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16. Abstract

In section 159 of the Surface Transportation and Uniform Relocation Assistance Act of 1987, Congress required the Secretary of Transportation to conduct a study of national highway-railroad improvement and maintenance needs. Nine specific issues were to be addressed. One of these (#4) was: "An examination of driver behavior at such crossings and what technologies are most effective in changing behavior and preventing accidents." This report reviews the literature on driver behavior at rail-highway crossings in support of FHWA (DOT)'s efforts in addressing this issue. It discusses the contributing factors and driver characteristics related to behavior at these crossings and considers countermeasures which have been developed in efforts to improve driver behavior.

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Prepared for
U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

Prepared by
COMSIS Corporation
8737 Colesville Road
Suite 1100
Silver Spring, MD 20910
(301) 588-0800

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1. INTRODUCTION

1.1 PURPOSE

Through Section 159 of the Surface Transportation and Uniform Relocation Assistance Act of 1987, Congress required the Federal Highway Administration to study the safety, cost, and operational concerns of rail-highway crossings, and to make recommendations. Nine specific issues were to be addressed. One of these (#4) was: "An examination of driver behavior at such crossings and what technologies are most effective in changing behavior and preventing accidents."

This report reviews the literature on driver behavior at rail-highway crossings, in support of FHWA's efforts in addressing this issue. It discusses the contributing factors and driver characteristics related to behavior at these crossings, and considers countermeasures which have been developed in efforts to improve driver behavior.

There is an extensive literature on driver behavior at rail-highway crossings, which constitutes only a portion of the considerable published work on grade crossings in general. This review of necessity is delimited to consideration of driver behavior. However, "driver behavior" is broadly conceived to include perception, knowledge, compliance, risk taking, decision making, motivation, and impairment.

1.2 METHOD

Relevant literature on driver behavior at rail-highway crossings was identified through several means. These included computerized bibliographic search, manual library search, review of the major previous bibliographies, and contact with experts active in the field. An initial master bibliography was assembled by combining the potentially promising citations from all of these sources. The references in this initial listing were then secured and screened to refine the bibliography. Additional references were added as they were identified in the course of the work. The final bibliography is attached as Appendix A.

The references in the bibliography were reviewed, together with other relevant sources on important aspects of driver perception and behavior. Based on this review, the study report was developed. The organization of the report discussion is based on the task demands facing the driver as he or she approaches a rail-highway crossing. The driver must become aware of the presence of the crossing. This is accomplished through detecting and comprehending traffic control devices, and through direct observation of the crossing. The driver must understand the demands and responsibilities engendered by the crossing. He or she must perceive the status of the crossing: the presence or approach of trains, the temporal gap before train arrival, warning lights, barriers, other traffic, etc. Having acquired this information, the driver must make decisions about the risks involved and what actions to take. Compliance with legal requirements also must be considered. Thus the driver must become aware, collect and evaluate information, make a decision, and execute that decision. The following discussion of "contributing factors" to driver behavior at rail-highway crossings is organized around this sequence of events.

Following the discussion of contributing factors, there is a consideration of specific driver characteristics that relate to rail-highway crossing safety.

Subsequently, countermeasures that have been developed to improve driver behavior at rail-highway crossings will be described. These include not only physical changes to the roadway environment, but also education, enforcement, and other approaches.

2. CONCEPTUAL MODELS OF DRIVER BEHAVIOR AND INFORMATION NEEDS

Many different models of driver behavior or driving subtasks exist. Some of these purport to be explanatory or heuristic models, while others are taken as descriptive or organizational concepts. Some are very extensive, others of limited scope. They may deal with perception, decision making, vehicle control, risk taking, and many other aspects. No single behavioral model of the driver can be characterized as the generally accepted model today.

However, one model has been particularly influential in traffic engineering concepts, and this model underlies the discussion in various major reports in the rail-highway crossing area. This is the Positive Guidance model (e.g., Post, Alexander, and Lunenfeld, 1981). This model has been used to describe driver requirements in the "Railroad-Highway Grade Crossing Handbook" (Tustin, Richards, McGee, and Patterson, 1986), as well as in various other reports and guides. The Positive Guidance approach divides a hazardous highway site into a series of information handling zones, based upon the informational requirements and temporal response requirements at each point. This model can provide a useful frame of reference for considering the demands that a rail-highway crossing imposes on the driver.

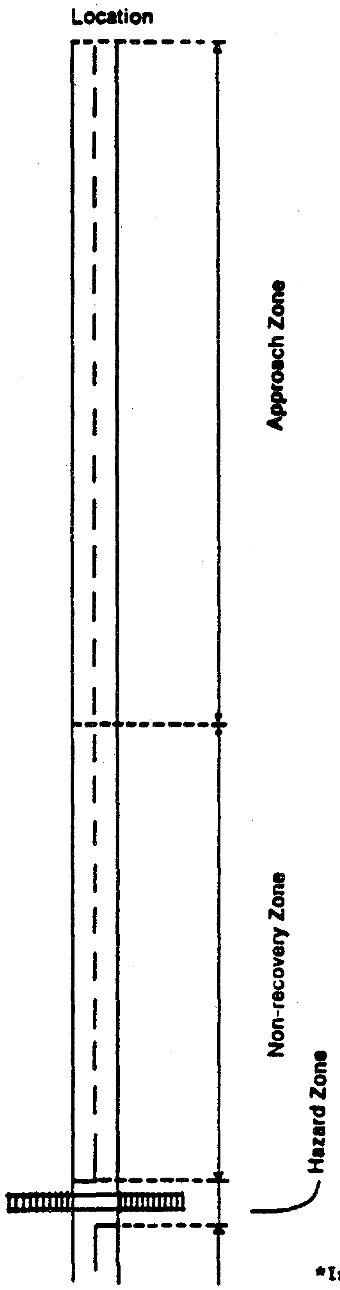
The major human factors safety concerns at rail-highway crossings are perceptual and cognitive; that is, they involve seeing, comprehending, and making decisions. Motor skills related to vehicle handling at these sites generally are not especially demanding. The issues therefore center on what has been termed the "Guidance Level" of driving performance, as distinct from the "Control Level" (dealing with physical manipulation of the vehicle, maintenance of position and headway, etc.) and the "Navigational Level" (determining route, finding destination, etc.). The Positive Guidance concept has been useful because it focuses on the driver's process of acquiring and using the needed information.

Five information handling zones are defined: the advance zone, approach zone, non-recovery zone, hazard zone, and downstream zone. The advance zone is the area preceding the specific demands of the hazard under consideration. This transitions into the approach zone at the point defined by the decision sight distance. The approach zone ends, and the non-recovery zone begins, at the point defined by the stopping sight distance. The non-recovery zone transitions into the hazard zone at the point where the hazard actually exists (for grade crossings, normally defined as 15 feet prior to the nearest track). The downstream zone is the area after which the hazard, or its effects (e.g., traffic actions), are past. The "Railroad-Highway Grade Crossing Handbook" provides engineering definitions to quantitatively define each of these zones for traffic engineering practices.

FIGURE 2-1

taken from Tustin, Richards, McGee, and Patterson, 1986

Table 9. Needed Information and Desired Responses of Vehicle Operator



Needed Information	Desired Response
Approach Zone	
Crossing is ahead	Look ahead for more data on present conditions
Train may be present	Look ahead
Non-recovery Zone	
If:	
1) Train is on crossing	Begin stop maneuver
2) Train is approaching crossing	Begin stop maneuver
3) Train not in vicinity	Be cautious and look left and right for information
Hazard Zone	
If:	
1) above	Stop
2) above and velocity and direction of train	Go/No-go across tracks
3) Verification of no train	Look and go across tracks

*Information should be obtained from signs, markings, and signals provided at, and in advance of the crossing. Vehicle speed should be adjusted to correlate with the length of the Non-recovery Zone.

The information needed by the driver in order to perform the desired actions can be related to the information handling zones. Figure 2-1, which is taken from the "Railroad-Highway Grade Crossing Handbook" (Tustin et al., 1986), illustrates this in simplistic form. The actual driver response required is determined in part by the type of traffic control device present at the site, its status, and the proximity of a train. This is further discussed below. However, Figure 2-1 serves usefully to show how the information handling zones are related to driver information needs and the time and distance requirements for vehicle control.

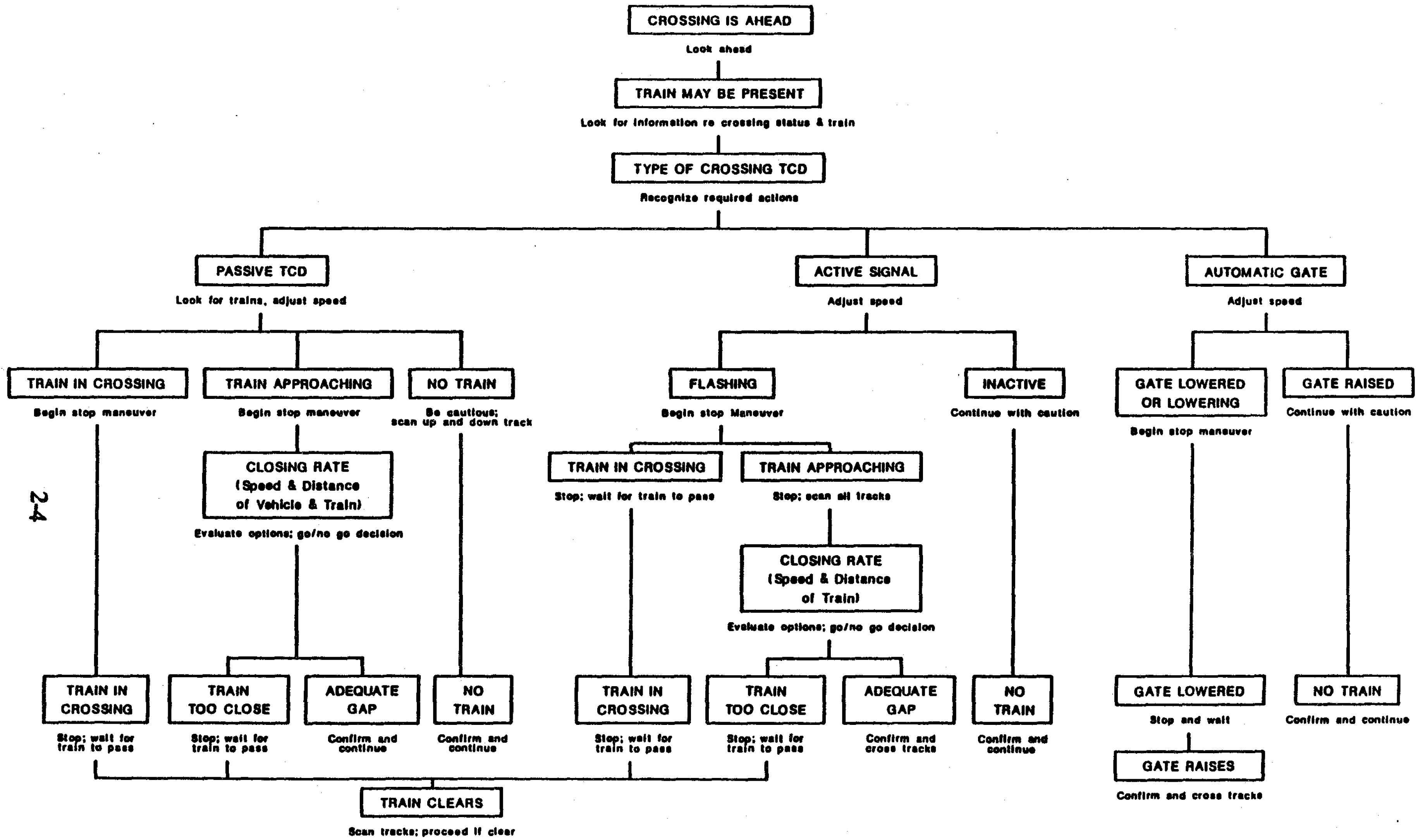
While this model will be useful for considering driver behavior at rail-highway crossings, it is important to distinguish the definition of the information handling zones for traffic engineering practices versus the definition of these zones for modeling driver needs and behaviors. For example, in defining the transition from the approach zone to the non-recovery zone, traffic engineering practice is necessarily based on fairly conservative assumptions about driver reaction time, vehicle braking distance, vehicle length, visibility conditions, and so forth. For design purposes, we for example may be viewing a slow acting truck driver at night with poorly corrected vision. In reality, any particular combination of driver/vehicle/trip/environment may define different transition points between zones. Thus the model above is a useful way of describing the demands on the driver, but the precise definition of the location of these points, as defined by traffic engineering practice, should not be taken as an appropriate definition for every passing vehicle. In fact, these points will be conservatively defined for most traffic. This may have implications for the credibility of signals for some drivers, and should also be kept in mind in interpreting the findings of some field studies (e.g., encroachment into a pre-defined non-recovery zone does not necessarily imply that particular driver cannot recover if necessary).

Figure 2-2 presents an expanded treatment of the driver information needs indicated in Figure 2-1. For each information item in the sequence, there is also a brief indication of the desired driver behavior. Note that there are different "paths" depending on the type of traffic control device at the crossing and the proximity of a train. This illustrates the point, made by various authors, that the advance information required by the driver depends on the nature of the crossing, yet advance warnings and markings fail to differentiate these situations for the driver.

A failure at any point along any of the information need sequences in Figure 2-2 could result in an accident. If a driver fails to acquire the information, acquires it inaccurately, or acquires it too late, he will not be able to act appropriately; even if the information is accurately acquired, decisions made about appropriate actions could be incorrect. The problems of perception, knowledge, decision making, and compliance, discussed in the body of this review, can be related to the information needs and actions illustrated in Figure 2-2. In a major investigation of causal factors in railroad-highway grade crossing accidents, Berg, Knoblauch, and Hucke (1982) examined the kinds of errors that underlie

FIGURE 2-2

DRIVER INFORMATION REQUIREMENTS AT RAIL-HIGHWAY CROSSINGS



vehicle-train collisions. Although the study did not include all types of such accidents (for instance, alcohol-related accidents were excluded, and crossings with automatic gates were not considered), some important findings emerged. Both recognition errors (detection or higher order perceptual failures) and decision errors (failure to properly interpret information or select appropriate maneuver) occurred frequently, and at various points in the decision process (illustrated by decision trees). Of course, some accident scenarios were more frequent than others, and these depended in part on the type of traffic control devices used. However, of most interest here, there was no single error path that accounted for the bulk of the accidents. Rather, failures of perception and decision making occurred all along the sequence. Many different scenarios, as illustrated by Figure 2-2, need to be considered in discussing the safety problems at rail-highway crossings. Furthermore, this suggests that no simple solution is likely to address all, or most, grade crossing accidents.

Although as indicated earlier, there is no single generally accepted model of driver behavior, there is one important feature shared by many of these models. Most comprehensive models have found it essential to incorporate the concept of "driver expectancy." This recognizes that the driver responds not only to what is physically present, but also to what is anticipated based on past experience. Although the precise definitions of "expectancy" have differed somewhat, the essence is that the driver is prepared to perceive or respond to some circumstances, and is unprepared for others. An expectancy may be based on an integration of long-term driving experience; for example, there is an expectancy that freeway exits will appear on the right, not the left. Or an expectancy may be based on recent, short-term experience. For example, if a driver has been traveling along a narrow road with many sharp turns, he has an expectancy regarding upcoming geometric demands which will be different than if he had been traveling a long straight highway. The concept of expectancy is important because driver performance tends to be rapid, accurate, and largely error free when expectancies are met; performance may be slow, inaccurate, or inappropriate when expectancies are violated.

Expectancies of many kinds may play a role in driver behavior at rail-highway crossings. For example, these expectancies could relate to: the likelihood of encountering a crossing; the types of traffic control devices that will be employed; the likelihood that a train will be in the vicinity; the warning time provided by flashing signals; the length of delay caused by the train; the probability of being cited for violating a crossing-related law; the probable speed of a train; and so forth. A driver's expectancies at a crossing site can influence what he sees, how he interprets it, what risks he is willing to assume, what response alternatives appear appropriate, and other aspects of behavior.

Expectancy is thus an important aspect of driver behavior in general, and for the rail-highway crossing situation in particular. In understanding the actions and failures of drivers, and methods for improving safety, the role of driver expectancies must be kept in mind.

3. CONTRIBUTING FACTORS

3.1 COMPREHENSION

This section concerns the knowledge that the driver brings to the rail-highway crossing situation. A driver must understand what he is encountering, what the appropriate actions are, and what the hazards are. Therefore this section deals with the comprehension of traffic control devices (TCD's), which are the formal means of communicating the location and nature of a rail-highway crossing; the understanding of the legal requirements and safe actions at grade crossings; and the recognition of the important factors related to vehicle-train accidents.

3.1.1 Comprehension of Traffic Control Devices

Five common traffic control devices relate to rail-highway grade crossings, as specified in the Manual on Uniform Traffic Control Devices (MUTCD):

1. Railroad Crossing (Crossbuck) Sign (R15-1), with an associated auxiliary sign (R15-2) indicating the number of tracks if more than one.

2. Railroad Advance Warning Sign (W10-1), with other versions (W10-2,3,4) for use on roads paralleling tracks.

3. Pavement markings, consisting of an X, the letters RR, traverse lines, and a no passing marking (for two-lane roads).

4. Flashing light signals (post or cantilever mounted)

5. Automatic gates (used with flashing light signals)

There have been a number of investigations of how well the driving public comprehends the meaning of these TCD's. The general finding is that there is a good understanding of the primary general message that there is a railroad crossing in the proximity, and that the active devices (flashing lights, gates) indicate there is a train in the proximity. However, there is often poor discrimination of the precise meaning and location of the TCD's, and of the driver actions they require. Some of these confusions are potentially dangerous. Most of the reported studies are limited in that test subjects were recruited from a limited geographic area, and so cannot be taken as representative of a national sample. However, there is reasonable general agreement between studies, and no apparent reason to consider any region as anomalous.

In evaluating studies of sign comprehension, one must be cautious about literally interpreting the percent of the test subjects cited as giving "correct" answers (Lerner and

Collins, 1980). This percentage is often a function of the general method, the specific choice alternatives (in multiple choice procedures) or the stringency of scoring. In fact, there are degrees of understanding. For example, a driver may be "correct" in understanding that the railroad advance warning sign indicates the presence of the crossing, but incorrect in believing the sign to be used at the crossing itself, rather than in advance. Furthermore, the manner of asking the question can influence the percentage of correct answers. For example, one may present a TCD and ask the test subject to write down its meaning; this will probably yield a lower percentage correct than a procedure which provides the meaning, and then asks the subject to choose which of several alternative TCD's matches the definition. Thus while these studies are important in showing where substantial numbers of people misinterpret a TCD, and illustrate what those misinterpretations may be, the precise percentages reported should not be taken too literally. Variation in the findings from one study to another may be partially accounted for by methodological differences.

Both the railroad advance warning sign and the crossbuck sign are well understood to relate to a grade crossing. For example, Ruden, Burg, and McGuire (1982), presenting filmed drive-by's to subjects, found essentially 100% comprehension of the general message of the advance warning sign; Fambro and Heathington (1984) found better than 90% correct answers using a questionnaire. Similarly for the crossbuck, Ells, Dewar, and Milloy (1980), in a Canadian study, found comprehension of the then-standard Canadian crossbuck (which contained the legend "Railway Crossing," in contrast to the U.S. "Railroad Crossing") to approach 100%. Kemper (in press) likewise found nearly 100% correct responses to the standard U.S. crossbuck.

However, beyond the general recognition that the message is related to a rail-highway crossing, the specific meanings of these TCD's are not as well understood, and the distinction between the advance sign and the crossing sign may not be appreciated. Tidwell and Humphreys (1981) surveyed 829 drivers at a Tennessee license renewal station in 1979, and Richards and Heathington (1988) recently updated this work at stations in three Tennessee cities. When asked to choose the correct meaning of a TCD from among several alternatives, less than two-thirds (64%) were correct for the advance warning sign, and 71-76% were correct for the crossbuck. Fambro and Heathington (1984) found very similar percentages. Sanders, Kolsrud, and Berger (1973), who interviewed drivers at actual grade crossing sites, also reported confusion in the precise meaning of these TCD's. Interestingly, Richards and Heathington also evaluated a sample of Knoxville police officers, and found that, while better than the public at large, they shared the same confusions.

The safety implications of the failure to understand the more precise meanings of the advance warning sign and the crossbuck are not clear. Certainly the message that a grade crossing is in proximity is getting across. Probably the more dangerous confusion would be to interpret the crossbuck as an advance sign, and thus not control vehicle speed and make a visual search sufficiently in advance. However, since the advance warning sign normally is also present prior to the crossbuck, the risk may be diminished. Richards and Heathington (1988) also found that many respondents chose a definition of the advance warning sign that indicated the driver must slow to 20 mph; the authors point out that this could cause rear end collisions, as well as operational conflicts. However, there does not appear to be any direct evidence regarding the magnitude of the safety implications related to confusion over the precise meanings of the crossbuck and the advance warning signs.

