purposes in this project, the issues of interest in this section on driver characteristics are familiarity and risk taking. The findings on crossing familiarity could be summarized by the adage that “familiarity breeds contempt.” Risk taking of one kind has often been correlated with other forms of risk taking in individuals; such as risk taking at crossings is correlated with risk taking in other driving situations.

## ***Countermeasures***

Most countermeasures have not been evaluated, only suggested. There are no global countermeasures that would solve all problems at crossings. Even if a counter measure would be found to be effective in modifying behavior in a limited way, there is no guarantee that this would result in a reduction in accidents. Furthermore, even if accidents were reduced the countermeasure might not be cost-effective. The thousand or so deaths occurring at crossings each year testifies to the difficulty in implementing broadly effective countermeasures.

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<sup>15</sup> Knoblauch, K., Hucke, W., and Berg, W. (1982). Rail highway crossing accident causation study. Vol.II: Technical Report (Report No. FHWA-RD-81-83). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

The major subsections in this Countermeasures section mirror those found in Contributing Factors: Comprehension; Detection and Recognition; Perception; Decision Making; and Compliance.

## **Comprehension**

The NCHRP Report 50, “Factors Influencing Safety at Grade Crossings” (Schoppert and Hoyt 1968)<sup>16</sup> was over 20 years old when Lerner wrote his review in 1990 and Lerner could state that neither the grade crossing problems nor the proposed countermeasures were new. Lerner points out the classes of possible countermeasures. The most effective intervention is either to close the crossing or implement grade separation. Next in order of effectiveness is automatic four quadrant then two quadrant gates because it simplifies drivers’ options and reduces decision making. Active crossing signals are more effective than passively protected crossings. Passive protection places the greatest demands on driver comprehension, detection, perception, and decision making. The relative virtues in terms of driver behavior are clear. The issues relate to cost of installation and maintenance, cost effectiveness and resource allocation.

Many studies have suggested some form of educational or public awareness efforts to reduce grade crossing accidents (Richards and Heatherington, 1988<sup>17</sup>; Knoblauch et al. 1982; Haga 1988)<sup>18</sup>. Some educational efforts have been directed toward improving drivers’ understanding of their own perceptual limitations (Knoblauch et al. 1982<sup>19</sup>; Leibowitz 1985<sup>20</sup>; Leibowitz and Owens

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<sup>16</sup> Schoppert, D.W. and Hoyt, D.W. (1968). Factors influencing safety at highway-rail grade crossings. (NCHRP Report 50). Washington, D.C. Highway Research Board.

<sup>17</sup> Richards, S.H. and Heathering, K.W. (1988). Motorists understanding of railroad-highway grade crossing traffic control devices and associated traffic laws. Paper presented at the 67th Annual Meeting of the Transportation Research Board. Washington, D.C.

<sup>18</sup> Haga, S. (1988). Prevention of accidents at road-rail level crossings protected with automatic barriers pp. 933-937. Proceedings of the Human Factors Society 32nd Annual Meeting Vol. 2. Santa Monica, CA: The Human Factors Society.

<sup>19</sup> Knoblauch et al. 1982. op. cit.

<sup>20</sup> Leibowitz, H.W. 1985. op. cit.

1986<sup>21</sup>; McGinnis 1979<sup>22</sup>). Most of these efforts, including Operation Life Saver have not been formally evaluated for effectiveness. In the evaluations which have been done, no correlations were found between educational programs and improved driver behavior at crossings. The Cerro Gordo County Iowa effort was another example of type of program which initially had a beneficial effect on drivers' behavior but this effect dissipated within six months.

## **Detection And Recognition**

Under detection and recognition the subtopics are: Advance Warning Signs; Active Advance Warning Devices; Rumble Strips; Crossbucks; Active Warning Devices; and Trains.

### Advance Warning Signs

Many studies have been done to improve advance warning signs. These studies have involved changing the size, shape, color, symbols, messages, locations and number of signs (redundancy). Some show slight enhancement but none have shown substantial effects on drivers' behavior and potential effects on driver behavior are unknown.

### Active Advance Warning Devices (AAWDs)

AAWDs have been proposed for both active and passive crossings particularly those with limited sight distances (geometry or weather) and high vehicle speeds (perhaps due to downgrades.) The rationale behind activating the AAWD prior to activation of the crossing device is to provide sufficient time for drivers located between the AAWD and the crossing to clear the crossing before activation of the crossing signals. When AAWDs have been tested at active crossings with limited sight distances, they appeared to facilitate driver detection of the activated crossing signal, but primarily under daytime viewing conditions. In a field test (Ruden et al., 1982)<sup>23</sup> using flashing lights on the approach to the crossing, about half of the drivers recognized that this signaled the approach of a train. The other half wanted to know whether or not the lights flashed continuously. This latter response was caused by familiarity with continuously flashing lights such as those at rural intersections or at construction zones. The "TRAIN WHEN

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<sup>21</sup> Leibowitz, H.W. and Owens, D.A. (1986). We drive by night. *Psychology Today*, 20(1), 55-58.

<sup>22</sup> McGinnis, R.G. (1979). The benefits and costs of a program to reflectorize the U.S. fleet of railroad rolling stock, Report No. FRA-OPPD-79-12. Washington, D.C.: Federal Highway Administration.

<sup>23</sup> Ruden, R.J., Burg, A. and McGuire, J.P. (1982). Activated advance warning for railroad grade crossings (Report No. FHWA-RD-80-003). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

CROSSING” and the neon “R X R GATE” AAWDs have been shown to be effective. Acoustic warning signals have been tested and found to result in some improvements, however, neighbor’s complaints limit their applicability. Various authors have suggested in-vehicle warning messages but this advanced concept has not been adequately tested and usage would need to be nearly universal before this technology could replace conventional AAWDs. Thus AAWDs have been shown to provide a benefit, particularly when they are only active when a train is present.

### Rumble Strips

Rumble strips have been shown to have advantages over purely visual warning signals in alerting drivers to the crossing and also the detection of other warning signals. Painted rumble strips cause speed reduction even before the strips are reached. The most serious disadvantage is the avoidance behavior of drivers familiar with the crossing. The consensus is that rumble strips should be used only at crossings with special hazards such as limited sight distances, unusual geometries or excessive vehicle speeds.

### Crossbuck

There are many studies which have evaluated size, shape and color of crossbuck signs since the standard crossbuck has limited conspicuity. Overall the case for changing the standard crossbuck is not strong.

### Active Warning Devices

Even under ideal viewing conditions the standard narrow-beam lights used for active crossing signals are not readily detected by drivers at short distances from the crossing (Hopkins and White, 1977<sup>24</sup>; Lindberg, 1971<sup>25</sup>). Efforts to increase the conspicuity of crossing signals have included manipulations of intensity, beam size, size color, flash rate, placement and source of light such as incandescent or strobe.

Most attempts at improvements have involved the addition of strobe lights and most of these efforts have been at least partly effective. The major drawbacks have been that some drivers attend to the strobe light rather than the train or the other signals which signal the presence of a train. It

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<sup>24</sup> Hopkins, J.B. and White, E. (1977). Improvement of the effectiveness of motorist warnings at railroad-highway grade crossings. Report No. DOT-TSC-FRA--76-25). Washington, D.C.:USDOT, FHWA.

<sup>25</sup> Lindberg, V.L. (1971). How to make crossing signals more observable to drivers. Railway Signal Controls, 2(1), 24-30.

appears that strobe lights have more value at urban crossings where conspicuity is an issue. In addition to strobe lights, studies have considered the use of traffic control signals at grade crossings. The advantage is that these signals are familiar to drivers. However, traffic control signals have not been shown to be superior to flashing lights.

Of all the active warning devices studied, strobe lights seem to offer the greatest promise. However, whether strobes will maintain their attention getting properties if they come into widespread use is not known.

### Trains

Countermeasures for increasing the conspicuity of trains fall into two categories: at the crossing or before the train reaches the crossing. Accident data shows that in 10% of crossing accidents the driver could have stopped safely if he had detected the train when it was at the crossing. This type of accident could be reduced by increasing the visibility of the train when it is at, or about to enter, the crossing. However, for the majority, about 90%, of accidents, the train was still approaching the crossing when was at the decision point. For these accidents the counter measure is to increase the sight distances and train conspicuity. Lerner discusses these factors under the following headings: illumination at the crossing, reflectorization of railcars, reflectorization of trackside objects and on-train devices.