The railroad advance warning sign is unique in its round shape. Most advance warning signs, as presented in the MUTCD, are diamond-shaped. This could contribute to confusion over its meaning. Ruden et al. (1982), recognizing this, developed and evaluated some alternative sign prototypes. These also had the advantage of being able to incorporate into the sign a directional arrow to represent the path ahead, which the authors felt might help direct the driver's visual search. Ruden et al. developed these signs as an integral part of an activated advance warning system, which used flashing yellow signals to indicate the presence of a train. However, they may also be considered in the context of passive signing, and were tested for comprehension as such. The three signs developed all presented some version of the "RXR" symbol on a yellow, diamond-shaped field. The signs were also unique in incorporating red (as well as yellow, black, and in two cases, white) into the sign. The initial comprehension (measured by having subjects write the meaning of signs encountered in a filmed drive) of these prototype signs appeared quite good (88-96%), although this may be contrasted with the 100% correct comprehension of the standard advance crossing sign. When the subject's answers were scored with respect to the precision of the answer (crossing is ahead or crossing location), there was some indication of a superiority of the new signs. While the experiment was not designed to specifically address the confusion in precise meaning among crossing-related signs, it does suggest that a railroad advance warning sign which better conforms to highway sign stereotypes might reduce this confusion. Schoppert and Hoyt (1968) also suggested a variety of advance warning signs, all using diamond-shaped sign fields, which they felt better met drivers' stereotypes regarding warnings, had more meaningful graphic content, and provided improved information content by discriminating active and passive crossing sites.

Crossbuck designs which differ from the standard have also been evaluated for comprehension. Ells et al. (1980) compared crossbuck versions that contained the Canadian "Railway Crossing" message (in black letters, on a white background), with "blank" crossbucks of either white with a red border, or yellow with a black border. The version with lettering was the Canadian standard at the time, although the blank white-with-red border version is now standard. Subject-provided definitions were nearly 100% correct for the versions with lettering, versus 64-77% for the white-with-red version, and 40-68% for the yellow-with-black version. Kemper (in press) recently conducted a similar study in the Washington, D.C. area. He compared the standard U.S. crossbuck (with the "Railroad Crossing" legend) with blank white versions that had either a red or a black two-inch border. Subject-provided definitions were nearly 100% correct for versions with the written legend. For the other versions, the percentage correct ranged from 70-83%.

This experiment had a methodological peculiarity in that all subjects saw the signs in the same sequence (contained within a set of 40 slides of various signs and markings). In general, the crossbuck versions with a written message were not presented until after the blank versions. Thus, order effects were confounded with sign type. Furthermore, there was a drop in comprehension after the initial presentation of the blank crossbuck, with some indication this may be attributable to some subjects trying to make a discrimination in meaning between sign versions because they felt that different versions necessarily must have different meanings. Despite these problems, it appears that the crossbuck itself has meaning to many subjects, even without the wording. The report did not indicate to what extent subjects realized that the device identified the site of the crossing, rather than serving as an advance warning. Schoppert and Hoyt (1968) suggested some sign alternatives that incorporate the crossbuck onto a larger sign field, rather than in isolation. This not only might provide better target value, but in placing the crossbuck on an inverted triangular field, the authors felt that the meaning might be reinforced by highlighting the similarity with the "yield" sign in terms of the motorist's obligation.

In addition to signs, pavement markings are specified in the MUTCD for both active and passive crossings. Subjects' understanding of these markings is not clear from the literature. Tidwell and Humphreys (1981) and Richards and Heathington (1988) showed subjects at license renewal stations three different illustrations of pavement markings, and asked which is the standard marking for railroad crossings. About 70% chose the correct alternative. Of course, this observed percentage may depend on the other choice alternatives (which included the "RR" or the "X," but not both). It certainly does not indicate how many people would have known that the standard marking precedes a grade crossing. Kemper (in press), in the experiment mentioned above, did have subjects provide the perceived meaning of the pavement markings. The motivation for this part of the study grew from a concern over the maintenance of the standard marking: the "R"s, as well as the outer portion of the "X," are subject to wear from tires. Eliminating the "R"s, and possibly reducing the size of the "X," could reduce maintenance needs. Kemper addressed the question of whether such changes would degrade motorist comprehension. The standard marking was correctly defined 98% of the time, although an advance warning sign was also present in the photographed scene. When the "R"s were eliminated, and no other signs were present, the correct percentages were 25% for a "small" "X," 45% for a "medium" sized "X," and 31% for a "regular" "X" (full width of lane). As noted above, this experiment suffered from a confound of marking type with the order of presentation, which was the same for all subjects. The percentage correct increased steadily throughout the sequence of six slides of markings (within the context of a full set of 40 slides). Overall then, it is difficult to infer what the level of comprehension of the standard marking (last in the sequence, and containing an advance warning sign in the scene) is, and to what degree the "X" and the "RR" contribute to meaning.

The two standard active TCD's at grade crossings are flashing light signals and automatic gates. Drivers appear to understand the meaning of these devices, although they do not necessarily fully understand and/or comply with the actions required by these devices. A potentially dangerous misunderstanding, however, is in the deployment of these active TCD's. There is some indication that many drivers believe that all, or most, crossings are protected by an active device. Since the absence of a signal at an active crossing implies a safe condition, such drivers may be at risk when approaching a passive crossing, where no such safety should be inferred. Sanders et al. (1973) interviewed 1267 drivers in the field just after they passed a grade crossing. At active crossings, 22.8% of the respondents indicated they thought all crossings had signals or gates; at passive crossings, 15.4% also thought this. In Tidwell and Humphreys' (1981) large survey at a license renewal station, over half the respondents, when shown a picture of a flashing signal array, chose answers that indicated the signal is used at all, or all but rarely used (by trains), crossings. This is an alarming high frequency of misunderstanding, and is widely cited. However, in Richards and Heathington's (1988) update of the Tidwell and Humphreys' survey, this figure was about 23%, still large but less than half of the earlier finding. The reasons for this difference are not clear. It should be noted though, that in these surveys some respondents may have been responding to the crossbuck element that is part of the signal display. Since the wording of the survey question did not focus on the lights per se, and since the crossbuck is equally prominent in the figure shown, it is possible that some people who indicated that the device is used at all crossings may have been attending to the crossbuck itself (which is to be used at all crossings). Nonetheless, it is apparent from the Sanders study and the Tennessee surveys that a substantial number of drivers do not expect to encounter crossings without active devices.

Flashing lights are well understood to mean "a train is coming;" Tidwell and Humphreys (1981) found 97% correct in their survey, and Fambro and Heathington (1984), in a smaller survey, found 100% correct. Nearly all of Richards and Heathington's (1988) respondents understood flashing lights meant that the driver should stop at the crossing (although they did not necessarily understand what subsequent actions were permitted). Similarly, nearly all drivers understood a lowered gate to require a stop (Fambro and Heathington, 1984; Richards and Heathington, 1988), although none of the research identified actually asked people to provide their own interpretation of what the gate TCD configuration (whether shown raised or lowered) meant. However, it appears reasonable to assume that there is good comprehension of the general message of flashing lights and gates. People's perceptions of the warning time provided by these devices (the delay between onset of the signal and arrival of the train) is quite variable and not particularly good; this will be discussed further in the section of this review on decision making.

In addition to the primary crossing-related TCD's discussed above -- the crossing sign (crossbuck), railroad advance warning sign, pavement markings, flashing light signals, and automatic gates -- other TCD's have sometimes been employed. Driver comprehension of primary regulatory signs and signals, such as stop signs and the circular indications of traffic control signals, is quite good. Active advance warning devices have also been used, such as hazard identification beacons or variable message signs (Ruden et al., 1982).

However, there appears to be little formal evaluation of motorist comprehension of these TCD's within the context of rail-highway grade crossings.

3.1.2 Comprehension of Driver Responsibilities

For the rail-highway crossing situation, the motorist must be aware of the general degree of safety responsibility that rests upon him, and also of the specific actions and responsibilities required of him by law.

Because the train is very limited in the avoidance actions it can take, the responsibility for accident avoidance rests almost entirely with the vehicle operator. There is some indication that many drivers do not fully appreciate this fact. In an impending collision, the train obviously cannot alter its path, and its braking distance far exceeds that of roadway vehicles, even heavy trucks. While the train's braking distance depends on numerous variables, some comparative estimates from the Operation Lifesaver public education courses illustrates the magnitude of the difference. At 55 miles per hour, and assuming dry road surface, tires and brakes in good condition, various vehicles have the following stopping distances:

Lightweight passenger car:	about 200 feet
Commercial van or bus, medium load:	about 230 feet
Tractor/trailer:	about 300 feet
Loaded train, 100 cars:	about one mile

Yet despite the magnitude of this disparity, a significant portion of the public fails to recognize this, as seen across several recent questionnaire studies which asked people to compare the stopping distance of a train vs. a large truck (Fambro and Heathington, 1984; Tidwell and Humphreys, 1982; Richards and Heathington, 1988). The correct percentage actually observed appears to depend to some extent on the choice alternatives given (e.g., allowing a "don't know" response). Summarizing across the studies, however, it appears that about 10% of the respondents felt they did not know whether a heavy truck or a train required greater stopping distance, while from 3-7% incorrectly thought a truck required the same or greater stopping distance. Since the limited ability of the train to actively avoid a collision is a prime reason why so much responsibility is placed on the driver, the failure of perhaps 10% or 20% of the driving public to realize this may have important safety implications. As discussed earlier, it also appears that a significant minority of drivers believe all (or all but rarely used) crossings have active signaling devices; again, this indicates a failure to recognize the driver's own level of responsibility for collision avoidance. In Richards and Heathington's (1988) survey, respondents were also asked what actions the train operator should take if he saw cars crossing the track ahead of the train; these authors felt that the choice of active strategies (e.g., 27% said slow the train, 18% said stop the train) also indicates a failure of drivers to accept total responsibility for collision avoidance.

Considering the specific actions and responsibilities required by law in response to various crossing-related TCD's, the limitations of driver understanding are rather remarkable. In a number of cases, a substantial majority of drivers has a wrong opinion about the appropriate action required. As already indicated in the consideration of comprehension of TCD's, drivers do appear to appreciate that the various devices indicate the presence of a crossing, and that the flashing lights and the crossbuck require a stop. However, beyond this there is real confusion. While state laws differ somewhat in their requirements for driver behavior at rail-highway crossings, most are quite similar and resemble the Uniform Vehicle Code. The appropriate actions, following the code, for the typical TCD's are:

- Automatic Gates: Stop, and do not proceed until the gate has been raised.
- Flashing Light Crossings: Stop, but may proceed after stopping if it is safe to do so.
- Passive Crossings: Stop is required only if the train is an immediate hazard or in hazardous proximity to the crossing; stopping, or even slowing, is not specifically required otherwise.

The research literature has been quite consistent in showing that drivers do not have a clear understanding of what their responsibilities are. The greatest error is for passively protected (crossbuck only) crossings, where the fallacious "stop, look, and listen" rule is widely cited. Across various studies (e.g., Tidwell and Humphreys, 1982; Fambro and Heathington, 1984; Richards and Heathington, 1988; Tidwell and Humphreys, 1981), a definite majority of subjects (54-84%) indicated that the appropriate behavior is to stop at the tracks and look for a train. If people act on this erroneous belief, it could cause traffic conflicts (in particular, rear-end collisions) and operational problems. Interestingly, however, observational studies have found very few vehicles (excepting those required by law, e.g., school buses) to actually stop at crossings. Thus if many people do believe a stop is required, they routinely disregard this "rule." While the perceived rule may be more conservative than the actual requirement, this may not actually enhance the chances of avoiding collision with a train. The presumed requirement may appear as unreasonable to motorists, and so contribute to credibility problems and lack of compliance with grade crossing behavior in general.

At crossings protected by flashing signals, nearly all drivers recognize that they must stop, although a few see the lights as advisory or requiring slowing only (Tidwell and Humphreys, 1981; Richards and Heathington, 1988). However, most drivers erroneously believe that they must remain stopped until the flashing lights terminate (88% in Fambro and Heathington's study; 74% in Richards and Heathington's study). They do not recognize that the driver is given the option of proceeding if safe. Again the possible unreasonableness of the presumed rule could contribute to general problems of credibility and non-compliance.

With the exception of a few states, a driver must stop for a lowered gate, and remain stopped until the gate is raised. This is well understood by nearly all drivers, but a small number (3-5%) appear to believe the driver may stop and proceed around the gate if safe (Richards and Heathington, 1988; Fambro and Heathington, 1984).

Considering the driver requirements for the various crossing-related TCD's, it is apparent that they parallel the requirements of various intersection-related TCD's. A rail-highway crossing is, of course, an "intersection" involving two different transportation modes. The crossbuck at a passively signed intersection functions as a "yield" sign: the driver must look for approaching traffic and yield the right-of-way if there is any potential conflict. The active flashing light signal functions like a (two-way) stop sign or flashing red traffic signal: the driver must come to a complete stop prior to the intersection, and proceed only when there is no conflicting traffic. The automatic gate functions like a normal traffic signal: when activated, it parallels the red phase, so that a car must stop and wait until the signal terminates. It is ironic that the common intersection-related TCD's are so well understood by the public, and yet despite the close parallels, the analagous TCD's for rail-highway crossings are so poorly understood.

This raises the question of why, if the analagous intersection-related devices are much better understood, can they not be used or adapted for grade crossings as well? This issue has long been debated and remains controversial. Stop signs are sometimes used at crossings, depending on local practice. Objections to this practice include breeding contempt for and reducing compliance with stop signs; traffic delay, energy consumption, and operational problems; and increases in non-train related accidents (in particular, rear end collisions). Sanders, McGee, and Yoo (1978) addressed a number of these concerns in a field and accident evaluation study. Some of the findings will be discussed elsewhere, but in particular the "disrespect" or generalization of non-compliance issue should be noted. This is because the same argument is brought to bear for using any of the intersection-related TCD's for rail crossing applications. In fact, observance of stop signs was found to be lower at grade crossings than at highway intersections (60% vs. 80%). However, degradation of compliance at a nearby intersection stop sign was not detectable as a result of the presence of a rail crossing stop sign. However, it should be noted that reduced respect for stop signs is not necessarily an effect that might be anticipated at one particular intersection as the result of one particular rail crossing sign. Rather, there is concern over system-wide effects, such that the more frequent presence of stops at rail crossings may lead to more general disregard for stop signs at other situations. This general concern, for stop signs, yield signs, and other such TCD's, remains unresolved.

Two potential sources of confusion that could contribute to problems of motorist comprehension of appropriate actions should be noted here. One is the variability between states in specific laws regarding driver behavior at crossings. For example, a few states permit the driver to legally drive around a lowered gate, after stopping, if the train is not imminent. The contribution of this variation to driver confusion is unknown.

The other potential source of confusion comes from the fact that railroad advance warning signs, pavement markings, and crossbucks do not in any way discriminate between crossings with gates, lights, or only passive protection. Thus although different driver behaviors are called for, identical TCD's are used, and this could blur distinctions for the driver. In contrast, the MUTCD specifies quite distinct advance warning signs for analagous highway intersection conditions of "stop ahead" (W3-1a), "yield ahead" (W3-2a), and "signal ahead" (W3-3). Various authors have argued that the railway crossing TCD's should discriminate between crossing types because drivers need this information (discussed later in this review). We add to this the speculation that failure to discriminate in signage and markings may also contribute to the failure of some motorists to understand that different behaviors are called for.

3.1.3 Comprehension of Accident Factors

In order to evaluate the hazards at a crossing and to recognize their responsibilities, drivers must appreciate the dynamics of vehicle-train accidents and the kinds of risks that are involved. There is evidence that many drivers do not have a good appreciation of the accident factors.

One example is that drivers do not recognize the limitations of the train operator in effecting any crash avoidance maneuver in the event of a conflict. As discussed above, some drivers do not appreciate the great disparity in braking distances, and the fact that the responsibility for avoiding a conflict thus rests primarily with the driver. Related to this is the finding, also discussed previously, that substantial numbers of motorists believe they will receive active protection at all grade crossings. The absence of active warnings is a factor the driver must recognize, and responsibility for detecting a train must be accepted.

Another important factor is the frequency and severity of sight limitations. While visibility restrictions are common (e.g., NTSB, 1986), drivers may not expect or recognize this. In Sanders et al.'s (1973) field study, all of the sites used had a limitation of sight distance along the track in at least one direction. Yet only 22% of the drivers interviewed at the sites indicated that something made it hard to detect trains approaching the crossing. In interpreting such findings, Berg (1985) argued that this "implies that most drivers either do not even consider the possibility that sight distance may be restricted, or they have no reasonable basis for judging that the sight distance is inadequate. The latter should not be unexpected because generally no information is provided regarding train speeds, sight obstructions, or maximum recommended approach speeds." Various field observations of overt driver looking behavior (head turning), discussed further in the following section, confirm the insensitivity of motorists to sight restrictions.

Drivers also appear insensitive to the risks of multi-track crossings. One accident scenario at such sites is that the motorist waits for a train to pass, and then proceeds; however, the passing train obscures the approach of a train coming in the other direction, and this second train collides with the vehicle. In addition, with multiple tracks it will take more time for the vehicle to clear the crossing, and from a distance it will be difficult to judge which track an approaching train is on. Although the number of tracks (if more than one) is indicated by a supplementary sign affixed to the crossbuck, Sanders et al. (1973) found that drivers generally did not know why this information was important.

Another problem at rail-highway crossings is the difficulty of accurately judging the speed, distance, and closing rate of a train. This will be discussed further in later sections. The important point here is that people are probably not aware of how inaccurate their judgments are, and the related need for extra caution. Most of our experience in gap perception comes from highway traffic situations -- crossing roads, turning against approaching traffic, merges, etc. We routinely get "feedback" about the accuracy of our judgments in these situations. In contrast, trains are infrequently encountered, and feedback is very limited. Thus it may be expected that drivers who are unaware of the difficulties of judging the approach of a train will overestimate their accuracy, based on generalization from inappropriate situations.

Another factor drivers may not be fully appreciative of is the variability inherent in the crossing situation. For example, train speeds are highly variable, as is the time from activation of a warning to the arrival of the train. There have been studies which have considered what the typical expectations of people are regarding such factors. For instance, Sanders et al. (1973), Tidwell and Humphreys (1981), and Richards and Heathington (1988) all had people indicate how long they thought it generally took for a train to arrive after signal activation; all three studies found a great deal of variability between people, as well as a pronounced tendency for overly-long estimates. However, none of these studies considered how sensitive people are to the actual variability of these times. It is not clear whether drivers appreciate how brief a warning interval may be, how fast an approaching train may be traveling, etc.

In addition to factors specific to the railroad crossing situation, also relevant are various accident factors that are common to other traffic situations as well. For example, drivers tend to underestimate their required braking distances, and further underestimate the additional stopping distance required by wet or icy roads. Night driving raises a number of problems. For various reasons related to both visual functioning and highway engineering practices, drivers fail to appreciate the limitations to visual detection at night (Leibowitz and Owens, 1986), and headlights are routinely overdriven. It may be difficult, for either day or night, for drivers to appreciate how an object as large, dramatic, and noisy as a train can fail to be perceived.

In summary, there are factors about rail-highway crossings that are importantly related to accident potential, and that drivers should be aware of. In many cases, it appears motorists do not comprehend the significance of these factors.

3.1.4 Comprehension – Summary

This section has addressed how well motorists comprehend that which is important for acting appropriately at rail-highway crossings. Comprehension of three general types of factors was considered: understanding of the information communicated by formal traffic control devices; understanding of the requirements and responsibilities of the driver in various crossing situations; and understanding of certain factors that can contribute to accidents at grade crossings. In all three cases, it was found that the knowledge that drivers bring to the grade crossing situation is sometimes limited or inaccurate.

3.2 DETECTION AND RECOGNITION

In order to draw on his understanding of traffic control devices, a driver must first detect one or more critical features of a rail-highway crossing. This section covers driver detection of cues for a rail-highway crossing, the possible interference of other stimuli at the crossing that compete for his attention, and the influence of his expectations about encountering a train on the search for and detection of trains.

The detection process is quite complex when one considers all the aspects of the rail-highway crossing that the driver must be aware of in order to choose an appropriate speed and path. In the case of a passive crossing, the driver must detect:

1. that there is a rail-highway crossing ahead,
2. that it is passively rather than actively protected (e.g., by detecting the absence of gates or flashing lights),
3. the crossing itself, and
4. the presence or approach of a train.

The looking behaviors necessary to detect the train will differ, depending on the train's location and on the alignment of the roadway with the tracks. Moreover, the driver's view of the train may be obstructed. In order for him to modify his approach speed and looking behavior to take account of the restricted sight distance, he must first detect the presence of visibility restrictions. Once a train is detected, it must then be recognized as a potential hazard and a decision made about whether to stop or proceed. At the same time that these detections must be made, the driver is exposed to other inputs near the crossing, such as other vehicles or adjacent intersections, that compete for his attention to the primary cues for safely negotiating the crossing.