### **Perception**

Improving perceptual judgments by the use of illusions have been proposed but not tested. Leibowitz (1985)<sup>26</sup> has suggested that the apparent size of an approaching train should be reduced since smaller objects appear to have a greater speed than larger objects. Leibowitz also suggested that the looming effect should be increased to make drivers more conservative in their estimation of the train's distance from the intersection and the train's speed of approach. In general the potential benefits from perceptual countermeasures are untested.

### **Decision Making**

Decision making concerns the ways in which drivers deal with the information available to them. Issues involve the kind of information, its credibility, when and where it is received and the results compared to alternative decisions. Decision making was covered under five main headings:

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<sup>26</sup> Leibowitz, H.W. (1985) op. cit.

enhanced information content in advanced warnings; enhanced information content at the crossing; information credibility; distribution of information; and the costs of alternative actions.

### **Enhanced Information for Advance Warnings**

Advance warnings only inform the driver that there is a crossing ahead. More information could be provided. Active vs. passive crossings might benefit from different information; at least notification of which kind of crossing is ahead. Active advance warnings provide additional information which could be especially valuable when sight distances are short. Different sight distances may require different search strategies on the part of the driver and this could be indicated in advance of the crossing. Advisory signs relating to approach speed, path, and braking have been suggested.

### **Enhanced Information at The Crossing**

The information presented at the crossing now is well known. Other information could be given such as “Do Not Stop On Tracks” or some form of “It Is Safe To Proceed” sign. Information about circuitry malfunction could also be provided. An amber warning could precede the red signal light. The direction of the approaching train could be indicated but not by an arrow sign which could confuse the driver since the meaning of train is approaching from the left vs. train is heading to your left is ambiguous. Studies have shown that many drivers go through the red flashing signal and cross in front of the approaching train when the train still distant (14 seconds on average in one study). Yield signs at passive crossings (other than the crossbuck) have been proposed but improved performance has not been demonstrated.

### **Information Credibility**

Signs which state that a crossing exists are credible because the crossing does in fact exist. However, warning signs may have a credibility problem. The reason is that the frequency of trains at the crossing is low. Extended warning times and false alarms also help to lower credibility. Constant Warning Time (CWT) circuitry is the countermeasure for this problem. There is evidence to show the effectiveness of CWT on driver behavior and accident rates.

Overall, little has been identified in the way of promising decision-error countermeasures that address the relative costs of safe vs. unsafe actions.

### **Compliance**

To improve drivers' compliance with crossing laws and devices the following categories of countermeasures have been suggested: enforcement; crossing traffic control device validity; use of

intersection-related traffic control devices with better compliance rates; and the perceived reasonableness of driver requirements.

Enforcement is sporadic; officers are not routinely stationed at grade crossings although their presence would undoubtedly improve compliance.

One program to improve traffic control device compliance is the “800” number posted at the crossing for reporting signal malfunctions (Lamkin, 1985)<sup>27</sup>. In one year this program received 5,000 calls and 84 per cent of them concerned false alarms. False alarms reduce credibility. Lerner devoted a short section to perceived reasonableness pointing out that drivers are more apt to obey traffic control devices if they think they are reasonable.

### **An Appropriate View of the Driver**

Lerner believes that our view of drivers involved in accidents includes ideas of inattention, inappropriate speed, unnecessary risk-taking, disregard of signs and signals and the like. That is, accidents are completely assignable to avoidable driver error. Lerner presents a different view quoted as follows:

“The image of the more typical driver is that of a reasonable, rational, if imperfect, decision maker, who is trying to optimize his situation based on his knowledge and the facts at hand. He brings to this task a variety of perceptions and opinions based on personal experience, and these have some validity. He is not just relying on the formal information provided by the traffic engineer and the railroad. This driver is probably quite familiar with the crossing site and has expectancies about its geometric, operational, and hazard characteristics. At a personal level, the relative importance of some benefits or costs may not be weighted the same as they would be for a highway safety specialist from his perspective; ‘wrong’ actions could thus result not from errors as much as from different decision criteria. Viewing the driver in this way, one can place potential safety treatments in the full context of the driver’s decision making task.”

Lerner points out that for an average crossing, a driver could cross safely twice a day for fifteen years even if the driver was deaf and blind to everything but the pavement directly in front of the vehicle and even the worst driver would not be as oblivious as the hypothetical driver. This illustration may partly explain the lack of correlation between accidents and knowledge of signs, signals and laws. At the other end of the spectrum consider a driver whose attention is completely occupied with compliance with signs, signals, laws and crossing safety. This driver at least

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<sup>27</sup> Lamkin, J. (1985). The Texas grade crossing signal notification program: Call 1-800. Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, MO, July 1985.

partially accounts for the statistic which shows that for every train related accident at a crossing there are two non-train related accidents.

In the quotation above Lerner describes a driver as a decision maker with a difficult task. The following quote from Lerner suggests a countermeasure for aiding this driver. “Given the view of the driver as a reasonably rational decision maker facing a complex task under information constraints, what are the implications for countermeasures? First, it would de-emphasize the approach of trying to instill greater safety motivation or knowledge of rules and laws. While this is not to imply that there is not merit in such efforts, they do not attack the crux of the decision making problem. Similarly it would place less emphasis on passive signage that generally describes a desired action (e.g., slowing, looking) that the driver may already recognize as an option. Again, this is not to imply such signs may be without benefit; rather, the suggested view of the driver as a decision maker considering a variety of information sources and behavioral option means that one cannot presume mechanistic compliance with such signs. What is suggested by this perspective of the driver is that the roadway approach to the crossing be viewed as a decision context, and that the decision task itself be as well-structured as possible. The desired action should be obvious; other options should be eliminated or made less desirable; extraneous concerns should not be present; and influence should be exerted early in the decision chain.”

### **Sight Distance**

All three types of sight distance are targets for countermeasures: visibility ahead to the crossing; visibility along the track on the approach to the crossing (from the decision zone); and visibility along the track when stopped at the crossing. Instead of a distance problem sight distance can be considered as a speed control problem. The sight distance required by the driver is determined by the train’s speed and the vehicle’s speed and braking ability. A posted speed limit does not require a predetermined sight distance. This viewpoint places difficult burdens on the driver and is not ideal from the driver’s behavioral standpoint. Effective counter measures to address the sight distance problem need to adopt realistic expectations about what drivers will do, what information they need and will use, and what expectancies they bring to the situation. The Positive Guidance model might be a useful tool for addressing the sight distance problem.

### **Driver Familiarity with The Crossing**

Most accidents involve victims that were familiar with the crossing. This suggests that passive information will not be helpful because it will lose its salience. An intermittent police presence might be a successful if impractical countermeasure.

## **Directed Visual Attention**

Drivers detect trains visually and there are many factors which interfere with acquiring a train visually. There is also the problem that visually searching for a train will divert attention from vehicle control possibly resulting in single or multiple vehicle accidents at the crossing. Redundant information using different sensory modes is a possible countermeasure. Rumble strips are a possibility but they suffer the disadvantage of all passive devices in that they are present whether or not there is a train.

## **A System Perspective**

The idea of a system perspective is that introducing CWT at a crossing may have a favorable effect on credibility that drivers will generalize to other crossings. There is also a negative consequence. For example as more active devices are added at crossings drivers may tend to believe that all crossings have active devices.

## **Comparison of Flashing Light Signals with Traffic Control Signals**

This comparison is reported in the form of a four page table. This table suggests that relative to the traffic control signal, the railroad crossing flashing light presents a more ambiguous message about appropriate driver actions.

## **General Summary**

The summary is presented in the form of 16 points described in two or three sentences each. The information in the summary is covered above.

### ***Additional References***

**Agent, K.R. (1980).** Transverse Pavement Markings for Speed Control and Accident Reduction. Transportation Research Record, N773, Washington, D.C.: Transportation Research Board.

Markings were placed on the pavement so that drivers rounding curves on the approach to the crossing would see the markings at a rate proportional to their speed. The spacing of the lines was such that it created the illusion of acceleration in hopes that the driver would slow down. Results showed that transverse markings can reduce speeds. At the very least, they can warn drivers that there is an upcoming hazard for which they need to slow. This would only be a “warning” to drivers who see these markings frequently. Most accidents at railroad-grade crossings do not involve high enough speeds for transverse markings to create the illusion of acceleration.