3.2.1 Visual Detection and Recognition

Some general principles of human visual detection and recognition can be applied to the complex set of detections required at a rail-highway crossing. Detection is concerned with whether or not an observer senses anything there, while recognition has to do with identifying what it is. An observer can become alerted to or aware of the presence of an input, but not have the capacity to recognize it as a member of a familiar class of objects. For example, at night, a driver may be aware of a point source of light that is moving in a particular direction, but may not have sufficient information to recognize it as a locomotive headlight. In the case of a driver at a rail-highway crossing, we are interested in what facilitates or hinders his ability, not only to simply detect the presence of something, but also to identify it as a crossing-related cue. Therefore, factors that have been shown to affect recognition of objects and events are relevant to understanding the problems that a driver faces in detecting crossing cues.

First, the recognition process is influenced by the observer's expectations and by the physical context in which the input occurs. The driver brings to the situation some expectancy about the likelihood of encountering a train at a particular crossing or at crossings in general. A low expectancy of the presence of trains at a crossing would increase the time required to detect and recognize a train.

There is also evidence that it takes longer to detect an object when it occurs in an improbable context than when it occurs in a probable context (Biederman, Mezzanotte, and Rabinowitz, 1982). The judgment of whether a particular context is probable depends to a large extent on the past experience and knowledge of the observer. This finding would imply that an input such as an approaching train is more readily detected when the surrounding environment is consistent with the driver's expectations of what a typical rail-highway crossing looks like than when it is inconsistent. For example, if the presence of a train is not part of the driver's likely scenario for a passive rail-highway crossing, then he will take more time to detect the train at a passive crossing than at an active crossing. Note that we are not talking here about searching for trains, but about how the brain interprets the visual information it receives in order to recognize an object.

A related principle from the area of signal detection theory is that the higher the perceived probability of an event, the higher the likelihood that an observer will report having detected the event. If the driver assigns a low probability to the presence of a train at a rail-highway crossing, he will adopt a higher criterion for detecting the train, and this will increase his chances of missing the train. It is important to note that the criterion for detection is not consciously set, but rather corresponds to the amount of visual "evidence" required for detection.

Finally, the difficulty of the discrimination has been found to interact with the role of expectancy and context: The more difficult the discrimination that is required for recognition, the more likely it is that expectations and context will influence the observer's judgment (Glass and Holyoak, 1986). For example, if there is low brightness contrast between an approaching train and the background against which it is viewed, a low expectancy of encountering trains at rail-highway crossings will tend to be weighted more heavily than if the discrimination task were less demanding.

3.2.2 Dependent Measures of Detection

Some studies of detection have used laboratory settings, where a person's detection or non-detection of a target object can be directly measured. However, much of the research on grade crossings has used field observational methods. In the field, detection of cues related to the crossing can be measured only indirectly, and the following variables have been most frequently used:

1. head movements,
2. characteristics of the vehicle's speed profile on the approach to the crossing (e.g., deceleration rate), and
3. perception-brake reaction time (PBRT).

Head movements provide an indirect measure of looking behavior. An examination of the flowchart depicting driver information requirements reveals that some type of looking behavior is appropriate at both passive crossings and crossings protected by flashing lights. It is plausible to infer from a driver's head movements on the approach to a crossing that he is scanning the tracks for the presence of a train. However, the absence of head movements does not necessarily imply that no looking behavior has occurred. For example, as Sanders et al. (1973) have pointed out, when the view of the crossing is unobstructed and the driver can look for trains well ahead of the crossing, looking behavior is less likely to involve observable head movements. Thus, the usefulness of head movements as a measure of looking behavior will depend on the available sight distance.

The reasoning behind using speed profile information or PBRT as an index of detection is as follows. The more conspicuous the stimuli that inform the driver about the crossing, the earlier he will detect these inputs, and, therefore, the sooner and more gradually he will begin to slow down. When a warning device is activated, it is possible to measure the time between its onset and the activation of a vehicle's brake lights, and this time is referred to as perception-brake reaction time. The earlier the driver is able to detect the activation of the warning device, the faster his PBRT will be.

A few cautions are in order regarding the use of speed profile characteristics as measures of detection. First of all, the point at which the driver detects the crossing will not always be reflected in his speed profile: At crossings with passive warning devices or inactivated flashing signals, the driver is not required to slow down if he detects no conflict with the train. Secondly, even if one observes a decrease in speed on the approach to a crossing, it is difficult to specify what the driver is slowing down or braking in response to. He could be reacting to a familiar crossing location, to the salience of an advance warning sign, to the deceleration of a vehicle in front, to the activation of a warning device, or to the anticipated roughness of the crossing surface (Heathington, Fambro, and Richards, 1988).

3.2.3 Conspicuity of Traffic Control Devices

In order for a sign to be recognized and responded to, it must be detected at some level, draw the viewer's attention, and the information content of the sign must be "processed" to a level that can influence the driver. Detection and recognition of a sign is not an all-or-none process. Rather, there are levels and degrees of "information processing" of the message. For example, through eye movement studies, it may be established that a sign "drew attention" in the sense that a glance was directed at it. However, the driver may or may not become consciously aware of the sign. The research finding that the likelihood of a driver reporting the presence of a sign is related to the significance of the sign message (e.g., Johansson and Rumar, 1966) illustrates that the sign information must have been processed to at least a certain level in order that content could even begin to be a factor.

The property of a sign that causes it to be noticed and attended to is termed "conspicuity." While there is little direct research on the conspicuity of grade crossing signs in particular, there is a large literature on the conspicuity of passive signs and other TCD's in general. In fact, two kinds of conspicuity have been distinguished (Hughes and Cole, 1984). "Search conspicuity" refers to how readily an object is identified when it is explicitly being searched for. "Attention conspicuity" refers to the ability of an object to attract attention when it is not expected or explicitly sought for. While different, both are important at rail crossings. For example, the attention conspicuity of an advance crossing sign is important to alerting the driver to the upcoming hazard. The search conspicuity of the crossbuck is important to detecting the location of a crossing. The major findings of the literature on conspicuity will be briefly summarized for the implications regarding the detection of rail crossing signage.

Whether or not most passive traffic signs are readily detectable by drivers depends primarily on how detection is measured. If a research subject/driver is asked to indicate every time he sees a sign (search conspicuity), nearly all signs will be detected; if an uninformed motorist is randomly stopped and asked what sign he just passed, many motorists will fail to realize they even passed a sign. Other measures may yield intermediate findings. No one measure is correct. Rather, the question revolves around the degree to which signs are attended to and processed. It is clear that in many cases traffic signs have little impact. Good information on grade crossing signs is lacking. Interviewing drivers who had just passed a crossing, Sanders et al. (1973) asked questions about what features were noticed and alerted the driver to the crossing. Eighty percent of the respondents selected "remembered location" as the crossing cue that had first alerted them to the presence of a railroad crossing ahead. The advance warning sign, crossing protection device, railroad tracks, and crossing pavement markings were reported as the first cue noticed by 7.5%, 7.2%, 2.8%, and 1.9% of the drivers, respectively. However, since this procedure required unalerted drivers to remember and introspect about their recent mental processes, which they were not consciously attending to, the reported data need to be viewed skeptically. There is ample evidence from the literature on memory that people can mistake for an actual memory their after-the-fact reconstruction of what was most plausible, given the context of the event in question.

Many different factors have been identified as important to sign conspicuity. The key point to note is that conspicuity is not inherent in a sign per se, but is a characteristic of a sign in its environment. The same sign may be attended to at very different levels in a rural setting on a straight road, versus an urban setting with distracting stimuli, attention demands from interacting traffic, and limited viewing time. One sign may be more conspicuous in one environment, another sign in another environment. Therefore conspicuity features concern the sign, its immediate surround, and its environmental setting. Among the features identified as important to conspicuity are: size; shape; luminance (brightness); external brightness contrast (contrast of sign with surrounding area); internal brightness contrast (contrast of features within the sign image itself); color; color contrast; scene features of complexity, visual "noise" density; uniformity of sign surround; proximity of distractors; sign placement relative to expected driver line of sight, and relative to driver expectancy for sign location. All of these factors can play significant roles, and a severe problem with any one may seriously degrade conspicuity. Extensive work in Australia has pointed to size, location, and brightness contrast as especially important sign characteristics. In the United States, Mace, Perchonok, and Pollack (1982) examined how well a whole array of predictors correlated with driver recognition of signs. Their finding was that, in general, scene variables (complexity, clutter, etc.) were more strongly related to conspicuity than were surround (e.g., number of bright objects within 2-degree radius of sign), contrast (e.g., brightness contrast of sign with immediate background), or target (e.g., sign brightness) variables.

The effective conspicuity of railroad advance warning signs has been questioned (e.g., Ruden et al., 1982; Michael, 1968). Certainly the location and environment are often not favorable. The use of red (and white) within the sign has been suggested as one means of improving conspicuity (Ruden et al., 1982; Koziol and Mengert, 1978; Ells et al., 1980). The use of the unique shapes of rail crossing signs (round advance sign and crossbuck) is sometimes pointed to as an advantage for drawing attention, and other times questioned because it violates driver expectations about warning sign characteristics. However, it should be noted that a primary problem might not be with the visual characteristics, but with the "urgency" that the driver perceives in the message. Johansson and Rumar (1966) found wide differences in driver recall of visually similar signs, and argued that the degree of risk or demand presented by the sign message was the major factor. Therefore if drivers fail to judge a railroad crossing sign as especially significant, it will not get proper attention. Thus despite the critical importance of visual variables, problems in the detection of grade crossing signs may also relate to knowledge of the hazards and demands of grade crossings.

3.2.4 Detection and Recognition of Advance Warning Devices

The advance warning sign is one of the first cues that a driver is likely to encounter as he approaches a rail-highway crossing. In order to maximize the time a driver has to detect and recognize inputs at the crossing, the advance warning sign must be effective in capturing his attention. Once the advance warning device has been recognized, it becomes part of the context that can facilitate the detection and recognition of subsequent inputs related to the crossing.

When experimental advance warning signs have been tested, they have often been used in conjunction with experimental passive crossing signs. The designs of some of these studies do not permit the effects of the advance and at-crossing components to be evaluated independently of one another. When this is the case, it is impossible to infer what proportion of the observed effects on driver behavior can be attributed to the advance sign as opposed to the crossing sign. Such studies have yielded mixed results. For example, Dommasch, Hollinger, and Reilly (1976) compared the effectiveness of experimental advance warning and crossbuck combinations against that of the standard pair. One experimental combination consisted of a yellow diamond-shaped advance sign with a black silhouette of a train and a yellow diamond-shaped crossing sign with a superimposed crossbuck. The signs used for the second experimental condition were also diamond-shaped, but differed from the first set in color (they were a brilliant yellow-green); the advance sign had a black silhouette of a track crossing a road instead of a train. Experimental conditions were compared to standard sign combinations at three passive crossings: experimental conditions were associated with an increase in the percentage of motorists observed applying their brakes on the approach to the crossing, and an increase in average spot speed reductions at the crossing. Dommasch et al. conclude that their experimental advance and crossing signs were more effective than standard signs in alerting drivers to the presence of the crossing. However, it is unclear from the report which of the two experimental conditions produced the increase in braking and the greater reductions in spot speed at the crossing, and whether the observed increases in these dependent measures were statistically significant.

Koziol and Mengert (1978) also focused on driver detection and reaction to various combinations of crossbuck and advance warning signs at passively protected crossings. In addition to the standard passive signing system (the baseline condition), three new configurations of signs were tested. All of the new configurations used the Texas system's advance warning sign -- a standard advance warning sign with the top and bottom quadrants red rather than yellow. In one condition, the red and yellow advance sign was paired with the standard crossbuck, permitting a direct comparison of the Texas advance sign with the standard yellow and black advance warning device used in the baseline condition. The red and yellow advance warning sign was not associated with a significant increase in the percentage of head movements observed, nor did it affect speed reduction measured between 800 feet and 200 feet from the crossing.

In an outdoor laboratory test of several candidate advance warning devices, Ruden et al. (1982) had 17 subjects drive an automobile on a closed-course roadway that displayed one standard and four experimental advance warning signs, as well as a number of standard warning and regulatory signs (e.g., curve signs, stop signs, speed limit signs, and "DIP" signs). Drivers were instructed to describe, as soon as they were detected or identified, the following aspects of each shoulder-mounted sign on the roadway: 1) any features of the sign, such as its color or shape; 2) the meaning of the sign; 3) the supplemental message or symbol. The experimenter recorded the subject's comments and the distances at which the sign features were verbalized by the subject. Observations were made under daytime sun, daytime shade, dusk, and nighttime viewing conditions. Most of the experimental advance warning signs were modeled after those used by Ruden et al. in a comprehension test of advance warning signs, and were described in a previous section of this report. Briefly, the advance warning signs consisted of the "RXR" symbol on a yellow, diamond-shaped background (the primary sign), and a supplementary sign with a two- to four-word message (e.g., "RAILROAD XING AHEAD"); some primary signs contained a turn arrow or vertical arrow to convey crossing location. Two activated flashing yellow signals were added to two of the experimental signs, and their identification will be discussed in the section that follows on active advance warning devices. Data on when drivers first reported detecting other aspects of the warning signs are pertinent to the design of passive signs in general.

One particular advance warning sign (Sign B) showed greater recognition distance of the overall crossing warning message and greater legibility distance of its red and X components. This sign consisted of a flattened (60-degree) red X on a yellow, diamond-shaped field, with a black border; the upper and lower quadrants were bounded by a white stripe. Another advance warning sign (Sign D) was similar to Sign B in most respects, except that it had no black border, and its upper and lower quadrants were black instead of yellow. When viewed in direct sunlight, the red X on Sign B was reported by drivers earlier on their approach than was the black X on the standard advance sign. At night, drivers reported seeing the red on Sign B earlier (200 to 400 feet from the sign) than they noticed the red on Sign D (less than 200 feet from the sign). The red X was always the first feature that subjects reported detecting on Sign B; moreover, for all signs containing red viewed in direct sunlight, red was always part of the first feature reported as seen. The accuracy of these results depends on drivers having conscious access, not only to which aspects of signs they have detected, but also to the order in which these features were detected or recognized. The point that detection and recognition of a sign is not an all-or-none process has already been made. In addition, Ruden et al. acknowledge that, because subjects were driving as they introspected on what they saw, there may have been delays between the time when they first noticed a feature and the time when they reported seeing the feature. Thus, the recognition and legibility distances recorded by the experimenter were subject to inaccuracy. In summary, these data suggest that a red X on an advance warning sign is more detectable than the standard black X, although the angle of the X also differed between these two signs and so may have contributed to the difference in legibility distances of the X.

Two of Ruden et al.'s experimental advance warning signs and a 48-inch standard advance warning sign were field-tested in a study of active advance warning signs (Bowman, 1987a); there was an opportunity to compare their effect on driver behavior during the unactivated state, when yellow beacons mounted above and below the signs were not flashing. Although there are may be differences in how drivers respond to advance signs with and without unactivated flashers, the unactivated condition gives some indication of the relative conspicuity of the advance sign component of the AAWD. At most test sites, under both day and night conditions, Bowman observed no significant differences in mean approach speeds among the different advance signs.

In summary, alternate advance warning signs that utilize either a diamond shape (the standard shape for non-railroad advance warning signs), or different colors (brilliant yellow-green, or red and yellow) have not resulted in clear-cut benefits for the earlier alerting of drivers to crossings.

A major deficiency of advance warning devices is that they do not provide information about whether the crossing ahead is active or passive (Schoppert and Hoyt, 1968; Sanders et al., 1973; Ruden, et al., 1982; Berg, 1985). As a result, the driver must detect the presence or absence of active warning devices <u>at</u> the crossing in order to determine the extent of his responsibility for detecting an approaching train. The recognition of the crossing as active or passive is likely to occur later than it would if the driver were informed by the advance warning sign. Moreover, detecting the <u>absence</u> of a stimulus tends to require more time than either detecting the presence of a stimulus or discriminating between two inputs (in this case, between an advance warning sign for passive devices and one for active devices). Any delay in becoming alerted to the type of crossing decreases the time available for the driver to carry out subsequent detection and decision tasks. However, this delay is more of a disadvantage for the driver at a passive crossing where the driving task is more complex.

The lack of information about whether or not a crossing is actively protected is particularly critical at night. As Berg (1985) has pointed out, the driver may be unable to discern the type of crossing until he is already in the nonrecovery zone. Compounding the problem is the fact that, although crossbuck signs and gates (when present) at crossings are reflectorized, active warning lights at the crossing are not usually reflectorized. Therefore, if the crossing is not illuminated and it is not gate-protected, there are no obvious cues to distinguish between an unactivated signal and the absence of an automatic signal until the driver is relatively close to the crossing.

In the section on comprehension of traffic control devices, some evidence was presented that roughly one-quarter of drivers believe active warning devices are used at all, or most all, crossings (Richards and Heathington, 1988). This faulty belief would exacerbate the safety problem created by not providing information about the presence of active or passive warning devices in advance of the crossing. For example, a driver who expects most crossings to be actively protected will interpret the absence of an activated signal to mean the absence of a train, rather than recognizing the need to detect whether automatic signals are present at all. Wigglesworth (1978) makes a related point that a driver who has come to associate advance warning signs with active warning devices will not recognize the need to distinguish between an unactivated warning device and the lack of an active warning device.

Advance warning signs that explicitly inform the driver about whether the crossing ahead is active or passive have not received much attention in the United States. Schoppert and Hoyt (1968) generated two distinct sets of alternative advance warning signs for use at active versus passive crossings. The signs were intended to inform the driver of whether the crossing ahead is actively or passively protected, and thus whether it is his responsibility to look for an approaching train. Employees of the contractor and members of the crossing study staff viewed filmed drive-by's of the experimental signs installed at an active or passive crossing, and slides of individual signs; both daylight and simulated night conditions were represented. In one part of the study, subjects were asked to rank the signs in order of preference. The preferred design for passive protection advance warning was a track angle sign. This sign consisted of a yellow, diamond-shaped background with a vertical white symbol of a roadway (outlined in black) crossed by a black symbol of a track. The angle at which the track symbol crossed the roadway symbol was intended to inform the driver about the crossing angle ahead. The track angle sign was preferred over the standard advance warning sign, and over a diamond-shaped yellow sign with the words "TRAIN CROSSING." For active crossings, the highest-ranked advance warning sign contained the words "RAILROAD AHEAD" and a black symbol of flashing signals with red lights; the words and symbol were placed on a yellow, diamond-shaped background. This active advance warning sign was judged superior to the standard advance warning sign, and to several alternatives. On the basis of these evaluations, Schoppert and Hoyt recommended the use of the top-ranked advance signs to clearly distinguish for the driver between active and passive crossings.

In various foreign countries, such as Great Britain and Israel, distinctive advance warning signs are used, depending on the type of protection system at the crossing; if the crossing is actively protected, the signs inform the driver of whether there are flashing lights or gates. Heathington, Wunderlich, and Humphreys (1981) presented diagrams of the types and locations of TCD's required at active and passive crossings; the diagrams were originally published by the United Kingdom Department of Transport. The basic design of the advance signs involves a triangular sign that contains either a gate symbol, used at active crossings with gates, or a train symbol, used at either passive crossings or active crossings with flashing lights only. At active crossings, a supplementary message plate is positioned below the triangular sign. The messages "AUTOMATIC BARRIERS" and "AUTOMATIC CONTROL (NO BARRIERS)" are presented at gate-controlled and non-gate-controlled active crossings, respectively. At both types of active crossing, the supplementary sign contains "STOP when lights show." Thus, the distinction between active and passive crossings is clearly indicated by the various types of advance warning signs. In Israel (Shinar and Raz, 1982), similar triangular signs, containing symbols, appear above the Israeli standard advance warning sign (three black diagonal stripes on a light rectangular background). A train symbol with a filled circle above it indicates a crossing protected by flashing lights; a train symbol without a circle indicates a passive crossing; and a gate symbol with a filled circle designates a crossing with flashing lights and gates. In view of the fact that advance warning systems have been implemented in other countries to distinguish between active and passive crossings, more attention should be devoted to this type of improvement for the U.S. advance warning system. Data are not available on how effective such signs are in actually improving driver recognition of the type of crossing ahead.

Active Advance Warning Devices

A number of studies have focused on the design and testing of active advance warning devices (AAWD's) as a means of counteracting the problems mentioned above with advance warning signs. In their outdoor laboratory test of the detectability of various features of advance warning signs, Ruden et al. (1982) sometimes used flashing yellow signals as part of the advance sign configuration. They did not report whether the flashing signals were detected earlier by drivers than other features of the advance signs; however, they did present data on whether drivers recognized the meaning of the flashing yellow signals. When drivers were asked about the meaning of the flashing lights, about half the drivers indicated that the lights probably meant a train was coming; the remaining drivers usually wanted to know whether or not the lights flashed continuously.

As a follow-up study to this outdoor test, Ruden et al. field-tested a number of AAWD's at three actively protected railroad crossing sites, under both day and night viewing conditions. All sites had some feature, such as restricted sight distance, which prevented the driver from seeing the active warning device until it was too late to stop his vehicle at the crossing. As in earlier phases of the study, the AAWD's consisted of a primary warning sign, a supplemental message beneath the primary sign ("WATCH FOR TRAINS"), and flashing yellow beacons located above and below the primary and supplemental sign configuration. Two of the primary advance warning signs contained an arrow indicating the location of the crossing when the approach roadway was curved.