**Alexander, G.J. (1989).** Search and Perception - Reaction Times at Intersections and Railroad Grade Crossings. ITE Journal 59, 11, pp. 17-19.

This paper had two objectives: 1) It addressed the subject of perception reaction time (PRT) in hopes of modifying formulas on intersection sight distance contained in *A Policy on Geometric Design of Highways and Streets* (the Green Book); and 2) To suggest that an intersection geometry-based traffic signal and activated train warning signal warrant be considered for adoption in the relevant standards.

The elements of perceived reaction time (PRT) are detection, recognition, decision, and action initiation. Search is considered to be a separate part of the activity. Drivers that are stopped will be alerted to approaching vehicles. This shortens PRT but complexity increases the time required for decision making. The possible actions for the driver are known but the judgment of when and how much to accelerate are issues. Since search time can vary from milliseconds (eye movements) to several seconds (head movements of 180 degrees), and should not be included in PRT. Thus search time could be used as a variable and PRT could be held constant. When roadways are intersected by other roads and train tracks, the processing of information can become longer due to different sizes, speeds, and angles, thus the variable “search” should be added to make the model more realistic.

The Green Book indicates that intersection angles less than 60 degrees create problems for drivers. A right angle (90 degrees) is preferred but anything over 60 degrees is acceptable. It also states that any intersection of less than 60 degrees requires some adjustment in corner sight distance. Both statements ask “what is visible and when” but neither address human factors issues. Alexander suggested that when the design conditions of an intersection create decision making

problems for drivers, the decisions should be made for them. Signalizing the intersection clearly assigns right of way and eliminates search time. Alexander also says that not all intersections need to be signalized but a new warrant may be developed for the *Manual on Uniform Traffic Control Devices* (MUTCD). The new warrant would reflect the accident warrant. Several driver responses are predicted: 1) drivers may “fly” through the intersection because they neither heard nor saw a train, 2) more cautious drivers may reduce speed to try and detect a train’s presence, and finally 3) head and torso movements may be required at the intersection and different types of drivers will react differently. Alexander goes on to say if guidance is provided by stop signs and traffic signals, then the same guidance should provide the same traffic control for railroad grade crossings. Steps need to be taken to develop traffic control warrants for such intersections in the MUTCD.

**Andrews, W.H., Armstrong, G.A. and Bowers, T.L. (1987).** Railroad-Highway Grade Crossing Signal Visibility Improvement Program. Volume I. Final Report, Oak Ridge National Laboratory, Oak Ridge, TN, Federal Highway Administration.

This study addressed reported problems in visibility of grade crossing warning signals. The first approach was to enhance the standard crossing signal’s effectiveness with minor design changes (a brighter signal) without altering the familiar appearance. The second approach was to evaluate and, if needed, develop devices for the signal maintainer to use in adjusting the signal and in verifying satisfactory signal performance. The conclusion was that the problem was neither the warning system nor the tool to calibrate the system but the problem was the drivers.

**Berg, W.D., Fuchs, C., and Coleman, J. (1980).** Evaluating the Safety Benefits of Railroad Advance-Warning Signs. Transportation Research Record N773. Washington, D.C.: Transportation Research Board.

This article suggested that an accident study not be undertaken due to the cost of the study compared to the expected value of the results. The authors found that this study would be both experimentally and economically impractical for the following reasons:

- 1) The large sample size needed to detect the minimum percentage of reduction in accidents that would economically justify deployment of the new sign significantly exceed the population of available sites.
- 2) The estimated large cost would equal or exceed the approximate total cost of deploying a new sign on an as-needed basis over a seven year period.
- 3) No study design is likely to reveal a statistically significant accident reduction (if in fact there is one.)

These conclusions suggest that the following policy options are available regarding proposals to establish the new advance-warning sign as a national standard:

- 1) Take no further action of any type.
- 2) Undertake a study to experimentally measure the accident-reduction potential of the new sign.
- 3) Undertake further study of the potential safety effectiveness of the new sign by using alternative measures of effectiveness such as the frequency with which drivers look for trains.
- 4) Approve the use of the new sign by state and local highway agencies on an as-needed basis.