The results obtained were tied to the unique characteristics of each field site, and so it is difficult to state any general conclusions. Therefore, the findings for just one of the locations will be presented. At this site, the standard advance warning sign was used as the primary sign. First, when the AAWD was not activated but the signal at the crossing was activated, speed reductions were observed more often at night than during the day. This supports the idea that it is easier to detect the crossing signal at night than during the day. Second, when both the AAWD and the crossing signal were activated during the daytime, they produced significantly more speed reductions (greater than or equal to 10 mph) than the activated crossing signal produced when the AAWD was not activated. However, the AAWD was activated prior to the crossing signal, and it is not clear whether these speed reductions occurred prior to or subsequent to the activation of the crossing signal. When both the AAWD and the crossing signal were activated at night, there was a greater amount of early deceleration prior to the activation of the crossing signal than when the AAWD was not activated. Finally, Ruden et al. recorded the point at which the driver initially activated the brake lights on the approach to the crossing. During the daytime, they observed earlier activation of brake lights in response to crossing signal activation when the AAWD was activated than when it was not activated. If earlier activation of brake lights indicates faster detection of the flashing lights at the crossing, then it can be argued that the activation of the AAWD prepared the driver to respond more quickly to crossing signal activation. Overall, the authors report that the AAWD has greater benefits for detection during the day than at night.

Although these data suggest that the AAWD helps the driver to detect an activated crossing signal more quickly when there is restricted sight distance, the generalizability of these results to other crossings is unknown. One shortcoming of the study is that in the condition where the AAWD was not activated, the advance warning sign was present, but the yellow beacon lights were not. Therefore, there is no comparison between the condition in which the lights on the AAWD are present-inactive and that in which they are present-active. In the context of this study, unactivated lights on the AAWD might convey the information that there is an active crossing signal ahead, and that it is currently inactive. However, drivers were not provided with this potential source of additional advance information. When Bowman (1987a) used one of Ruden et al.'s prototypes for an experimental advance sign as the basis for an AAWD with two yellow flashers, he observed significantly lower speeds (about 10 mph lower) near the AAWD when it was activated than when it was not activated during the day. Nighttime observations of driver response to the activated AAWD were not obtained in the Bowman study.

Sanders et al. (1973) observed the effects of continuously flashing AAWD's at a passive crossing. As in the Ruden et al. (1982) study, the crossing had a limited sight distance. The AAWD was constructed by attaching two flashing yellow lamps to the left and right sides of a standard advance warning sign. Because of very limited track visibility, it was reasonable to use head movements as an index of looking behavior: Drivers could not see an approaching train until they were 100 feet from the crossing, and looking at this close proximity required an obvious head movement. In the absence of trains at the crossing, flashing lights were associated with increased driver looking behavior within 100 feet of the crossing. Relative to the standard advance warning sign, the AAWD also produced larger speed decreases between the location of the AAWD and 10 feet from the crossing.

In summary, an AAWD can facilitate driver recognition of the crossing, but the conditions under which there are meaningful benefits are unclear. There is some evidence that an AAWD, activated prior to the crossing signal, facilitates detection of the activated crossing signal, particularly during the daytime; a continuously flashing AAWD facilitates detection of the crossing. These results are specific to crossings characterized by limited sight distances, and to either active or passive crossings.

3.2.5 Detection and Recognition of Crossings

The question of what problems drivers have in detecting a rail-highway crossing has most often been addressed indirectly by examining the effects of advance warning devices and crossing signals on driver behavior. Such warning devices are intended to alert the driver to the presence of a crossing. In a field study, it would be difficult to measure detection of the crossing per se. However, studies of the effects of crossbuck design, rumble strips, and illumination at the crossing are pertinent to crossing detection, and will be covered in this section. Other relevant factors such as insufficient sight distance or competing visual input near the crossing will be discussed elsewhere.

Crossbuck

Alternative versions of the crossbuck sign were tested in a laboratory setting by Ells et al. (1980). They used the then standard Canadian crossbuck ("RAILWAY CROSSING" in black letters on a white background) and two nonverbal versions -- a white panel with a red border and a yellow panel with a black border. Subjects viewed slides of the crossbuck signs and other traffic signs on a sky-blue or grass-green background, under simulated daytime viewing conditions. When subjects were asked to classify individual signs as railway crossing signs or distractor (non-railroad) signs, they responded faster to the red and white sign than to the other two signs, but only when the signs were viewed against a blue background. In a second experiment that used the same set of slides and the same classification task, stimuli were presented for very brief durations (less than 100 msec), and recognition accuracy was recorded. No significant differences in "glance legibility" were observed. Ells et al. also measured the visibility distances at which the crossbuck signs could be identified. The maximum distance at which crossing signs could be identified depended on the angle of separation between the blades of the crossbuck, and on the background against which the signs were viewed. Crossbucks with 90-degree angles between the blades were identified from a greater distance than were signs with 45-degree angles. The nonverbal signs were superior to the then standard Canadian crossbuck, but only when viewed against the blue background. These findings clearly show that background viewing conditions are an important variable in assessing the detection and identification of crossing signs.

Schoppert and Hoyt (1968) recommend that at passive crossings, the standard crossbuck be replaced by a crossbuck sign that is easier to detect. They had subjects rank order their preferences for experimental crossbuck signs (refer to the section on detection of advance warning signs for a description of their procedure). The sign that was judged superior to the standard crossbuck, and to several alternative prototypes, consisted of the crossbuck symbol displayed against a yellow triangular background. Two features of the experimental sign were cited as giving it an advantage over the standard sign: 1) the contrast between the yellow sign and the surrounding area makes it more conspicuous than the white and black standard crossbuck, particularly against a light background; 2) use of the YIELD sign shape is consistent with, and may reinforce, the driver's obligation at a crossing. Alternative crossbuck signs with a rectangular shape were not thought to be as appropriate as the triangular sign, because drivers have had experience with diamond and rectangular signs as advance warnings, and not as markers at the actual point of hazard.

In their study of advance warning and crossing sign combinations at passive crossings, Koziol and Mengert (1978) tested a blank yellow and black crossbuck similar to the one used by Ells et al. The design of the study did not permit an independent evaluation of the crossbuck's effect on driver behavior. When paired with the red and yellow advance warning sign, the blank yellow and black crossbuck did not produce a higher percentage of head movements than the standard system (black and yellow advance sign and standard crossbuck).

In summary, although a blank yellow and black crossbuck was not associated with more head movements on the approach to a passive crossing, the use of blank yellow and black, or red and white, crossbucks in the Ells et al. (1980) study did yield shorter classification times and longer visibility distances for the crossbuck. Earlier recognition of the crossbuck should alert the driver sooner to the presence of the crossing. However, the effectiveness of these experimental crossbucks was specific to a blue background.

Illumination of the Crossing

Illumination of the crossing provides a way to improve detectability of the crossing at night, by alerting the driver earlier to the presence and location of the crossing. However, most studies of the effectiveness of illumination have focused on its benefits for detection of trains, and so will be discussed in a later section devoted to that topic.

Rumble Strips on the Crossing Approach

Although reaction time to tactile stimulation is slower than that to visual or auditory stimulation, the simultaneous presentation of tactile, visual, and auditory stimuli produces shorter reaction times than if any one stimulus were presented separately (Schoppert and Hoyt, 1968). In general, redundant stimulation of several sense modalities increases the likelihood of detecting an event. The principle behind the use of rumble strips on the approach to stop-sign controlled intersections or to rail-highway crossings is to alert the driver to a potentially hazardous situation ahead and to upcoming warning devices. Rumble strips in advance of a crossing, together with warning signs, road markings, and auditory warnings of approaching trains, provide the driver with redundant information about the presence of the crossing ahead, and so increase his chances of detecting the crossing. Rumble strips appear to have three advantages over other types of warning devices. First, they provide both vibratory and auditory stimulation when the driver travels over them, whereas other warning devices and signals each stimulate only one sense modality. Second, rumble strips have the potential to capture the attention of the driver sooner and more readily than visual signals can: They can be positioned in advance of various warning signs (e.g., standard advance warning sign or "LOOK FOR TRAIN" sign) to facilitate detection of those signs, and they do not rely for their effectiveness on the driver's eyes being oriented properly for picking up visual information about the crossing. The unique alerting capability of rumble strips is particularly useful if the driver is distracted from advance warning signs or other visual cues for the crossing by competing stimuli, such as other vehicles. Finally, Zaidel, Hakkert, and Barkan (1986) have suggested that rumble strips are more resistant to familiarity effects than other countermeasures, because vibratory stimulation at high speeds is uncomfortable for the driver regardless of how frequently he has experienced it. Zaidel et al. installed rumble strips on the minor leg of a stop-controlled intersection, and found them to be effective in lowering approach speeds one year after installation.

The Zaidel et al. study supports the effectiveness of rumble strips in reducing speed and promoting earlier deceleration at a low-volume rural intersection with limited sight distance. The strips of rough pavement material that were used were one-half inch high, and spanned the full width of the two-lane road. In one test, 38 of these strips were installed from about 900 feet to 55 feet from the intersection, and were arranged with increasingly smaller intervals between them as they got closer to the crossing. Since the rumble strips were sprayed with a reflective yellow paint, they provided visual stimulation, in addition to tactile and auditory stimulation. After one month, the rumble strips were found to reduce approach speeds by an average of 40%, relative to the before-treatment condition. In addition, with rumble strips installed, much of the deceleration occurred farther in advance of the crossing than when no strips were present: In the treatment condition, most of the deceleration took place in advance of the first rumble strip, as opposed to the last 200 feet of the intersection where most of the deceleration occurred in the no-treatment condition. Thus, speed reductions were first prompted by visual detection of the painted rumble strips, rather than by detection of their vibratory and auditory properties. The considerable speed-reducing effects of the rumble strips indicate that they were successful in alerting drivers earlier to the presence of the intersection ahead.

A few studies have examined the effectiveness of rumble strips at rail-highway crossings. Parsonson and Rinalducci (1982) installed rumble strips as part of a positive-guidance solution for a passive rural crossing. Both approaches to the crossing had restricted quadrant visibility, so the crossing was controlled by stop signs. On one approach, three rumble strips were installed at the following locations: 100 feet in advance of a "LOOK FOR TRAIN" sign (250 feet from the crossing); 100 feet in advance of a standard advance warning sign with a "HIDDEN XING" sign below it (535 feet from the crossing); and 100 feet in advance of a symbol stop-ahead sign (970 feet from the crossing). Since the rumble strips were added at the same time as the "LOOK FOR TRAIN" and "HIDDEN XING" signs, it was not possible to independently test the effects of rumble strips on driver behavior for this approach. On the other approach, three rumble strips were added in advance of the stop sign, a standard advance warning sign, and a symbol stop-ahead sign, but no new signs were installed. In a before-and-after evaluation of the positive-guidance solution, Parsonson and Rinalducci found that the addition of rumble strips and the new advance warning signs did not produce a significant change in the drivers' speed profile. The percentage of drivers who turned their heads to look for trains decreased significantly from the before to the after condition; the percentage of stop-sign violations at the crossing decreased in the positive-guidance condition. Thus, the rumble strips were not associated with greater reductions in speed compared to the before condition; in fact, the percentage of drivers who traversed the crossing at more than 25 mph increased from the before condition to the positive-guidance condition. An average of 12 drivers per day were observed to avoid the rumble strips by driving into the opposing lane. The overall pattern of results was similar for both approaches to the crossing. Parsonson and Rinalducci concluded that rumble strips will tend to promote unsafe avoidance maneuvers when they are installed at rural crossings used primarily by local drivers.

Skinner (1971) reported on the installation of rumble strips in 1967-1968 at 30 passive crossings in McCracken County, Kentucky. The crossings typically had low volumes of highway traffic; the percentage of crossings with limited sight distance was not specified. Although before-and-after results were not quantified, there were fewer accidents after the rumble strips were installed and fewer reports of near misses.

In summary, there is evidence that rumble strips can alert the driver sooner to the presence of a hazardous intersection ahead. Visual detection of painted rumble strips was effective in reducing speed, prior to the driver's experience of vibratory and auditory stimulation from the rumble strips. Studies on the use of rumble strips at rail-highway crossings have produced mixed results. The strips may have promoted greater compliance with the stop sign in one positive-guidance implementation, but also resulted in unsafe avoidance behaviors by some drivers. Since the benefits of cross-modality redundancy for detection of signals is well-established in the perception literature, further investigation of conditions under which rumble strips aid detection of the crossing seems warranted. There is consensus that rumble strips should be installed only at crossings with special hazards, such as limited sight distance.

3.2.6 Detection and Recognition of Active Warning Devices

Several characteristics of standard activated flashing signals limit their detectability. In order to maximize signal intensity, given the constraint of low power consumption for the signal system, roundels are used that produce a tightly-focused beam. Under ideal conditions, when the narrow-beam signals are aimed properly, they are detectable on a bright day from a distance of 1,000 feet (Hopkins and White, 1977). However, at distances closer to the crossing, the flashing signals may not be detectable as the motorist drives out of the brighter central area of the beam. Lindberg (1971) calculated the position of the driver's eyes in the signal beam, at different points on his approach to the crossing, and thus determined how perceived brightness varies as a function of distance from the crossing. He estimated that a standard 18-watt lamp will be visible (source intensity of 600 candelas) to an automobile driver at 1,000 feet from the crossing, but will probably not be detectable (intensity less than 100 candelas) from distances under 175 feet. These calculations were applied under the following conditions: When the approach is straight and level, when the axis of the signal is aimed at 400 feet and at the center of the approach lane (the common aim point), and when the lamps are mounted at a height of 9 feet above the road on the right side of the roadway. Under non-ideal viewing conditions, such as sunlight on the face of the signal, or small deviations in the aiming of the signal, visibility of the signal will be more limited (Lindberg, 1971; Hopkins and Holmstrom, 1976). Other factors, such as curves or changes in grade on the approach roadway, may produce considerable variation in the driver's viewing angle for the signals, particularly for cantilever-mounted signals (Hopkins and Holmstrom, 1976). Efforts have been made to design crossing signals that are intense enough to alert the driver at all positions that he is likely to occupy on the approach. For example, Lindberg (1971) reported that reflectorized bulbs, quartz-iodine lamps, and multiple-beam roundels provide better coverage at shorter distances from the crossing than the standard 18-watt bulb and 30-15 roundel used in crossing signals. However, the extent to which such improvements in crossing signal design have been implemented is unknown. Hopkins and Holmstrom (1976) pointed out that, although multiple pairs of signals have been used to compensate for the limited range of any one signal pair, the driver's eyes will not necessarily be oriented toward the signal pair that provides adequate or optimum brightness for his specific location on the approach. Thus, the tightly-focused beam, characteristic of activated crossing signals, places constraints on the alerting effectiveness of the signals, especially at short distances from the crossing.

In addition to beam shape and observer distance, there are many factors that affect the detectability of crossing signals, including flash rate, flash duration, signal size, signal intensity, signal position, signal color, ambient light level, color contrast, and number and configuration of signals. As part of a comprehensive study of active crossing warning devices, Ruden, Wasser, Hulbert, and Burg (1977) examined the effects of color, flash rate, size, and position on the conspicuity of incandescent flashing lights. Tests were conducted at the FAA's Low Visibility Facility (Fog Chamber), which permitted a comparison of signal conspicuity under daytime, nighttime (with low-beam headlights), and daytime fog (475-foot visibility) viewing conditions. In addition, observers viewed flashing lights and signs in both simulated urban and rural conditions. The urban setting consisted of a low-contrast, highly competitive background, with extra highway signs, street lights, pedestrians, advertising signs, and vehicles; the rural setting was a high-contrast, neutral background. Observers in a simulated vehicle viewed displays for brief durations, from a distance of 420 feet. A display usually consisted of three pairs of flashing lights, with one standard roadway sign (e.g., turn arrow, "ONE WAY," "SIGNAL AHEAD") below each signal pair, for a total of six different targets. Before each display was presented, observers were informed about the colors and signs they would be seeing. They were asked to report the single device among the six targets that attracted their attention for the longest period of time (during a 4.5-second exposure), or the one that first captured their attention (during a 1.5- or 4.5- second exposure). In each display, one pair of flashing lights was designated as the primary target; the other targets were intended to compete for the observer's attention. For example, when luminance level and color of primary targets were being tested, they varied independently from one display to the next, while the distractor targets were held constant. Ruden et al.'s findings can be summarized as follows. When luminance was held constant, red was more conspicuous during the day and blue was more conspicuous at night. Flash rates in the range of 70 to 90 cycles per minute attracted attention more than flash rates as low as 40 cycles per minute or as high as 120 cycles per minute; these optimum flash rates for incandescent lamps are higher than the rates (35 to 55 cycles per minute) typically used for crossing warning signals. At higher flash rates, the signals may have been dimmer than at lower flash rates, due to the heating and cooling properties of incandescent-lamp filaments. Increasing the lens size from the standard 8 3/8-inch roundel to a 12-inch roundel had greater potential for increasing signal conspicuity than increasing luminance, in the presence of background competition. With an unobstructed view of the signals, cantilevered light placement (17 feet high) and low-mounted (9 feet high) right roadway location were more conspicuous than high-mounted (17 feet) right placement. The validity of these data depends on how accurately observers are able to report on the distribution of their attention; observers may not be aware of which target first caught their attention, particularly at the short exposure durations used in this study.

Ruden et al. also tested the conspicuity of xenon flash strobe lights. They found that white strobes were much more conspicuous than standard 8 3/8-inch incandescent flashers, although red strobes were not as conspicuous as the standard signals. Conspicuity of the strobes increased as flash rate increased, up to 110 cycles per minute. In view of these results, Ruden et al. recommended supplementing standard crossing signals with three white strobes mounted above the flashers. Other features of xenon lamps have the potential to increase the conspicuity of active warning systems. Hopkins and Holmstrom (1976) argued that, when average intensity is held constant, the short-duration flashes of higher peak intensity produced by strobes are more effective at alerting drivers than the long-duration flashes of lower peak intensity produced by standard incandescent lamps. Moreover, because strobes can utilize greater horizontal and vertical beamwidths, they provide better coverage at short distances from the crossing than standard lamps.

When Ruden et al. field-tested an add-on strobe light configuration at an active crossing, no erratic driver behavior was observed; the influence of an upstream traffic signal on driver behavior in advance of the crossing prevented the meaningful analysis of speed profile data as an index of the alerting effectiveness of the strobe device. Hopkins and White (1977) observed the effects of adding two xenon strobes above standard flashers at a crossing; subjective judgments were that the strobes had high conspicuity, and drew attention more effectively than standard flashers, when viewed in peripheral vision. Hopkins and White (1977) also reported on test installations of add-on xenon lamps at active crossings, carried out by the Union Pacific Railroad: Most observers indicated that the xenon lamps increased the visibility and alerting potential of the active crossing device. As in the Hopkins and White study and a field study of strobes by Bates (1985), there were no quantitative measures of alerting effectiveness.

Strobes have also been evaluated as add-on devices for gate arms at active crossings. Ruden et al. (1977) added a red, white, and blue strobe to the gate arm at a gate-protected crossing in a rural desert location. During the daytime, earlier deceleration on the approach to the crossing was observed after installation of the strobes; at night, there was no difference in deceleration between the before and after conditions. The field test site had no background lights to compete for the driver's attention at night, so Ruden et al. concluded that the gate arm-mounted strobes would be more effective in increasing conspicuity at urban crossings that have competitive backgrounds. Finally, Russell (1974) upgraded a rural crossing with standard flashers by adding automatic gates, mounting red strobes on the gate arms, and increasing the size of the standard pair of flashers to 12 inches. The upgraded signal system resulted in slower approaches to the crossing, indicating that drivers may have detected the signals earlier than in the pre-existing condition. However, it is impossible to determine whether this effect was due to the gate arm-mounted strobes, the higher conspicuity of automatic gates compared to standard flashers, the increase in flashing signal size, or to some combination of these measures.

Other modifications to existing active warning systems, in addition to strobe lights, were investigated by Heathington, Fambro, and Rochelle (1984). They conducted an outdoor laboratory evaluation of two versions of each of three experimental active warning devices: a four-quadrant gate system with and without skirts, a four-quadrant flashing light signal system with and without overhead red strobe lights, and a highway signal system with one and with three white bar strobes. The supplementary strobe lights in the four-quadrant flashing light condition were centered over each traffic lane, and were not mounted above or below the standard flashers as they were in the studies discussed above. Perception-brake reaction time (PBRT) and maximum deceleration rate were recorded as test subjects repeatedly approached three crossings, at which the various devices were installed. The prediction was that, if more conspicuous devices are detected earlier, they may be associated with faster PBRT's and more frequent comfortable deceleration rates. Driver behavior was observed during the day and at night. Actuation distance, the distance of the vehicle from the warning device when the flashing signals were activated or when the highway traffic signal changed, was also manipulated. Driver response to each active warning device was observed when the vehicle was 330, 440, and 670 feet from the warning device when it was activated, and, in a control condition, when the vehicle was at the crossing. When PBRT's were analyzed, the pattern of results differed, depending on the actuation distance. The four-quadrant gates with skirts were consistently associated with the fastest PBRT's, while the two versions of the highway traffic signals were always among the slowest conditions. In the control condition and at long (670 feet) actuation distances, PBRT's for the four-quadrant gates were not significantly different from PBRT's for the four-quadrant flashing lights, although all four conditions produced faster PBRT's than the highway traffic signals. At the medium distance (440 feet), four-quadrant gates produced significantly faster PBRT's than four-quadrant flashing lights or highway traffic signals, and the latter two systems were not significantly different from one another. Thus, at the short and medium actuation distances, four-quadrant gates with skirts produced faster PBRT's than the other systems, whereas, in the control condition and at long distances, four-quadrant gates had no apparent advantage over four-quadrant flashing signals in being detected earlier, and thereby producing faster PBRT's. The pattern of deceleration rates also varied with actuation distance, but the results were difficult to interpret. Finally, both PBRT's and deceleration rates differed between day and night viewing conditions, at the medium and long actuation distances. The complex interactions exhibited in these data illustrate the many parameters that must be taken into account in evaluating the detectability of active warning devices. One drawback of the study is that the measures of driver behavior were compared across different crossing sites, and so drivers may have been responding, not only to differences in the conspicuity of the devices per se, but also to differences in their detectability, caused indirectly by such site-specific factors as roadway-crossing alignment and contrast with the background. Depending on characteristics of the approach roadway, the driver's eyes may be oriented in a direction that is more or less appropriate for detecting the device at the earliest opportunity.

In a follow-up field study of three active warning prototypes, Heathington, Fambro, and Richards (1988) found no significant differences between before and after conditions on measures that might reflect earlier detection, such as PBRT, speed profiles, and maximum deceleration rates. The devices tested consisted of four-quadrant gates with skirts, four-quadrant flashing light signals with strobes, and highway traffic signals with white strobes in front of each of the red signal lenses. Whenever flashing light signals were used in the experimental device, the standard flashers with 8 3/8-inch roundels were changed to 12-inch roundels. Unlike the 1984 laboratory study discussed above, this study compared each experimental warning system against the pre-existing two-quadrant standard active warning system at the same crossing. At two of the crossings, visibility of the crossing and the two-quadrant signals was limited, and so features of the experimental warning devices, such as the four-quadrant positions, the larger flashers, the overhead strobes, or the cantilevered highway traffic signals, were expected to increase their conspicuity. However, any increase in the detectability of the new warning devices, relative to the standard systems, was not reflected in decreases in PBRT's, decreases in average approach speeds, or more gradual deceleration rates. PBRT's ranged from 14 to 19 seconds, and were highly variable at all crossings; Heathington et al. pointed out that such long and variable PBRT's indicate that drivers did not perceive a pressure situation when any of the standard or experimental warning devices were activated. They also cautioned that PBRT's are difficult to interpret, since the driver could have been braking in response to a number of stimuli, besides the activation of the warning device: to the horizontal or vertical alignment of the road, to the roughness of the crossing, to a slower moving vehicle ahead, or to the presence of a recognized crossing. The finding that few drivers exceeded the practical deceleration rate (less than 8 feet per second) when stopping in response to any of the active warning systems is consistent with the results of other studies (e.g., Butcher, 1973). Although average approach speeds did not appear to be affected by the experimental active warning systems, Heathington et al. only obtained speed profile data beginning at a distance of 450 feet in advance of the stop bar at the crossing. Because of problems with the camera that covered the area between 700 and 500 feet in advance of the crossing, average speeds at farther distances were not reported. However, Shinar and Raz (1982) reported that, at a distance of 660 feet from the crossing, driver speeds were significantly lower when flashing signal lights were activated than when they were not activated. When Butcher (1973) recorded spot speeds of approach vehicles, beginning at a distance of more than 1,100 feet from the crossing, he also found significant differences in approach speeds, depending on the status of the active warning system. When standard flashers were activated, but a train was not in close proximity to the crossing (first unobstructed vehicle), the entry speed of the vehicle was about the same as when the flashers were not activated, and drivers did not slow down until they were relatively close to the crossing. When flashers were activated and a train was at the crossing, or close enough to present an immediate hazard, drivers slowed down sooner and decelerated more gradually than drivers in the first unobstructed condition. Butcher inferred that, in the first unobstructed condition, either drivers expected to cross safely ahead of the train, or they were not alerted as effectively by the flashing lights alone as drivers who also saw the train at or close to the crossing. The implication is that a more conspicuous warning device may be necessary to prompt earlier deceleration. In view of the Shinar and Raz and Butcher results, it is possible that Heathington et al. would have found differences in slowing on the approach, if they had observed vehicle speeds farther away from the crossing.

In summary, standard narrow-beam lights are not readily detected by drivers from distances close to the crossing, and their visibility is likely to be further limited by small deviations from proper aiming. Conditions such as curves or changes in grade on the approach, low contrast of signals against backgrounds, and the presence at night of competing lights add to the driver's difficulty in detecting the signals. Most research on the conspicuity of active warning devices has focused on adding alternately flashing strobe lights to standard flashing lights. There is some indication that add-on strobe lights, mounted above or below the conventional flashers, increase the conspicuity of the signal system, although the evidence consists primarily of subjective judgments. White strobes appear to be more effective than red strobes, perhaps because xenon light has limited output in the red portion of the spectrum. When strobes were added to gate arms, they resulted in slower approach speeds and earlier deceleration in the daytime at rural crossings.

As used in practice, and as evaluated in the above studies, active warning devices at crossings are intended to signal the presence of a train. However, active signals could also be used to indicate other status conditions. For example, a number of researchers have recommended using a signal, such as a flashing amber light or xenon flash, to indicate not only the absence of trains, but the presence of the crossing and functioning of the warning system (Hopkins and Holmstrom, 1976; Shinar and Raz, 1982).

3.2.7 Detection and Recognition of Trains at the Crossing

When a motor vehicle strikes a train, particularly when it hits a part of the train other than the lead unit, poor visibility of the train at the crossing is more likely to be a contributing factor than when a train strikes a vehicle. Therefore, comparisons of the frequency of motor vehicles striking trains versus that of trains striking vehicles are often used to highlight the difficulty drivers have in detecting trains at unilluminated crossings at night. The higher incidence of vehicles running into trains in darkness than in daylight has been well-documented (Schoppert and Hoyt, 1968; Russell and Konz, 1980). From their analysis of crossing accidents that occurred between 1967 and 1974, Russell and Konz (1980) found an increase in the vehicle-strikes-train type of accident from 23% during the day to 46% at night. Rail-highway accident/incident statistics for 1986 and 1987 show a somewhat smaller increase in the incidence of vehicles running into trains from 22% during the day to 33% at night. The 1986 and 1987 accident/incident inventories also contain data on the frequency of vehicles striking trains at illuminated and unilluminated crossings: About half these accidents occurred at crossings that were not lighted, and one-quarter at lighted crossings (for 23% of these accidents, lighting conditions were not reported). These data probably reflect not only the difficulty at night of seeing trains at or approaching an unilluminated crossing, but also the difficulty of becoming alerted to the crossing itself.

Statistics on accidents due to a vehicle striking a train include accidents that occur when the driver fails to see the train either as it approaches the crossing or at the crossing itself. A number of methods have been used to ascertain the percentage of crossing accidents in which the driver fails to detect the train at the crossing, since this is the situation most likely to benefit from increased visibility of the train at the crossing itself. Schoppert and Hoyt (1968) estimated that, in about 13% of all crossing accidents occurring between 1960 and 1964, the train was already on the crossing when the driver was at his decision point. This statistic was derived by analyzing such variables as the part of the train involved in the accident (e.g., the lead unit vs. the second quarter), the number of cars in the train, and the speeds of the train and of the vehicle. There was also evidence that train speed is systematically related to the frequency of accidents in which a vehicle strikes a train: decreases in train speed were associated with increases in the percentage of vehicles that strike trains. Moreover, in three-quarters of the instances in which the driver failed to detect the train when it occupied the crossing, the train speed was less than 10 mph; this figure includes those cases in which the train was stopped at the crossing. From these observations, Schoppert and Hoyt (1968) infer that lower-speed trains are more difficult to detect at night than higher-speed trains are. To target that portion of crossing accidents in which the problem is detecting the train at the crossing, Schoppert and Hoyt recommend illuminating crossings which have a high incidence of slow-moving trains at night.

McGinnis (1979) analyzed 1975 crossing accident data to determine, for each case, whether or not the train was already in the crossing when the driver needed to make a decision to stop. McGinnis took into account the part of the train involved in the accident, the speeds of the vehicle and the train, as well as the condition of the pavement (e.g., wet or dry). On the basis of these variables, accidents were classified into one of four categories. Category 1 consists of accidents in which the vehicle struck the train far back enough along its length to suggest that the driver could have stopped safely if he had detected the train when it was at the crossing. Accidents in which the vehicle struck the first unit of the train, but which otherwise met the criterion for Category 1 were assigned to Category 2. In these cases, although the train was estimated to be at the crossing when the driver was at his decision point, either low train speed for low vehicle speed resulted in collisions with the first car of the train. McGinnis noted that some accidents fell in to Category 2 because of missing data for train and vehicle speed. Category 2 accidents cannot be unambiguously interpreted; they will not be considered here. For accidents in Category 3 or Category 4, the train has not yet reached the crossing when the driver is at his decision point, and so collisions occur close to the front of the train. Category 3 is for the vehicle-strikes-train type of accident, whereas Category 4 consists of accidents in which the train strikes the vehicle. McGinnis (1979) found that, in 8.5% of all crossing accidents, the train is at the crossing when the driver is at his decision point (Category 1); when variations in frequency of travel by time of day are taken into account, Category 1 accidents occur about 9 times more often at night than during the day, and 3.7 times more often at dawn or dusk than during the day.

McGinnis' estimate of the frequency of Category 1 accidents is slightly lower than the 13% figure that Schoppert and Hoyt (1968) reported for a similar category of accident. These two studies indicate that only about 10% of all crossing accidents can be prevented by making the train more visible at the crossing; the problem for the driver is much more likely to be one of detecting the train <u>before</u> it reaches the crossing.

In their analysis of factors that contribute to crossing accidents, Berg et al. (1982) estimated that, at passive crossings, from 22% to 25% of all accidents attributed to driver recognition error are due to late recognition of a train that was already at the crossing. One of the primary causes of this type of recognition error was limited visibility due to darkness; Berg et al. recommended illumination of the crossing and reflectorization of the train as countermeasures.

In summary, difficulty in detecting the train when it is already on the crossing, as opposed to when it is approaching the crossing, may account for about one-quarter of all accidents due to recognition errors at passive crossings, and for about 10% of all crossing accidents. These cases would benefit from methods that improve the conspicuity of the train at the crossing.

Illumination

Evidence exists that illumination increases sight distance at non-railroad intersections, in general, and improves train detection at rail-highway crossings, particularly those with passive protection. Russell and Konz (1980) cited a study by Schwab (1976) in which fixed illumination at non-railroad intersections resulted in sight distance three times that produced by vehicular illumination alone. When illumination at 52 rail-highway crossings in Houston, Texas was evaluated in a before-and-after test (cited by Russell and Konz, 1980), a decrease was observed in the mean number of accidents per week in which a vehicle strikes a train; adding illumination to passive crossings resulted in an 85% reduction in the mean number of accidents per week, compared to a 13% reduction for active crossings. This difference in the effectiveness of illumination for active versus passive crossings may reflect the fact that the vehicle-strikes-train type of accident is more frequent at passive than at active crossings. For example, in 1986, 43% of accidents in which a vehicle struck a train occurred at passive crossings, while 27% of these accidents occurred at active crossings. The implication is that active warning devices help reduce visibility problems at night, and so passive crossings are stronger candidates for the benefits of illumination. In a study of illumination at rural at-grade intersections in Illinois, Lipinski and Wortman (1976) compared the ratio of night accidents to total accidents at 263 lighted and 182 unlighted intersections. The night accident to total accident ratio obtained for lighted intersections was 22% lower than for unlighted intersections. Although Lipinski and Wortman controlled for variations in traffic volumes by using a ratio measure, they did not control for variations in geometric conditions at crossings.

When Russell and Konz (1980) conducted a survey of current state, city, county, and railroad procedures for illuminating crossings, they found great variability in how respondents defined an illuminated crossing, and concluded that there were no standards for illuminating rail-highway crossings in the United States. They also had subjects rank different lighting conditions exhibited by a scale-model crossing. The variables manipulated in a series of experiments included the amount of light, number of lights and their position (up to four lights on each side of the track), and types of boxcar reflectance. Across all experiments, subjects preferred the relatively high light levels (vertical illumination of about 20 lx) for lamps positioned on the approach side of the train; the least preferred alternatives involved lamps on the far side of the train.

In summary, although there is little consensus in the United States on whether to illuminate rail-highway grade crossings or how to illuminate them, illumination has been shown to reduce accidents, particularly at passive crossings. It seems reasonable to conclude that adding illumination facilitates the detection of trains at the crossing.

Reflectorization of Railcars

The rationale behind adding reflectors to the sides of railcars is that the reflectors improve the visibility of the train by reflecting light from the driver's headlights back toward the driver. A number of studies suggest that reflectorization does improve the visibility of trains when there are no visual obstructions at the crossing and when the horizontal and vertical alignment of the roadway with the crossing permits adequate visibility of the crossing (Lepkowski and Mullis, 1973; McGinnis, 1979). Benefits are likely to be greatest at passive crossings. However, the reflective intensity of reflectors deteriorates rapidly with the accumulation of dirt, which means that washing frequency must be taken into account in estimating an effective reflector size (Poage and Hopkins, 1983). A laboratory study by Lauer and Suhr (1956) suggests that drivers are better at detecting simulated reflectors on a miniature, moving train when the same area of reflective material is concentrated in one to three reflectors per car than when it is distributed in eleven reflectors along the sill of the car.

McGinnis (1979) conducted an extensive analysis of the conditions under which high-intensity reflectors would be detectable as cues for the presence of a train. He cited a study in which Hare and Hemion (1968) observed vehicles in an "open road situation." Although high beams should be used at night in this type of environment, less that 25% of vehicles were observed to use their high beams. The conclusion is that reflectors must be detectable under low-beam illumination. A reflector, (.25 feet square) placed 1 foot above the plane of headlights at a 90-degree intersection, is likely to be detectable from 500 to 1,000 feet in front of the crossing with low beams, and from 900 to 2,000 feet from the crossing with high beams. Since 500 feet represents an adequate stopping distance for most vehicle speeds, McGinnis concludes that reflectors will improve the detection of trains. Other factors that make detection of the train even more likely are that more than one reflector will be in view at the same time, and that the reflectors will typically be observed on a moving train. By contrast, unreflectorized cars are likely to be visible at an adequate distance for safe stopping only with high beams; with low beams, there is insufficient safe stopping distance for a vehicle traveling as slowly as 20 mph. Recall that McGinnis classified accidents according to whether or not the train had reached the crossing when the driver was at his decision point. He concluded that reflectorizing railcars will have the most impact on Category 1 accidents, in which the train does not have to be detected until it is at the crossing. Since reflectors are detectable at only 50 to 200 feet to the left or right of the projected path of the vehicle, they are very limited in their capacity to improve detection of the train before it reaches the crossing. Therefore, the benefits of reflectorization apply primarily to visibility of the train at the crossing.

Reflectivity of reflectors can be expected to decrease with age as the reflective material deteriorates and accumulates dirt. Poage and Hopkins (1983) measured the reflective intensity of engineer-grade reflectors when first installed on Canadian freight cars, and after several periods of service: a reflector's reflective intensity declined to 23% of its original value after six months in service, to 14% after one year, and to 5% after two years. Moreover, when observers were asked to rate the visibility of reflectors on freight cars passing through crossings at night, only 17% of the reflectors were judged as clearly visible; 61% of the reflectors were classified as barely visible or not visible at all. It is important to note that these observers viewed the moving reflectors under ideal conditions, in that high beams were used and the stationary observers were expecting a train to pass. There was also evidence that high-intensity reflectors -- the kind that McGinnis (1979) used in his measurements of reflector visibility -- deteriorate at the same rapid rate as the engineer-grade reflectors do.

Reflectorization can improve the visibility of trains at the crossing, even if it is assumed that the majority of drivers will view them under low-beam illumination. However, there are important limitations on the effectiveness of reflectors: First, if the driver's view of the crossing is obstructed, the reflectors may not fall within the range of the vehicle's headlights soon enough to permit safe stopping; second, given the rapid deterioration of the reflective intensity of reflectors, their continued effectiveness after installation depends strongly on whether they receive adequate maintenance.

Reflectorization of Trackside Objects

If the backs of crossbucks or other trackside hardware were to be reflectorized, illumination from the driver's headlights at night might improve detectability of a train at the crossing: As the train passes, intermittent glimpses of reflectorization from the back of the crossbuck (on the other side of the tracks) would create a flicker effect. Although this potential cue for the presence of the train has been proposed (Schoppert and Hoyt, 1968), no formal evaluation of its effectiveness was uncovered in a literature search. "Flicker" is effective as an attention-getting cue. However, it may be presumed that the effectiveness of this treatment would vary as some function of train speed. It may be least effective for very slow moving trains, which constitute a greater hazard at night.

In summary, there is considerable evidence that drivers find it difficult to detect trains at unilluminated crossings at night, particularly when the crossings are passively protected. In about 10% of crossing accidents, the driver could have stopped safely if the train had been detected at the crossing. Illumination of the crossing appears to have fewer limitations on its effectiveness than does reflectorization of railcars.

3.2.8 Detection and Recognition of Approaching Trains

Becoming alerted to an approaching train is critical for safely negotiating a passive crossing, and entails some problems that are distinct from those encountered in detecting a train when it is at the crossing. Scanning the tracks is also important at active crossings equipped with flashing lights (refer to Figure 2 for points in the sequence where scanning is required). After the flashers are activated and the driver comes to a stop at the crossing, he may have to search for an approaching train more than once: Looking is necessary before the driver can evaluate whether it is safe to proceed ahead of the train, and/or after the train has been allowed to pass. In the case of unactivated flashing lights or raised gates, confirming the absence of an approaching train by scanning the tracks is appropriate.

Role of Peripheral Vision

Because an approaching train is far more likely to fall outside the driver's peripheral vision than a train at the crossing, the driver must look to his right and left in an active visual search for trains. When the driver scans the tracks, visual cues for the movement of an approaching train are likely to be picked up in peripheral vision, where sensitivity is greater for a moving target than for a stationary target, but where visual acuity or resolution is poor. This glimpse of some movement in peripheral vision may cause the driver to look toward the moving target in order to see its details more clearly in central vision. Although the driver's peripheral vision appears to be well-equipped for detecting motion, a glance toward the movement is probably necessary for the driver to recognize what is moving. However, under low levels of illumination, the driver may have to rely solely on information about the presence and direction of movement provided by peripheral vision, since the sensitivity to detail provided by central vision diminishes as illumination decreases. Expectancy can facilitate the search and identification process. Consider the case of a driver who is anticipating the possible motion of an approaching train. At the time that he glimpses some movement out of the corner of his eye, he is more likely to take a better look at the source of movement, and is better prepared to recognize the movement as a cue for an approaching train, than if he did not have this expectancy. Thus, detection and recognition of an approaching train involve both peripheral and central vision, and characteristics of these two systems place limitations on target recognition, particularly at night.

Quadrant-Sight Distance

In the previous section on detection of trains at the crossing, studies were described in which accident data were used to reconstruct where the front of the train must have been when the driver had to make a go/no go decision (Schoppert and Hoyt, 1968; McGinnis, 1979). These studies suggest that, in a large percentage of crossing accidents, drivers do not detect an approaching train soon enough before it reaches the crossing. McGinnis (1979) estimated that, in 81% of crossing accidents that occurred in 1975, the train was still approaching the crossing when the driver was at his decision point. Such estimates can only indicate the maximum number of accidents that could have been avoided if the driver had seen the approaching train in time to stop. They do not reveal whether the driver, in fact, failed to detect the approaching train, or, alternatively, whether he did see the train in sufficient time to stop, but made a decision error. However, there is evidence that limited quadrant-sight distance is a critical factor for accidents that occur at passive crossings: the driver must be able to see an adequate distance along the track to his right and left so that he can detect an approaching train when he is far enough away from the crossing to stop safely. Adequate quadrant-sight distance depends on both the vehicle speed and the train speed. For example, although a crossing may not permit adequate quadrant-sight distance for a train approaching at 60 mph when the vehicle is approaching the crossing at 50 mph, quadrant visibility may be adequate for a 35 mph vehicle approach speed. Berg et al. (1982) found that, at passive crossings, recognition errors accounted for about 80% of accidents. Three-quarters of these recognition errors appeared to involve an approaching train, and one of the primary contributing factors in these cases was limited quadrant-sight distance. In a field survey of 31 passive crossings, Schoppert and Hoyt (1968) discovered that a driver traveling at the speed limit often cannot see an approaching train before he is at the safe stopping sight distance; they note that an obstructed view up and down the tracks will be even more debilitating for the driver at night than it is during the day, given the special problems of detecting an approaching train at night.