The authors recommended that the first two policy options should be ignored and that the last two are the more realistic choices. If a new sign was to be approved as a national standard, it would imply that the new sign has the potential for offering at least marginal improvement in effectiveness over the current sign. Also, even a marginal improvement is all that would be required to economically justify the change in standard.

**Bowman, B.L. (1987).** Analysis of Railroad-Highway Crossing Active Advance Warning Devices. Transportation Research Record 1114. Washington, D.C.: Transportation Research Board.

The purpose of this study was to determine which of three candidate active advance warning devices for use on approaches to rail-highway crossings was the most effective. Each of the candidate devices consisted of a primary message sign, a supplementary “WATCH FOR TRAINS” message plate, and two eight inch amber, alternately flashing beacons. The devices differed only in configuration and in the message of the primary sign. The study was conducted at four sites where sight restrictions on the approach resulted in an insufficiently safe stopping distance. The train detection circuitry at each site was modified to provide train activation of each advance warning device approximately 10 seconds before the activation of the at-grade warning system. Each test device was installed at all four sites. The results of the speed profile analysis during the activated state indicated that the alternately flashing beacons produced a significant decrease in vehicle approach speed. Similar analysis, during the inactivated state, revealed that there was no significant difference in vehicle speeds resulting from the use of different primary signs. These results indicated that the test configuration that used a 48-in. standard (W10-1) railroad advance warning sign would be effective in providing motorists the required advance warning.

- 1) During the activated state, the flashing beacons were effective in producing large speed reductions.
- 2) The within-site analysis indicated that Primary Sign A [a 48-in. standard (W10-1)] was the only test sign to have a conclusive impact on vehicle speeds during the inactivated state.

- 3) The 48-in. (W10-1) was effective in reducing vehicle approach speed.
- 4) Most test configurations had a novelty effect when first installed. That effect dissipated after the device was in place for approximately 4 weeks.
- 5) Approximate cost of device assembly and installation can range from \$6,000 - \$10,300 for underground and from \$2,000 - \$6,300 for overhead installation. These costs would vary from site to site.

**Bowman, B.L. (1987).** The Effectiveness of Railroad Constant Warning Time Systems. Transportation Research Record N1114. Washington, D.C.: Transportation Research Board.

The purpose of this paper was to determine the effectiveness of railroad constant warning time (CWT) systems in (a) reducing motorists violation of activated at-grade warning systems and (b) reducing vehicle-train accidents. Analysis of data showed that CWT systems were effective in providing a uniform amount of advanced warning time and reducing violation of warning systems. A comparative analysis from 1980 to 1984 indicated that crossings with CWT systems had a lower accident rate than other crossings. However, the difference was not statistically significant. The selection process included accidents in which the vehicle was struck by or strikes the first unit of the train. The reason for selecting these accidents was that these motorists were miscalculating the amount of time available to cross the intersection or they were racing the train to the crossing. Accidents in which the vehicle hits any subsequent unit of the train would be less likely to be prevented by a CWT system because these accidents are the result of driver inattention, excessive speed, sight restrictions, or improper warning device operation

**Eck, R.W. and Halkais, J.A. (1985).** Effectiveness of Constant-Warning-Time Versus Fixed-Distance Warning Systems at Rail-Highway Grade Crossings. Transportation Research Record 1010.

The objective of this study was to determine the influence of road classification, angle of crossing, and train speed on the effectiveness of fixed-distance (FD) and constant-warning-time (CWT) systems at public rail-highway grade crossings. FD and CWT systems revealed similar effectiveness values (82 and 85 percent respectively). For changes from FD to CWT systems, the effectiveness value was 26 percent. This last point confirmed that CWT systems have greater credibility with motorists than do FD systems. Functional class of road had no apparent influence on the effectiveness of warning systems. For passive to FD or passive to CWT systems, effectiveness values in the 60-90 degree angle category were essentially equal to or slightly greater than those in the more oblique angle categories. Effectiveness of upgrades from the FD to CWT category was greatest for the angle of crossing class 0-29 degrees, which had 68 percent effectiveness. A significant relationship was found between train speed difference and CWT

systems; that is, system effectiveness increased as the variation in train speeds at a location increased. Train speed had no apparent influence on the effectiveness of FD warning systems. The authors recommend that additional research is warranted to analyze the DOT-AAR data files to determine if, when normalized by exposure, accident rates at crossings with FD systems differ from those at crossings with CWT systems. Only by normalizing the accident rates by exposure (traffic volume and train volume) can the credibility issue be addressed. Also, future research should develop statistical models to identify variables that are significantly related to grade-crossing accident rates for FD and CWT systems.