Looking Behavior

Of course, the driver will usually not be able to see an approaching train unless he looks for one. A number of researchers have tested the prediction that, when quadrant-sight distance is obstructed, a higher percentage of drivers will engage in looking behaviors, in the interest of safety (Sanders et al., 1973; Wigglesworth, 1978; Parsonson and Rinalducci, 1982; Aberg, 1988). Most studies indicate that drivers do not look more at crossings when visibility is restricted than they do when visibility is less restricted. One factor that has been implicated in this lack of correlation between frequency of looking behavior and severity of visibility restriction is that drivers do not readily recognize when quadrant visibility is obstructed. When Sanders et al. (1973) questioned subjects, after they had passed a crossing, about whether there was "anything that might have made it hard to tell if a train was coming" only 22% responded "yes," and most of these drivers selected visibility down the tracks as the reason for the difficulty.

As part of the same study, Sanders et al. recorded the looking behavior of drivers at active and passive crossings, all of which had restricted views of approaching trains in at least one of the two approach quadrants. Visibility was defined as sight distance to oncoming trains, which was measured at different points on the approach to the crossing. Because of restricted visibility at the crossings, only looking behavior that occurred a relatively short distance before the crossing could be effective. As discussed in the section on dependent measures of detection, near looking behavior produces observable head movements, and so provides a valid measure of efforts to detect an oncoming train. In this study, looking behavior was recorded if the driver made obvious head movements to search for an oncoming train when he was within 100 feet of the crossing. Frequency of looking was not found to increase with the severity of the visibility restriction at the crossings. In addition, looking behavior did not occur more frequently at passive crossings than at active crossings, despite the driver's full responsibility for detecting an approaching train at a passive crossing. However, drivers who were classified as the most safety-oriented, on the basis of such performance measures as frequency of looking behaviors, speed reduction on the approach to the crossing, and point of maximum deceleration, did engage in more looking behavior at passive crossings than the least safety-oriented drivers did. One of the few measures in Sanders et al.'s study that was systematically related to frequency of looking behavior was the driver's degree of familiarity with the crossing -- drivers who classified themselves as very unfamiliar with the crossing (had traversed the crossing zero to two times before) were observed to look <u>more</u> frequently than those more familiar with the crossing.

Several other studies of looking behavior at crossings support the Sanders et al. finding that roadway approaches with more restricted quadrant visibility are not associated with more frequent looking behavior than those with less restricted visibility. Wigglesworth

(1978) compared the frequency of head movements observed at two approaches to the same passive crossing; visibility of trains was obstructed in one quadrant for westbound vehicles and was unobstructed in both quadrants for eastbound vehicles. The crossing was in a rural location, and had low train volume. The percentage of drivers who made head movements was roughly the same for the westbound approach as for the eastbound approach: On both approaches, approximately one-third of all drivers looked to the left and right; one-third looked to the right only; and one-third did not appear to look at all. Wigglesworth's criterion for the observation of a head movement is not clearly defined in his report: He does not specify the maximum distance from the crossing at which head movements were recorded.

Parsonson and Rinalducci (1982) observed head-turning behavior at a passive, rural crossing with poor quadrant visibility from both approaches, but with more severely restricted sight distance from the eastbound approach than from the westbound approach. They compared driver performance at the crossing under three different conditions: 1) before any changes were made; 2) after an upgrade to advance warning signs and markings that conform to the MUTCD; 3) after the implementation of a positive-guidance solution which involved adding rumble strips on both approaches and adding "LOOK FOR TRAIN" and "HIDDEN XING" signs to the more restricted approach. (The results of the study that pertain to the effectiveness of conditions 2 and 3 have been discussed elsewhere in this report.) Within conditions 1 and 2, the frequency of looking behaviors was about the same, regardless of whether the driver was on the more severely restricted eastbound approach or on the less restricted westbound approach. In condition 3, about 10% more drivers looked for trains when visibility was more restricted than when it was less restricted, but this may not be a significant difference. The percentage of drivers who looked in one or both directions, averaged across all conditions, was 85%, in comparison to 65% of drivers in Wigglesworth's (1978) study. One difference between the two studies that may account for this discrepancy is that train volume was lower and more predictable at the crossing Wigglesworth studied than at the crossing investigated by Parsonson and Rinalducci. Evidence indicates that, as train traffic volume increases, head movement activity also increases (Sanders et al., 1973; Aberg, 1988), a result attributed to the drivers' familiarity with specific crossings under study. Thus, past experience with a particular crossing appears to affect the likelihood of searching for an approaching train, whereas the severity of visibility restrictions does not.

Aberg (1988) found that, at active crossings, fewer drivers look for trains when visibility is more restricted than when it is less restricted. For eight of the roadway approaches under study, visibility was more restricted on one side of the road than on the other. Of the 584 drivers observed at these approaches, 24% looked both ways, 10% looked only in the direction of the less restricted quadrant, and 5% looked only in the direction of the more restricted quadrant; 60% of the drivers did not exhibit any head movements at all. Significantly fewer drivers looked in the more restricted direction than in the less restricted direction. At one particular crossing, track visibility was unrestricted from one approach and restricted from the other approach. When the same drivers were observed on both approaches to this crossing, fewer drivers turned their heads to search for trains when visibility was restricted than when it was unrestricted.

In summary, visual scanning along the tracks at passive crossings is less than adequate, given that the driver is fully responsible for detecting an approaching train: Between 15% and 35% of drivers do not look for trains at all. The bulk of the evidence indicates that the tendency to actively look for an approaching train at a passive crossing is not influenced by visibility restrictions, but is influenced by the driver's familiarity with the crossing. For example, an expectancy of high train volume at a particular crossing will increase the likelihood of looking behavior, and thus will increase the driver's chances of detecting an approaching train. Many drivers may not even recognize when their view of the tracks is obstructed (Sanders et al., 1973), perhaps because they are not informed of the approach speed required for adequate quadrant-sight visibility, nor of the speeds of trains that use the crossing. For crossings with limited sight distance, investigators have recommended providing the driver with information about the appropriate approach speed and the point on the approach where effective searching for trains can take place (e.g., Schoppert and Hoyt, 1968; Berg et al., 1982; Tidwell and Humphreys, 1982). These countermeasures could facilitate detection of an oncoming train at passive crossings with sight obstructions since they prompt the driver to scan the tracks for an oncoming train as soon as it is practical to do so.

On-Train Devices

On-train devices, such as oscillating headlights, roof-mounted xenon strobe lights, outline lights, illuminated panels on the sides of railcars, and areas painted in contrasting colors, have been suggested as measures to improve the contrast of the train with its surroundings. At night, when viewed from a distance, standard locomotive headlights may not be distinctive relative to other moving point sources of light. Hopkins and Newfell (1975) cited a study by Sanders, Aylworth, and O'Benar (1974), in which five different on-train alerting light systems, as well as the standard locomotive headlight, were evaluated under both day and night conditions. Observers in the study gave the standard headlight a low conspicuity rating; the warning system reported as the most conspicuous was the pair of roof-mounted, emergency vehicle xenon strobes. Because of its narrow beam width, the standard locomotive headlight is difficult to detect, unless the beam is viewed from a position close to the axis of the headlight. Under daylight conditions, the angle between a vehicle and a train approaching the crossing is likely to be larger than the angle illuminated by the train's headlight: Most of the headlight intensity is found within 5 degrees from the axis of the headlight (Mortimer, 1988; Aurelius and Korobow, 1971). Thus, during the day, only the driver who is stopped at the crossing is likely to be at the appropriate viewing angle for detecting the headlight. At night, the headlight is more likely to be detectable from larger viewing angles than it is during the day, if atmospheric conditions like rain or fog scatter the light in different directions to make it more visible, or if illumination of trackside objects by the headlight serves as a cue for the approaching train (Mortimer, 1988). An oscillating headlight that turns 15 degrees to the left and right would be more readily detected than a fixed headlight (Schoppert and Hoyt, 1968); however, beam widths must be wider to be visible from typical driver viewing angles, under both day and night conditions (Hopkins and Newfell, 1975).

Because of these limitations on the detectability of locomotive headlights, other on-train warning light systems have been investigated. Data are available on the effectiveness of alternately flashing, emergency vehicle xenon strobe lights, mounted on opposite sides of the cab roof. Drivers are generally familiar with the use of xenon strobes on emergency vehicles as an alerting signal for potential hazard. The conspicuity of flashing lights depends on a variety of factors, such as flash rate, flash duration, effective intensity, spatial sweep of beam, spatial configuration, and color, and so the parameters that are most effective in one setting will not necessarily be optimal in another setting (Hopkins and Newfell, 1975; Howett, Kelly, and Pierce, 1987). Hopkins and Newfell (1975) conducted a field study in which xenon strobes were installed on locomotives. On the basis of discussions with train crews, their own on-board observations, and studies of "naive" subjects, they concluded that the strobes increased the conspicuity of the trains, especially at night. The procedure used to evaluate conspicuity was not specified. On one occasion during the study, under conditions of heavy snow, the strobe lights were reported to be clearly visible from 1,000 feet, when the train itself was not visible. In another field test of flashing strobe lights, Hopkins (1980) found that there were fewer accidents per locomotive mile when the accident rate for strobe-equipped locomotives was compared to that for unequipped locomotives. There was some indication that strobe lights were more effective at night than during the day. However, as Hopkins pointed out, the sample size was small, and the railroad characteristics that were sampled, such as type of railroad operation, region of the country, terrain, locomotive speeds, and locomotive color, were not necessarily representative of the national rail network. In a study by Devoe and Abernethy (1975), xenon strobe lights were observed on locomotives during yard and road freight operations, during the day, at dusk, and at night, and from a distance of up to one-half mile. Under all these conditions, observers reported that the strobes were "readily visible and attention-getting;" the criteria that observers used for these judgments were not specified. When the strobes were viewed by two observers in peripheral vision, the pulsation of the lights was detected up to 90 degrees from the light's axis. Devoe and Abernethy also found that, in an afternoon snowstorm, the strobes were clearly seen from a distance of 1,100 feet, even though the contours of the locomotive were barely detectable. Other observations indicated that the strobes were effective in aiding detection of operating trains: At a distance of several miles, flashing strobes caused the environment around the train to pulsate with light, well before the strobes were directly discernible as points of light; when the strobes illuminated reflectorized highway signs and license plates on either side of the tracks, they appeared to provide additional salient cues for the approach of the train. Thus, although there is evidence for the detectability of roof-mounted strobe lights at larger viewing angles than standard headlights, and at distances as great as several miles, most judgments of conspicuity in these studies were made by observers who were expecting to see locomotives equipped with strobes. This advance knowledge of what to look for may have made the strobes more conspicuous to the observers than they would be to drivers approaching a crossing with a low expectancy of seeing a train.

Other suggestions for on-train warning light systems include outlining the locomotive with amber incandescent lamps, and placing internally illuminated panels on the sides of locomotives. Although outline lights have been installed on a trial basis (Hopkins and Newfell, 1975), no data were found on its effectiveness in improving the detectability of an approaching train. Schoppert and Hoyt (1968) raised the point that illuminated panels on a freight train would simulate the appearance of the illuminated cars found in a passenger train. There is some indication from accident statistics that passenger trains are more detectable at night than freight trains are, and so mimicking the appearance of passenger cars, particularly at the front section of the train, may make freight cars more conspicuous.

Painting schemes for trains have been used to increase their contrast with the surrounding area. For example, Aurelius and Korobow (1971) recommended painting locomotives with contrasting areas of color, such as yellow or fluorescent yellow, used alternately with red, blue, or black. Mortimer (1988) suggested painting each railcar with three horizontal bands of color, each 5 feet in height; this is the minimum height required for the band of color to be detectable at a distance of 1,000 feet. If the middle band is yellow and the upper and lower bands are dark blue or some other dark color, the dark bands will provide good contrast against bright surroundings and the bright yellow central section will provide good contrast against dark surroundings (e.g., trees, night sky). Mortimer added that illuminating the central section with lamps on the side of the locomotive will enhance its detectability at night.

In summary, the standard locomotive headlight is not readily visible, under viewing conditions that are most likely to be in effect when the driver approaches the crossing. The on-train warning system that has received the most attention is the pair of roof-mounted xenon strobes, which appear to be detectable from larger viewing angles, and at greater distances, than the standard headlight. However, most evidence pertaining to strobe light effectiveness consists of subjective judgments of conspicuity, made by observers who were expecting to see a strobe-equipped train. It is unclear whether the roof-mounted strobe lights will facilitate detection of an approaching train under normal crossing conditions, when drivers have not already been informed about what feature to look for, and when they often do not expect to see a train. Tustin et al. (1986) reported that the FRA decided against the mandatory use of roof-mounted strobe lights at crossings, due to the lack of evidence that roof lights reduce the frequency of crossing accidents.

Auditory Warning Signals

Auditory signals from trains provide cues for the detection of a train. Auditory signals have the advantage of not requiring the listener to be oriented toward the signal; in contrast, visual stimuli cannot be perceived unless the eyes are directed toward them. Auditory signals perform an important function in providing redundancy to the messages provided by visual cues. However, auditory signals for grade crossings suffer from a number of serious drawbacks. Therefore, they are generally viewed as a useful supplement to visual cues, but not as the primary means of alerting the motorist. Perhaps consistent with this view, there is relatively little research, or even discussion in the literature, about the effectiveness of auditory signals.

An inherent limitation to the use of acoustic signals comes from the conflict with community noise. An optimal warning will be sufficiently loud so that it reliably alerts virtually all drivers (except the seriously hearing impaired) under common adverse listening conditions in vehicles, at a point where both the train and the vehicle are sufficiently far from the crossing so that the driver can take appropriate action. Unfortunately, since sound radiates from a point source, this signal impinges on the entire area surrounding the train. Annoyance and interference with home or workplace activities can take place at much lower sound levels than those required to meet the driver warning criteria (e.g., Kryter, 1970). Tustin et al. (1986) note that ordinances prohibiting the sounding of the whistle to lessen environmental noise impact have been passed in some areas. There can be extensive community complaints to regularly used horns, as a recent newspaper article illustrated (USA Today, August 30, 1988). When four railroads in the Chicago area began to comply with a state law requiring sounding horns at crossings, "steamed residents flooded police, state senators and railroads with complaints." An employee of one railroad helped handle more than 700 calls. In addition to community conflicts, consideration must also be given to potential hearing loss faced by train crews which could be exposed to frequent signals over extended periods (Cox, 1972). These kinds of conflicts place limits on the use and characteristics of audible train signals, so that realistically they should not be projected as the primary source of warning for the driver.

The detectability of an acoustic signal is a joint product of the intensity and acoustic frequency of the signal, and the level and frequency spectrum of the noise background against which it must be detected. There are three important limitations to the intensity of the signal, in addition to realistic constraints on the sound level at its source. First, sound intensity reduces with distance, according to the inverse square law; this means a decrease of about 6 dB for each doubling of distance. Thus simply due to such attenuation, the sound level 800 feet from the source will be 24 dB lower than it was 50 feet from the source. The FRA requires a minimum horn sound level of 96 dB(a) at 100 feet forward of the train; this would yield a level of only about 78 dB(A) 800 feet away. Second, there are physical barriers which may reflect or absorb sound, further attenuating its level at the ear of the listener. These include the car structure and windows (if closed), buildings, trees and foliage, etc. Third, the wind can play an important role in propagating sound. Listeners upwind from the sound source will suffer more sound attenuation; Cox (1972) indicates a wind effect of about 2 dB per doubling of distance for a 1,000 Hz signal with an 8.7 knot wind, and 3 dB per doubling for winds in excess of 10 knots.

Potential sources of background noise include car radios and tape decks, fan noise, engine and tire noise (especially severe for trucks), wind noise, conversation in the car, and outside noises such as traffic. In addition to these masking sources, possible limitations to the hearing capabilities of the driver must be considered. Age-related hearing loss (presbycusis) is common, more so for men than for women. The loss is more pronounced at the higher sound frequencies, but even at the important middle frequencies (2,000 to 4,000 Hz), loss for a typical 65-year-old male may be about 20-25 dB.

Research (Aurelius and Korobow, 1971) has suggested that a signal intensity of about 87 dB was required outside the vehicle for a horn to be adequately heard. However, this estimate may be quite specific to test conditions, and certainly does not represent a worst case condition. Higher levels would be required for older drivers, noisier vehicles, louder radio or conversation, higher speed, etc. The primary conclusion must be that train horns will not be reliably detected and recognized at adequate warning distances. Mortimer (1988) indicates that for noisier environments (e.g., trucks, loud radios), a train horn may be difficult to hear until it is only about 500 feet away, or 5-6 seconds from the crossing at 60 mph. The actual location for first sounding the horn varies from state to state, from 300 to 1,800 feet, with 1,320 feet being most typical (Tustin et al., 1986). However, it is clear that the effective warning time provided will vary dramatically with train speed, vehicle speed, and listening conditions.

In summary, there is little direct evidence on the role auditory signals play in actually alerting drivers of an approaching train. Auditory signals have attributes that make them useful as supplementary warnings. However, timely detection under real-life driving conditions may often be difficult. Once a train signal is detected, the train's direction, distance, and speed must still be determined visually. Therefore, auditory signals appear to be best viewed as a supplementary form of warning.

3.2.9 Competing Inputs Near the Crossing

Searching for trains requires the driver to shift his visual attention to a point off the road. In many cases it may require turning the head or torso to search areas far from the normal direction of gaze during driving. Thus this search is competing with the normal visual search activity during driving. In addition, special demands for visual attention may compete with search for trains.

In normal driving on a straight open road, the large majority of visual fixations occur within a few degrees of the focus of expansion (the point where the edges and markings of the road appear to converge). As the demands of traffic or road geometry increase, there are shifts to this pattern. When following another car, visual fixations become more compact and are closer to the car. On curves, fixations tend to shift between the road edge near the car and the uproad area ahead; this reflects the driver's need to determine path and maintain lateral lane position. When searching for navigational or other information, more fixations are directed to the typical sign locations, to the right road side.

Eye movement studies have quite clearly shown the visual demands imposed by surrounding traffic and roadway geometry. Where rail-highway crossings are located near demanding features such as curves or intersections, or where the driver is amid other traffic, these visual demands compete for attention and reduce the opportunity for large visual excursions to search offroad for trains.

Even where geometric and operational concerns are less severe, the tracks themselves may be a focus of visual attention. The findings of Sanders et al. (1973) suggested the importance of the crossing surface to the driver. The most common reason drivers reported slowing for a crossing was the bumpiness of the crossing, and vehicle speed was also correlated with crossing smoothness. Thus although no eye movement studies or other formal experiments on visual attention at grade crossings were uncovered, it appears likely that the crossing itself is a feature that attracts visual attention and competes with search for trains.

Roadway features uproad from the crossing may also command visual attention. For example, Peterson and Boyer (1975) describe a crossing where a traffic light was visible about 300 yards ahead of the crossing. The sensitivity of driver actions to this signal suggest that attention was being directed toward it; the signal, not the threat of a train, was the primary determinant of driver actions at this point. Ruden et al. (1982) have pointed to other nearby highway signage as a source of visual competition. Pedestrians and children near the crossing also command visual attention; Wigglesworth (1979), for example, describes an incident in which the driver was concentrating on some young children who were riding their bicycles in the area of the track, and failed to notice an oncoming train.

Factors unrelated to the driving task may also compete for visual attention. This is of course most true in urban settings, where roadside commercial development is designed to attract attention. Hughes and Cole (1986) systematically studied the features that attract visual attention by having drivers verbally report "all the objects or things that attracted their attention" in the course of a 21.9 km drive through a suburban area. About 30-50% of attention was directed toward objects unrelated to driving. On arterial sections of the route, and near shopping centers, nearly one-fourth of all the verbal reports were toward advertising.

Of course, competing inputs interfere with the detection and recognition of crossing-related signs, signals, and markings, as well as with the detection of trains themselves. The problem may be most acute for train detection because it requires directed search to off-road locations.

In summary, the detection of trains or crossing-related information may be compromised by the presence of other features which compete for visual attention. These features may be related to the driving task, and include road geometry, signs and signals, traffic and pedestrians. The tracks themselves may command attention. In addition, other features of the environment, unrelated to the driving task, may compete for visual attention.

3.2.10 Detection and Recognition – Summary

This section has covered the component detection and recognition tasks that are required to negotiate a crossing safely: The driver must detect advance signs indicating the approaching crossing, as well as the presence of the crossing ahead; he must recognize whether the crossing is actively or passively protected, and then search for trains at or approaching the crossing, to the extent dictated by the type of crossing protection system; at an active crossing, he must detect the crossing signal, which aids in locating the crossing itself; at a passive crossing, he must utilize such cues as the crossbuck to identify the location of the crossing. The sooner the driver becomes alerted to an upcoming crossing, the more time he will have available to actively search for the train or the active crossing device, and to decide whether it is safe to proceed. Moreover, being aware that there is a crossing ahead will facilitate the detection and recognition of other crossing-related information, because the driver will have a meaningful context to help interpret potentially ambiguous cues.