**Eck, R.W., and Halkias, J.A. (1985).** Further Investigation of the Effectiveness of Warning Devices at Rail-Highway Grade Crossings. Transportation Research Record 1010. Washington, D.C.: Transportation Research Record.

This main purpose of this paper was to analyze the national inventory of the U.S. Department of Transportation-Association of American Railroads and the accident files of the Federal Railroad Administration to develop measures of effectiveness for the following rail-highway grade-crossing upgrades: (a) passive systems to flashing lights on a single track, (b) passive systems to gates on single and multiple tracks, and (c) flashing lights to gates on single and multiple tracks. Other objectives included determining the influence of crossing angle, train speed ratio, and train speed difference on the effectiveness of warning devices. The only marked change from previous studies occurred in the flashing-lights-to-gates category; the effectiveness value determined in this study (72%) was higher than values obtained in previous work. Upgrades of warning devices on single track had higher effectiveness values than those on multiple tracks. Variation in train speeds had no apparent influence. Upgrades from passive to flashing light systems was 69% effective. Upgrades from passive to gate systems was 84% effective. An upgrade from a flashing light to a gate system was 72% effective which is higher than found in other past studies. Warning device upgrades on a single track had a higher effectiveness than for multiple tracks. Variation in train speed had no influence.

The greatest effectiveness of an upgrade was from the passive to gate system on a single track crossing at an oblique angle. However, passive to flashing light systems and flashing lights to gate systems had greatest effectiveness in the 60 to 90 degree angles. Results for multiple track crossings failed to show a definite pattern.

With fixed distance systems, trains activate the signals or gates at a predetermined distance from the crossing. The major drawback to such systems is that warning devices operate continuously while the train is on the approach track circuitry, regardless of train speed. Motorists may become impatient in situations in which the warning device is active for a long time. Constant warning time equipment has the capability of sensing a train in the approach section, measuring its

speed and distance from the crossing, and activating the warning device. Thus, regardless of train speed, a uniform warning time is provided.

**Faghri, A. and Demetsky, M.J. (1987).** A Comparison of Formulae for Predicting Rail-Highway Crossing Hazards. Transportation Research Record 1114. Washington, D.C.: Transportation Research Board.

The need for improvement at a rail-highway crossing typically was based on the expected accident rate (EAR) in conjunction with other criteria carrying lesser weight. The priority list produced by this formula was only one criterion used in determining the need to improve conditions at any crossing.

In this study, the DOT accident prediction formula outperformed the other four nationally recognized accident prediction formulae. The DOT formula is fully documented in the *Rail-Highway Resource Allocation Procedure User's Guide*. Also described in the guide is a resource allocation model that, together with the accidents prediction formula, provides an automated and systematic means of making a cost-effective allocation of funds among individual crossings and available improvement options. The DOT accident prediction formula takes into account the most important variables that are statistically significant in predicting accidents at rail-highway crossings.

**Halkias, J.A., and Blanchard, L. (1987).** Accident Causation Analysis at Railroad Crossings Protected by Gates. Transportation Research Record 1114. Washington, D.C.: Transportation Research Board.

This study sought probable causes of factors responsible for accidents occurring at railroad crossings protected by gates. Two goals were to (a) compare results from fixed distance and constant warning time systems, and (b) test the idea that warning times create lack of credibility in warning systems. An accident classification by circumstance highlighted some causes and factors responsible for the different types of accidents. Analysis confirmed and quantified the small impact of environmental factors such as weather and reduced visibility. Trends found in relation to warning times tended to indicate that lack of credibility in warning signals was a factor in the accidents. Some of the conclusions reached were as follows:

- 1) Results from present data confirmed the theory generally adopted that the majority of accidents occurs during good weather and visibility conditions.
- 2) The actual cause of many accidents seemed obscure.
- 3) Study of warning times led to two main conclusions. (a) Inconsistency in warning time length led motorists to distrust signals. At railroad crossings that had a

narrow typical warning time distribution, most of the accidents occurred beyond the typical maximum warning time. (b) Extended warning times led motorists to ignore warning signals and cross the tracks.