The driver faces many problems in carrying out these detection and recognition tasks. Advance warning signs may lack conspicuity. The driver is not informed in advance about whether the crossing is active or passive, and must therefore rely on detecting the presence or absence of flashing lights or gates at the crossing. At night, if the crossing is unilluminated and it is not gate-protected, it is very difficult to distinguish between the presence of unactivated (and usually unreflectorized) flashing lights, and the absence of an automatic signal. Although the crossbuck marks the crossing location, it is not very conspicuous when viewed against a light background, and the driver's eyes must be properly oriented to view it from a distance. The crossing itself may not be visible from a safe stopping sight distance, if it is obstructed by vegetation or objects, or by the alignment of the roadway with the crossing. A train at the crossing is difficult to detect at night when the crossing is not illuminated, especially if the train is moving at a slow speed or is stopped at the crossing. Finally, detecting and recognizing a train approaching the crossing is a complex task that requires the coordination of peripheral and central vision, and that is heavily influenced by driver expectancy. Recognizing cues for an approaching train is particularly difficult at night when brightness contrast between the train and its background is low, and when the locomotive headlight may not be distinctive among other moving point sources of light viewed at a distance. In darkness, the driver may have to rely largely on peripheral vision to detect an approaching train. Although peripheral vision is sensitive to the presence and direction of movement, it does not provide the resolution of detail that may be necessary to identify <u>what</u> is moving. Limited sight distance along the tracks will compound the driver's difficulty in detecting and recognizing an approaching train. The driver may not even recognize when visibility is restricted, and lacks critical information to help him deal with the problem, such as what his approach speed should be, given the speeds of trains at the crossing, and where he should begin looking for trains.

3.3 PERCEPTION

If a driver detects the presence of both the crossing and an approaching train, he may also need to make higher-order perceptual judgments about speed, distance, closing rate, gap width, and so on. At a passive crossing these judgments are made from a moving vehicle, which requires additional judgments to be made. This section deals with the problems drivers have in making such judgments, and the particular characteristics of trains which contribute to perceptual misjudgments.

3.3.1 The Perceptual Problem

The driver must determine if he can safely clear the tracks prior to the arrival of the train. If stopped at the crossing, he must judge the time to arrival of the train, based on apparent distance and speed. He must also estimate the time it will take his vehicle to accelerate and clear the tracks. This judgment must also take into account the length of the vehicle. While the primary perceptual problems involve judgments about the approaching train, judgments about one's own vehicle's clearance should not be overlooked, particularly for larger vehicles. Factors such as road traction, grade at or near the crossing, roughness of the crossing, length and weight of load of a trailer, etc. all impact crossing time. Gillespie (1986) estimated that a fully loaded tractor-semitrailer requires from 11.5 to 33.7 seconds to clear a set of tracks, depending on the number of tracks and the vertical grade of the road.

For the passive crossing situation where the driver is not required to stop, the driver must in addition perceive his own speed and distance from the crossing, and his projected time of arrival relative to the train's.

The perceptual problems become even more difficult at night, when many cues to speed and distance are lacking. Approximately 42% of train-vehicle collisions occur during the dark, including about 38% of all cases where the train struck the vehicle (Rail-Highway Crossing Accident/Incident and Inventory Bulletin for Calendar Year 1987).

Sight distance is a critical part of the driver's problem. At the point at which the train becomes visible, the driver must determine whether he can safely clear the crossing, and if not, there must be adequate space prior to the crossing to permit safe stopping. This problem is related to the definition of the various information handling zones described earlier, and in particular the point of transition from the approach zone to the non-recovery zone. The driver's decision making problem and vehicle handling concerns are not appropriate to this section, which deals with the perception of trains, gaps, and collision courses. However, it should be noted that the perceptual and decision processes are interrelated. A restricted sight distance may limit the time the driver has to process and evaluate train speed and closing, and may also alter the perspective from which the train is viewed. Likewise, a difficult perceptual problem may require more time for the viewer to resolve, and the time taken will add to the driver's overall decision response time, thus functionally increasing the length of the non-recovery zone.

3.3.2 Motion and Gap Perception

There have been many research studies of how drivers perceive the relative speed and distance of other vehicles. While a literature review uncovered no data specifically on the judgments of speed or temporal gap for trains, the more general literature indicates a number of important issues. These will be discussed in this section. However, there are certain unique attributes of trains at crossings that may contribute to driver misperceptions. These will be discussed in the next section.

The literature on speed and distance judgments for highway traffic situations sometimes distinguishes between "gap time" and "lag time." Gap time is the time between two successive vehicles on a roadway. Lag time 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. For purposes of the discussion here, this distinction will not be critical, and the term "gap" will be used generically for all situations.

Gap acceptance has been studied in both field and laboratory settings, for situations including crossing intersections, right turns into traffic, left turns across traffic, merging, and passing. In general, both perceptual judgments (laboratory studies) and actual traffic behavior show a systematic relationship to the temporal aspects of the situation. For example, Ebbesen and Haney (1973) presented data for turns into traffic at intersections, and found that the probability of turning (accepting the gap) was a normal function of the logarithm of temporal distance. In its summary of the literature, the OECD (1974) found that gap acceptance corresponded to a lognormal distribution of gap times, with a median value of 7.3 seconds. The 85th percentile was approximately 10 seconds, and the 15th percentile was about 4 seconds. Overall, the acceptable gap decreased further as the road volume increased (the probable influence of impatience). For some drivers, gaps as small as 2.5 seconds were acceptable. Two aspects of these findings are worth noting for the rail-highway crossing situation. First, these acceptable gaps are quite short, relative to the duration of the warning times for many active crossings; this may impact the perceived credibility of the warnings. Second, drivers have a great amount of experience with gaps at intersections, and likely will have learned that a gap of less than 7 seconds is safe and provides a satisfactory margin of error. To the extent that the approaching train situation differs from a highway intersection situation, and the driver fails to appreciate the differences, the driver's experience may lead him to make overly-risky decisions. Among the important differences, other drivers in the traffic situations can take actions to compensate for the entering driver's misperceptions, enhancing the margin of safety in a way that does not occur for trains.

Even for highway situations, spatio-temporal judgments may be subject to considerable error. For both passing situations (e.g., Farber, 1969) and turns (e.g., Shoptaugh, 1988), drivers do not adequately take into account the speed of on-coming vehicles. Farber found that the likelihood of a vehicle deciding to pass a lead car was related to the available passing distance and the speed of the lead car, but not to the speed of the approaching traffic; passing was as likely when the on-coming car was going 60 mph as when it was going 30 mph. Given the distances involved, this is probably related to the difficulty of perceiving the speed of approaching vehicles.

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 of an object is a tangent function of its distance, the size of the image grows exponentially as the object approaches at constant speed. As the distance halves, the visual angle subtended is doubled. The implication of this can be seen graphically in a figure presented by Mortimer (1988, page 58), which illustrates the image size of a locomotive at various distances. As a train approaches from 5,000 feet away to 1,000 feet away, the image size changes relatively little; but inside about 500 feet away, the rate of growth ("looming") increases dramatically. Thus difficulty in perceiving the rate of approach from a target at a distance is inherent in the geometry of the situation.

Even without the difficulties of judging the oncoming vehicle's rate of approach, the visual difficulties of gap acceptance in passing maneuvers lead to poor performance. For example, Gordon and Mast (1976) found, in a test track experiment, that drivers badly underestimated the distance required to pass a lead vehicle, and that the percent of drivers underestimating the distance increased as speed increased. Hills (1980) has reviewed a number of other studies of passing, primarily done in Europe, which confirm the findings of poor perceptual judgments and underestimating the distances required. Judgments about passing, just as judgments made on approach to a crossing, require accurate perception of one's own speed, other vehicles' speeds, speed differentials, distances, and closing rates. In the rail-highway crossing context, Sanders et al. (1973) asked drivers stopped just after passing a crossing to estimate the speed at which they had been approaching. The reported estimates (which of course could be biased) underestimated speed by about 30%. The general literature on how people perceive the speed of their own vehicles is not entirely consistent. Some studies have found drivers to overestimate their speeds, other have found them to underestimate; a number of variables affect perceived speed, including vehicle characteristics, acoustic cues, road characteristics, roadside environments, immediately preceding driving experience (adaptation), etc. (e.g., Shinar, 1978; Triggs and Berenyi, 1982). Errors in either direction could be quite dangerous at a grade crossing, where they could impact judgments about whether the vehicle could beat an approaching train to the crossing, or whether the vehicle could stop safely before the crossing.

Like speed, studies of perceived distance have also found variable results, with both underestimates and overestimates reported (Hills, 1980). Perhaps the best summary regarding both perceived speed and perceived distance is that these perceptions can be quite variable and inaccurate, subject to a number of factors which influence the direction and magnitude of perceptual errors.

There is research on the perceived distance and motion of large trucks, which is also relevant. Henderson, Ziedman, Burger, and Cavey (1983) provide a summary of this literature. The perceived distance of trucks is related to the extent of patterning and delineation, with a fully outlined pattern seen as closer. Minimal patterns defined by the presence of vehicle lights appear farther away. Minimal patterning, particularly at night, may be more typical of trains, where the outline of the approaching locomotive is not distinct. This could contribute to the driver acting as though the train were actually farther away. Motion detection for trucks (e.g., headway changes) is enhanced by greater visible linear extent and by the degree of separation between lamps. Again, locomotives do not fare well in this regard.

3.3.3 Unique Problems in the Perception of Trains

There are features of trains which cause them to appear farther or slower moving than is the case, or which cause speed or distance to appear ambiguous. This obviously can lead to serious errors in judgment.

Leibowitz (1985) discussed some of the factors which contribute to misperception of approaching trains. A primary source of misjudgments is the "large object illusion." Larger objects in a class appear to move slower than smaller objects. As an example, Leibowitz compares large jets and smaller jets coming into an airport for a landing. Although the approach speeds are similar for both, there is a very compelling illusion that the larger planes are moving more slowly. This illusion can be generalized to other classes of objects, in particular trains vs. smaller vehicles. This is similar to a classic effect in motion perception called "velocity transposition" (Brown, 1931). This states that the perceived velocities of moving targets are related to the relative sizes of the targets and the visual fields in which they move.

A grade crossing can provide cues to depth that may emphasize the apparent distance of the train (Leibowitz, 1985). For example, the apparent convergence of the parallel tracks, and the gradient of visible detail along a uniform texture, such as track ballast or stone, are learned perceptual cues that signal depth in the environment. These unconsciously-used cues may increase the viewer's perceived distance of a train in this setting.

Mortimer (1988) has pointed out that a driver can make more accurate estimates about time and distance if he can see the front end of the train from a side view, such as at about a 45-degree viewing angle. When the angle is more oblique, some cues are lost, and judgments must be based upon apparent size, and looming. Given the frequent sight distance limitations at many crossings, the driver may not have the benefit of much lateral view of the train.

Even where greater sight distance up the track is possible, an important visual cue can be lacking. A driver can use retinal displacement (changing position of the image of the moving target on the retina) as a cue to speed. Unfortunately, as noted by various authors (e.g., Hulbert, 1967; Leibowitz, 1985), if the vehicle and train are on a collision course at constant speeds along straight line paths, the image of the train remains at the same point in the visual field. There is no lateral motion.

For high-speed trains, the failure of drivers to properly incorporate speed into gap judgments, already discussed, adds another source of potential error. Furthermore, because they must be judged from greater distances, there is a slower rate of growth of the retinal image as the train approaches. Mortimer (1988) presents a table (page 57) showing the size of the retinal image for a 10-foot-wide by 15-foot-high locomotive at various distances. In traveling from 250 to 125 feet from the viewer, the visual angle subtended increases from 3.43 to 6.84 degrees. In contrast, in traveling the 1,000 feet from 2,000 feet away to 1,000 feet away, the visual angle changes from 0.43 to 0.86 degrees. Thus the rate of growth of the approaching target is much smaller in absolute terms. Yet such distances are quite meaningful for higher speed trains. At 60 miles per hour, 1,000 feet is only 11 seconds away; at 90 miles per hour, only 7.5 seconds away.

At night, distance perception of a train can be limited by the fact that the locomotive headlights are placed close together, giving the appearance of a single point source (McGinnis, 1979). In contrast, the spacing between automobile headlamps or tail lamps provides additional distance cues. Not only does the degree of separation provide a clue to absolute distance, it has been found that greater spacing of lamps leads to better perception of movement and closure (e.g., Henderson, Sivak, Olson, and Elliott, 1983). The color of lights can also influence distance perception. Due to "chromostereopsis" related to the anatomy of the eye, the refraction of different wavelengths of light leads to different apparent degrees of retinal disparity. For this reason, a blue light appears closer than is truly the case, while a red light appears farther.

Another possible cause for underestimating the speed of a train at night comes from reliance on the eye-head movement system. A distinction is made between cues to motion from the image-retina movement system and the eye-head movement system (Coren, Porac, and Ward, 1984). The former is based on movement of the image on the retina, as in lateral movement or looming. The latter is based on the pursuit movements of the eye and head as a target is tracked (thus remaining more or less in fixed position on the retina). At night, tracking a moving train lamp against a background that provides few patterning cues, the path and speed of one's own eye movements become the major source of information about train speed and path. This reliance on monitoring eye tracking actions leaves room for perceptual error, particularly since this tracking does not occur with perfect accuracy. There is a tendency for the eye to trail the target to some degree, and the magnitude of this lag increases with the speed of the target. Thus, for faster moving targets, such as higher speed trains, there will be more of a tendency to underestimate the actual speed. There is another unusual visual phenomenon related to reliance on the eye-head movement system, called the Aubert-Fleischel paradox. When an object moves relative to a stationary background, that movement appears slower, and of lesser extent, when one tracks the target with the eyes, as opposed to fixating on the background.

In summary, there are a variety of reasons why trains, as moving visual targets, will be misjudged, under either day or night viewing conditions. The biases in these misjudgments tend toward underestimating speed or overestimating distance, which may lead to riskier driver actions.

3.3.4 Other Sensory Modalities

Sensory modalities other than vision make little contribution to the perception of trains, beyond the level of simple detection. Auditory stimuli from the train -- horns and general train noise -- theoretically could provide distance information. One means is through the absolute intensity (loudness) of the sound, since intensity is inversely proportional to distance. Another theoretical means is through the Doppler effect, where the pitch of a sound increases as the approaching object nears, and then drops as it passes. Neither of these mechanisms would appear to be important in a practical sense, although no actual research on the perception of train signals was uncovered. To use the absolute loudness of the sounds as a cue would require the listener to have an accurate expectancy about the actual acoustic intensity of train noise or signals. The Doppler effect would require very precise pitch differentiation, since the most obvious perceptual changes occur only when the object is quite close to or actually passing the listener. In addition, as already discussed for train detection, the acoustic environment while driving may be very poor; detection itself is a problem, let alone higher order perceptual judgments about distance and closing. Given factors such as raised windows, noise from heaters or fans, wind noise, engine noise, radios or tape decks, and other outside noise sources, acoustic train signals cannot be considered useful means of providing accurate information on dynamic aspects of trains.

In contrast, non-visual modes can make a contribution to the perception of the speed of one's own vehicle. However, this generally is not a factor under control of the highway or railroad authorities. An exception is where perceptual "tricks" are used to make approach speed seem faster than it really is, thus inducing the driver to slow down. This can be done with both visual and non-visual stimuli. For example, rumble strips, or transverse painted lines, can be spaced progressively closer on an approach, so that the shortened time between pairs of them gives an illusion of greater speed. However, it is not clear how such treatments might effect the accuracy of perceptions about gap acceptance. The primary purpose is to get the driver to reduce speed, and particularly for rumble strips, to increase driver attention.

3.3.5 Perception -- Summary

Visual judgments about speed, distance, and closing rate are subject to a number of influences and can be in considerable error. Studies of gap acceptance in traffic indicate that drivers' perceptions are not particularly sensitive to the speed of approaching vehicles, and there is also a tendency for drivers to misjudge their own speeds. But in addition to the perceptual difficulties a driver faces in any traffic situation, there are features about the perception of trains at crossings that make misperceptions even more likely. These include the "large object illusion," cues in the environment that emphasize depth, viewing angle and reliance on looming cues (especially from a distance), limited delineation and spatial separation of cues from the locomotive, and reliance on eye-head movement system cues for motion. Sensory modalities other than vision provide little information.

3.4 DECISION MAKING

The problems described in previous sections may be characterized as failures to accurately acquire necessary information. The problems addressed in this section are failures to appropriately process and apply the information that has been acquired. In their study of rail-highway accident causation, Knoblauch, Hucke, and Berg (1982) distinguished decision errors from recognition errors (recognizing trains and identifying available actions) and action errors (failures to successfully execute a planned maneuver). They defined a decision error as "a breakdown in either the analysis of [necessary] information, or the selection of an appropriate collision avoidance maneuver. For this type of error, it was assumed that the necessary information to perform these tasks had been detected and perceived in sufficient time to make a decision and successfully complete the maneuver." Of course in practice, it is difficult to know how accurately and at what point the driver acquired information. Furthermore, the conceptual distinction between perception and decision is not as clear cut as the definition implies. They are mutually interdependent aspects of human "information processing." However, the distinction remains useful for emphasizing the kinds of problems that stem mainly from the manner in which the driver translates the information he has acquired into a course of action.

3.4.1 Decision Making Errors in Rail-Highway Crossing Accidents

In the initial section of this review dealing with driver information needs, Figure 2 was presented to show the sequence of information and the required driver actions. A decision making error can occur if a driver misinterprets information to follow an incorrect path in the chart, or if the appropriate action indicated for each information item is not properly selected. At each point in the chart, a multitude of factors may contribute to the likelihood of an error. Thus decision making errors of many different sorts can occur, and from a variety of causes.

In accidents of many sorts, it is common to find that an accident occurred as the result of a chain of poor decisions. Initial poor decisions may not have been inherently catastrophic, but each bad decision facilitated the next. Thus the motorist who makes a poor choice of approach speed prior to a passive crossing site may be triggering a dangerous chain of problems. The speed might result in a decreased decision zone if sight distance is limited, and the demands of vehicle control might limit off-road visual search. When the driver realizes there is a crossing ahead, he has the option of slowing, even if it may be abrupt. But he may not want the inconvenience or discomfort of such braking when no hazard is visible, or he may feel committed to continue, and so he relies on his expectancy that trains are unlikely. Having chosen to continue in any case, he may not be attentive in his search for a train. If he belatedly detects a train, he may have drastically reduced his time to reconsider his decision while at the same time being confused about what alternative avoidance actions are available. At this point the wrong choice of actions may be made. This sequential nature of many accident scenarios often tends to get lost in the simplification that necessarily comes with categorizing accidents for analysis. Ultimately the accident scenario above can be described as a single bad decision: The driver did not stop when he ought to have stopped. However, there are two important consequences to consider when keeping in mind that there is often a chain of events. One is that a safety intervention at any point in the chain may have some impact, even if the primary decision error occurred at some other point. The second implication is that it may be difficult to encourage a driver to make a decision which involves breaking a sequence of planned action to which the driver is psychologically committed.

Driver decision errors play an important role in safety at rail-highway crossings. They are the predominant category of error for certain crossing types. A major study contributing to understanding the role of decision making errors in rail-highway crossing accidents was that of Knoblauch et al. (1982). These authors reconstructed accidents from accident records and site investigations, and classified drivers' errors as "recognition errors," "decision errors," or "action errors." Decision errors were predominant at sites with flashing lights (estimate of from 53-71%), and less frequent (estimate of from 17-19%) at cross-buck only sites, where recognition errors predominated (estimate of from 77-85% recognition errors). The estimates are shown as ranges because some accidents were ambiguous as to which alternative categories they should be included in. These authors further classified decision making errors into several categories, and identified common contributing factors to each case. The primary kinds of decision errors (and their approximate frequencies) were:

- Flashing Light Sites:
    - Driver recognizes signal from approach zone, does not stop, 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%)

One interesting point to note is how few accidents occur after the vehicle has stopped. This suggests that for passively protected and flashing light sites, relatively few accidents occur because a stopped driver misjudges the temporal gap and proceeds. The large majority of decision errors are made by drivers in moving cars. This might be because controlling the vehicle interferes with cognitive or higher-order perceptual functions, but might also simply reflect exposure, particularly at crossbuck-only sites (very few drivers stop to begin with). Despite the importance of the Knoblauch et al. (1982) study and the frequency with which it is cited, it is important to recognize certain limitations. For example, Knoblauch et al. only considered sites with flashing light signals or crossbucks. Thus gates, stop signs, or other treatments were not included. They also excluded cases that involved alcohol; this is a significant portion of accidents, particularly at night. Important limitations to the sample include its size (43 flashing light accidents at 41 sites; 36 crossbuck-only accidents at 34 sites) and limited geographic area (all accidents from North Carolina or southeastern Wisconsin). Thus the estimated frequencies will be subject to error, and factors such as weather, driver characteristics, local traffic laws, land use, etc. likely may not be representative of national characteristics.