4) Lack of credibility in warning signals was a factor in accidents occurring at crossings equipped with fixed distance warnings.

5) The warning signals' lack of credibility might also contribute to the accidents occurring at crossings equipped with constant warning time systems.

**Office of Traffic Safety (1992, 1993, 1994).** Minnesota Motor Vehicle Crash Facts, Minnesota Department of Public Safety, Section IX. Motor Vehicle/Train Crashes, pp. 88-91.

These reports show demographics and causes of vehicle/train accidents. Across all three years, the most common sites for accidents were intersections with stop signs or the crossbuck at rail crossings. In 1992, 86% of the crashes were at these types of intersection, 53% in 1993, and 35% in 1994. The next highest were intersections with a RR crossing stop sign and flashing lights. The traffic control devices with the least number of accidents were the RR crossing gate and/or the RR overhead flashers.

The age group of the people most often injured or killed was 15 to 29 years of age in all three years. In 1992, 46% of the accidents were in this age group, in 1993 it was 51%, and in 1994 it was 25%. The factors most cited for all three years were that drivers were not giving adequate attention to the crossing, did not yield to the train, or they simply ignored the traffic control device. Driver inexperience had an extremely low incidence of 0.8% of accidents. The most common time of day for accidents was from 9:00 A.M. to 4:00 P.M. The months most accidents occurred was from October to March. Spring (April - June) had the lowest number of accidents.

The last statistical data collected from *Crash Facts* was population size. Accidents happened most often in areas of populations of less than 1000 people. In 1993, 46 of 128 accidents were in areas of less than 1000 people, 16 of the same 128 accidents were in populations of 10,000-25,000, and 13 were in populations over 100,000. In 1994, 84 of 144 accidents occurred in populations of less than 1000, 13 occurred in populations of 10,000-25,000, and 15 occurred in populations over 100,000.

**Russell, E.R. and Konz, S. (1980).** Night Visibility of Trains at Railroad-Highway Grade Crossings. Transportation Research Record, N773, Washington, D.C.: Transportation Research Board.

Of grade-crossing accidents, 37% occur at night. Of these night accidents 47% are accidents in which the vehicle runs into the train. There are no illumination standards now in use for railroad-highway grade crossings.

<u>Type of Accident</u>	<u>No. of Accidents</u>		
	<u>Day</u>	<u>Night</u>	<u>Total</u>
Vehicle hits train	3,870	4,637	8,507
Train hits vehicle	<u>12,997</u>	<u>5,479</u>	<u>18,476</u>
Totals	16,867	10,116	26,983

If illumination was perfect, how many of the vehicle hits train at night accidents could have been prevented? The authors stated that due to the slow speeds involved, only the immediate vicinity of the crossings need to be illuminated. Other studies cited by the authors showed improvements anywhere from a 15% to 90% drop in accidents simply by illuminating the crossing. Four low pressure sodium lamps per crossing, 2 on each side, placed 25 feet from the track centerline was suggested by an Oregon study cited by the authors of this article. Also, these lamps should be a different color than regular street lamps in order to bring attention to a specific type of intersection.

**Ryan, T.A., and Erdman, J.W. (1985).** Procedure for a Priority Ranking System for Rail-Highway Grade Crossings. Transportation Research Record 1010. Washington, D.C.: Transportation Research Board.

A portion of this paper was to develop a procedure that would rank the crossings in terms of their relative need for improvement. An equation that considered safety, vehicular delay, and emergency access problem potential was used as the basis of the ranking procedure. The procedure developed had weaknesses but it was found to be "quite useful" for the purpose of the study. The crossings involved were identified for one of the following reasons: (a) severe delays to roadway vehicles (especially emergency vehicles) resulting from extensive use of the crossing by trains, (b) there was already an unusually high accident rate, and (c) the number of crossings by trains was expected to increase. A general equation was used for the ranking procedure. This equation required the user to supply weighting coefficients for the normalized variables deemed important in determining a priority score for the crossing. The equation summed the products of the weighting coefficients and normalized variables.