The other point to keep in mind is that Knoblauch et al. used a specific definition of a "decision error." While appropriate, their definition is in some ways a rather narrow one. For example, if a locally-familiar driver is aware of a crossing ahead, but selects an inappropriate approach speed, this could be considered an error in decision making. However, it may not be treated as such by Knoblauch et al., because if the driver does not detect the presence of a train until after he has entered the non-recovery zone (which is defined in part by the chosen vehicle speed), it is a perceptual error. Another concern is that the non-recovery zone for a site was defined "on the assumption that worst case driving conditions exist." Therefore some cases where the driver did not detect a train until he already was in the nominal non-recovery zone actually may have occurred when the driver was far enough away to take evasive action if he so decided. This would then actually constitute a decision error. The point here is not to question how a decision error "ought" to be defined. Rather, it is to point out that viewing decision-making more liberally, one would classify even more cases than Knoblauch et al. as decision errors, perhaps especially for crossbuck-only sites.

Numerous authors have pointed to the prevalence of decision making errors in rail-highway accidents, and the complex decision making problems facing the driver. The actual incidence of decision errors depends in part on how they are defined, but by any definition they are common. Inherent in the dilemma facing the driver are features conducive to decision errors. It is important to recognize the constraints and conflicts faced by a motorist who has acted unsafely, rather than simply dismissing him as "careless" or "stupid."

3.4.2 Risk Perception and Risk Taking

Because people recognize that a moving train constitutes a hazard, decision making at crossings clearly involves the concept of risk. "Risk" refers to a potential for harm as a result of a course of action. Risk taking therefore refers to the willingness to accept a certain potential for harm, for whatever benefits derive from the action. Risk perception refers to a person's ability to perceive the potential for harm as a consequence of the action. Thus to talk about a driver taking 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. These aspects can be illustrated by considering the influence of a limited quadrant sight distance (visibility up the track) on driver actions. Field studies (e.g., Sanders et al., 1973) have shown that many drivers are often unaware that sight distance is limited as they approach, and even continue through, a crossing site. If there is no appreciation that a risk exists, it is not meaningful to view the driver's actions as risk taking. However, if a driver does recognize that sight distance is limited, he must understand what risk this entails. His expectancies about the likelihood of trains and their probable speeds, the nature of the warning devices, past experiences at grade crossings, and so forth will determine how much risk is perceived. Finally, two drivers who perceive the same level of risk, or even the same driver perceiving a given level of risk at different times, may make different decisions about whether to accept that risk. Risk taking is not only a function of various personality traits, but also is influenced by many situational factors (e.g., the presence of other passengers in the car) and by transient emotional states (e.g., angry over something that happened earlier). Thus to understand driver risk taking at railroad crossings, it is important to understand how people view the risks, and what factors contribute to accepting the risk.

One important point should be clear at the outset. While the traffic engineer may presume that the rational driver would always act so as to minimize the risk of an accident, risk minimization is usually not the strategy that best describes the behavior of people. Models of risk taking and choice have characterized this in different ways, but the essence is that risk is but one factor that people incorporate into deriving an "optimal" solution in their terms.

Recently, an entire special issue of the journal "Ergonomics" (April 1988, Volume 31, No.4) was devoted to "Risky Decision-Making in Transport Operations," and good reviews of risk perception and risk taking may be found there. Also, Lerner, Williams, and Sedney (1988) provided a comprehensive review of risk perception. The discussion here is limited to a few considerations of most importance to the rail-highway crossing problem.

An initial question of interest is: How do drivers perceive the magnitude of hazards associated with grade crossings? In their survey done in 1979, Tidwell and Humphreys (1981) asked respondents to indicate about how many people were killed at railroad crossings in the previous year, and offered choices of: 10; 100; 1,000; 10,000; and 100,000. At the time, the best estimate was about 1,000, the choice indicated by 40% of the respondents. However, nearly as many said 10,000, and 5% estimated 100,000. Thus apparently a high proportion of the driving population believes there are many more grade crossing accidents than actually occur. But what does this mean? People lack a good conception of accident frequencies in general, so these findings do not say much about the relative risk seen at crossings. The problems people have in estimating accident frequencies can be seen in a study by Bragg and Finn (1982). They asked young (aged 18-24) and experienced (38-50) drivers to estimate the annual number of injury accidents and fatal accidents, for both the entire United States and for Massachusetts only (where the study was conducted). For national data, both age groups greatly overestimated the number of fatalities (by a mean factor of 10.5 for experienced drivers, 4.6 for young drivers). On the other hand, they greatly underestimated the number of injury accidents (by a mean factor of 0.06 for experienced drivers and 0.22 for young drivers). For Massachusetts state accidents, both groups overestimated the frequency of both injury and fatal accidents, by factors of from 2.6 to 8.4. Data such as these show that (a) people are not very good at estimating the actual frequency of injury and fatal accidents, and the nature of their errors is variable; and (b) the overestimate of the frequency of rail-highway crossing accidents found in other research should not be taken to mean that people are especially sensitive to the unique hazards of grade crossings.

The relative perceived risk of grade crossings, compared to other driving situations, was studied by Heathington and Urbanik (1972). In an Indiana study of 259 people, subjects were shown photographic slides related to six hazards: a grade crossing, a stop-controlled intersection, a yield-controlled intersection, a signalized intersection, a crossroads, and a curve. The slides did not depict the actual hazard. Rather all the scenes were the same view of an advance warning sign, and only the content of the warning sign was changed to indicate the upcoming feature. When a paired-comparison method was used (pairs of scenes presented, with the subject indicating which of the pair was the more hazardous), the rail-highway crossing was found to be seen as the most hazardous of the six features.

However, using another procedure in which subjects simply rated the hazard of each scene using a scale from 1 to 7, there was no significant difference between the features. Thus while there may be some indication that the grade crossing was seen as relatively more hazardous, this was not a robust effect.

In another rating scale experiment, conducted in Australia, Cairney (1982) gave brief verbal descriptions of 38 different driving situations, and had subjects rate each based on "how easily an accident could occur." One situation was "Going over a country railway crossing without gates." This was rated as one of the lesser hazards in the set, roughly comparable with "Driving along residential streets" or "Turning left [equivalent to right for U.S. direction of travel] off a main highway." However, the wording of the instructions seemed to emphasize accident frequency, not severity, so the findings may not fully capture the sense of hazard.

Watts and Quimby (1980), in a British study, examined drivers' perceptions of risk at 45 sites along a 16-mile course. At each site, the driver rated "the chance of a near miss" on a scale of 0-to-10. One site was a rural grade crossing. This was rated among the most hazardous sites (6th of the 45), even though no accidents had actually occurred during the preceding four-year period. The representativeness of this crossing was not discussed, however. Similar findings come from a study by Lerner et al. (1988). Subjects viewed brief (10-second) video clips of highway scenes, shot from driver's eye view perspective. A variety of geometric and operational elements occurred in the 25 scenes, including one scene of a railroad crossing. Subjects rated the perceived level of risk for each site. The railroad crossing was rated the riskiest of all the scenes. These included narrow bridges, sharp curves, hill crests, intersections, and so forth. Since only one rail crossing was included in the set of scenes, it is not known how representative this finding was.

In summary, studies in which people report the subjective risk of crossings have not yielded clear-cut results. The two experiments which put subjects in the most realistic situations (Watts and Quimby, Lerner et al.) found relatively high perception of the hazard at a crossing, but both of these experiments included only one crossing site of unknown representativeness.

If drivers do perceive risk, it may be expected that this perception will be reflected in the driver's overt behavior, such as reducing speed. Studies have looked at driver behavior at crossings, but there are two limitations. First, one is more directly measuring risk <u>taking</u>, of which risk perception is only one determinant. The second limitation is that overt measures such as vehicle dynamics may not be sensitive measures of perceived risk. Many unobservable actions might occur, such as hard-to-detect movements (e.g., "covering" the brake) or non-overt behaviors (e.g., devoting greater attention, being "set" to respond). Lerner et al. (1988) obtained continuous on-the-road measures of risk perception by having subjects continually adjust a dial to reflect their momentary perception of the level of risk. Perceived risk "profiles" could then be constructed for different sections of roadway. It was found that perceived risk profiles tended to be mirror images of actual vehicle speed profiles (i.e. higher risk = lower speed). However, the changes in risk were much more evident and dramatic in the perceived risk (dial setting) profiles; driving was a much less sensitive measure. One should therefore not fall into the assumption (as some reported studies have) that trivial or non-significant vehicle speed differences mean that there are no important differences in the degree of risk perceived by drivers.

Despite this caveat, vehicle speed has been a sensitive measure in many crossing studies. In some cases this may involve drivers' responses to perceived risks; however, it may often be reasonable to interpret findings without regard to this concept. But overt driving actions at rail-highway crossings do seem clearly related to risk-taking tendencies of drivers. Those drivers who show higher risk acceptance in general are more likely to act dangerously at the crossing. For example, Sanders et al. (1973) sorted drivers at their field study crossing sites as "safe" or "unsafe" based on measures such as looking behavior and speed reduction. They found a significantly higher proportion of "unsafe" drivers failed to wear seat belts, and other risk behaviors showed a similar, but statistically non-significant relationship. Haga (1988) reported similar findings from Japan. In his survey, people who reported driving through active crossing signals were much more likely to also characterize themselves as "high speed" drivers and were less likely to wear seat belts. This simply confirms for the grade crossing situation the finding that risk taking can be a general characteristic of certain drivers; for example, drivers who do not wear seat belts also tend to show shorter following headways in traffic, accept shorter gaps for turns into traffic, and more frequently run red lights (Lerner et al., 1988).

One of the important characteristics of risk perception is personal immunity. This refers to the general finding that while people may accurately perceive the risk to others, including their peers, they see considerably less risk to themselves in the same situations. This phenomenon is well-documented in driving safety (e.g., Svenson, 1981). One implication of this phenomenon is that educational efforts aimed at teaching motorist awareness of crossing hazards may be more successful at an "intellectual" level than at the subjective level of personal risk perception.

Another behavior of interest is termed "risk compensation." This refers to the tendency of drivers to trade off safety benefits for other goals. Thus for example, making some roadway improvement may lead vehicles to travel faster, counteracting much of the safety gain. An extreme view of this is the risk homeostasis theory (e.g., Wilde, 1986), which holds that drivers will act so as to exactly maintain risk at some predetermined level. Therefore, the only safety programs that will ultimately have an effect are those that can get drivers to alter their target level of risk; all other safety "improvements" will be compensated for. Without accepting this theory, there is still ample evidence (Evans, 1985) that in many cases drivers have reacted to safety improvements so as to greatly reduce, or even eliminate, any safety gains. The potential for such problems certainly exists for many grade crossing countermeasures. An obvious example is that drivers exhibit less caution while approaching a protected crossing (lights not flashing) than when approaching a passive crossing (e.g., Shinar and Raz, 1982). Risk compensation theory would argue that improved sight distance might be compensated for by higher vehicle approach speeds. The same process can operate for vehicle factors; for instance, improvements in vehicle acceleration characteristics are partially compensated for by driver acceptance of smaller gaps (Evans and Herman, 1976).

3.4.3 Factors in Decision Making Errors at Crossings

There are many factors inherent or frequent at rail-highway crossings that contribute to the likelihood that a driver will make a decision error. In this section, a number of these factors are listed and briefly discussed. Some have already been alluded to in previous sections. The large number of factors in this list, of itself, indicates the potential for driver decision errors at grade crossings.

Information Limitations and Ambiguity

Traffic control devices are the formal means by which the highway and railroad authorities provide the driver with information relevant to decision making at the crossing. The appropriateness and timeliness of driver decisions will be related to the quality of this information. Unfortunately, the information provided by crossing TCD's is limited in nature and ambiguous in its meaning.

In terms of the driver's decision making, there is a tremendous difference between active and passive crossings. In the active case, when a signal is detected, the appropriate behavior is entirely specified: a flashing light or lowered gate means "stop." The only decision conflict that might be faced by a compliant driver is when he detects the signal at a point near the stopping sight distance, where he must decide whether he can safely stop prior to the tracks. In contrast, at a passive crossing, the driver may continue, slow, or stop, and these decisions are influenced by vehicle speed, sight distances ahead and along the track, train speed and distance, the number of tracks and the crossing width, and other factors. If we could "package" the desired information for the driver approaching a passive crossing, it would include the direction of the train, its speed and distance (gap), the precise point of the hazard (the tracks and the hazard zone), the driver's speed and distance from the crossing, and where the driver can expect to visually detect and monitor the train. Even at an active crossing with flashing lights, we would want the driver to know the direction, speed, and distance of trains on all tracks at the crossing. Obviously, current crossing TCD's do not provide this information.

However, the information provided is not only limited, it is ambiguous. Many authors have pointed out that the railroad advance warning sign is particularly ambiguous: It does not discriminate active from passive crossings, despite the fact that quite different actions are called for, and different kinds of information are required. The function of any advance warning sign is to alert the driver and prepare him for the choices he may have to make. It is an aid to detection and decision making. Railroad advance warning signs do not fully accomplish this. For a driver to distinguish an active from a passive crossing, he must actually detect the presence of the lamp housing or gate arm at the point of the tracks. Consider the driver who encounters the advance warning sign, but sees no signal ahead. Does this indicate a passive crossing, an active crossing in the non-warning mode, an active crossing with the flashing light not yet in view, or an active crossing that is not working properly? These ambiguities come about not only because there is no distinction of active and passive crossings, but also because there is no explicit "safe" signal for the active crossing, analagous to a green light.

Since the speed and accuracy of decisions are related to the number and complexity of choices, good driver decision making will be promoted by restricting alternative choices to a few simple and clear options. Barriers do this to the greatest extent; the driver must stop if the barrier is down, and the point at which he must stop is apparent. Passive crossings provide a more ambiguous situation with various options for driver action.

In some countries, it is the practice to provide greater information at crossings, and in particular to distinguish active from passive crossings through advance signing. Numerous authors in the United States and elsewhere have made suggestions for or demonstrated the use of systems that include such features as: indicating type of crossing protection; train direction indicator; safe condition indication; failure (out-of-order) indicator; limited sight distance information; location (direction and distance) of crossing; time to train arrival; angle of the crossing; where and when to look for trains; vehicle speed information (reduce speed, speed limits). In addition, the importance of information redundancy has been emphasized, including the use of more than one mode of sensory input (e.g., acoustic signals, rumble strips).

However, in addition to providing a driver with the full complement of useful information, a parallel concern must always be with the overall amount and density of information, and its spatio-temporal relation to the hazard. These concerns underlie the Positive Guidance approach (Post et al., 1981) to information system design, including the concept of "spreading." "Spreading" avoids peaks in the information density so that the driver is not overloaded at any point, and takes into account the primacy of each information need in distributing the information. Failures to follow good positive guidance principles constitute another source of information constraint for the driver approaching a crossing, because the demands essentially limit his ability to take in and use the information that may exist.

In summary, current practices for informing drivers about rail-highway crossings lead to information limitations and ambiguities that often do not support good driver decision making.

Information Credibility

Warnings lose their effectiveness if they are not credible (Cunitz, 1981). This is a significant concern for grade crossing TCD's. At active crossings, false alarms (activation when no train is present) are the most serious case. Where this problem is chronic, routine ignoring of the signal can occur (see "Compliance" section). However, an active crossing signal can also have its credibility weakened if the delay before train arrival is so long that waiting was unnecessary. Drivers see this form of credibility as a problem with crossings. Many people feel the typical warning time exceeds one minute (see "Compliance" section). The use of constant warning time devices to improve credibility leads to much better motorist compliance.

Passive crossing signage has a different credibility problem. The driver may seldom actually experience a train at these sites; most track crossings are uneventful. Such repeated "benign experience" is also known to weaken the effectiveness of a warning.

If a warning is to influence the decision a driver makes, it must be viewed as credible. Grade crossing TCD's often suffer credibility problems.

Expectancies Regarding Trains

The driver's expectancies regarding the likelihood and speed of trains are among the most critical factors in decision-making errors at crossings. The fact that there was a decision-making error related to these expectancies does not necessarily mean that the victim's expectancy was inaccurate. Perhaps a train's appearance at the particular time and place was extremely unlikely. But whether the expectancy was accurate or not, the actions based on it were in error.

A large majority of grade crossing accident victims are familiar with the area, and even the particular crossing (e.g., Wigglesworth, 1979). There is no question that familiar and unfamiliar drivers often behave differently at crossings, and that traffic is sensitive to the schedule of train operations. Sanders et al. (1973) found that driver looking and speed reductions were inversely correlated with the frequency of using the crossing. Expectancies based on familiarity have been implicated in accident causation research (Knoblauch et al., 1982). Sanders et al. (1973) also found that drivers were sensitive to the actual frequencies of trains. The correlation of looking with train frequency at the crossing was $r=0.66$, and the correlation of speed at the crossing with train frequency was $r=-0.85$. Others have reported similar findings (e.g., Aberg, 1988).

Given that driver behavior at crossings appears to be systematically related to driver expectancies about train volume, the literature on how people generally assess the probability of uncertain, and infrequent, events was examined for its pertinence to decision making at crossings. Evidence suggests that, when individuals must make decisions on the basis of uncertain information, under time constraints, they utilize "rules of thumb" that often lead to quick and reasonable conclusions (Kahneman, Slovic, and Tversky, 1982). Although these rules of thumb, or judgment heuristics, do not always result in accurate predictions and optimal decisions, they have the benefit of simplifying and expediting the decision process. Their use is largely an automatic and unconscious process. People often judge the likelihood of an uncertain event by the ease with which they can retrieve past instances from memory. This strategy, known as the availability heuristic, will lead to fairly accurate estimates of the probability of encountering trains at a crossing: Observing no trains at a crossing is an objectively frequent event, and so these past instances will be more prevalent in memory than instances of encountering trains, which are objectively rare events. However, estimates of the rates of infrequent events (defined as those occurring less than 10% of the time) tend to be less accurate than estimates of events with less extreme rates (probabilities ranging from 10% to 90%), although the direction of error is unclear. Some studies have shown that individuals overestimate the frequency of rare events (e.g., Erlick, 1961), while others indicate underestimation (e.g., Pitz, 1965) under these circumstances.

Two points can be made with regard to decision making under uncertainty at railroad crossings. First, if the driver's sample of crossings is biased, such that he has been exposed primarily to low-volume crossings, he will underestimate the probability of observing trains. As a consequence, he will make more erroneous decisions than if he had based his expectations on a representative sample of train volume at crossings. Second, even if the driver's probability estimates were based on a perfectly representative sample of crossings, he would not be sensitive enough to the possibility that a given crossing may not be typical of crossings he has experienced before.

In summary, to minimize cognitive effort, people are likely to use unconscious strategies (judgment heuristics) that generally lead to accurate estimates of the probability of uncertain events. In the case of a rare event, such as encountering trains at a crossing, slight overestimates or underestimates are possible. The factor of greatest importance seems to be that the low expected frequency of trains is roughly accurate; the possibility that the next crossing does not typify the average crossing is not a salient factor in the decision process, despite the great potential cost of making an erroneous prediction.

Because optimal collision avoidance strategies begin in advance of the conflict situation, anticipating the possibilities before all the visual evidence is in, the driver's expectation of a potential conflict can play a major role. This has been suggested in an interesting manner by a study by Roer (cited in Wilde, 1976). He computed a "safety index" for 137 intersections. Based on traffic volumes and physical layout, one can compute the expected number of accidents that would occur at a particular intersection if drivers approaching the intersection took no defensive action (i.e. just continued on their way, ignoring other traffic). Comparing this projection with the actual number of accidents experienced gives an indication of the number of potential accidents avoided. The proportion avoided was the "safety index." It was found that the safety index was high for high-volume intersections, and low for low-volume intersections. Thus drivers avoid fewer of the potential accidents where traffic is sparse, a finding presumably related to the drivers' expectancies of conflict. The same phenomenon presumably applies at grade crossings.

Wigglesworth's (1979) description of the typical crossing victim, based on accident analyses, portrays a normal local driver, familiar with the crossing, who "did not look to the right or to the left but drove slowly and carefully straight in front of the train."

Expectancies Regarding Crossings

Driver actions may be based on a variety of expectancies about crossing characteristics. These expectations will affect the driver's choice of actions and his "set," or readiness to respond. For example, a substantial minority of drivers believe that all (or nearly all) crossings are actively protected. If the driver does not anticipate a passive crossing, his choice of approach speed and search strategies may not be appropriate. Similarly, drivers do not seem sensitive to the existence of sight restrictions up the track (e.g., Sanders et al., 1973). The quality of the road, and the adequacy of other forms of sight distance, may produce an expectancy counter to reality. For the driver unfamiliar with the particular road, even the expectation that a crossing might occur can be important for providing the proper "set." The presence of train operations or previous crossings are of course relevant to this expectancy. Beyond this, roadway elements other than those directly related to the hazard can also influence expectancy. For example, Hostetter, McGee, Crowley, and Hughes (1985) found that features of the road shoulder (presence, width, quality) can broadly influence expectancies about features and demands that lie ahead. Messer, Mounce, and Brackett (1981) showed how both the general quality of the roadway facility, as well as its specific geometric features, alter expectancies about various roadway features. The importance of such expectancies has been shown, for example, in accident data regarding curves (e.g., ITE, 1976). The likelihood of an accident at a curve of a given character depends on how frequently such curves appear on the road. Where the driver's experience prepares him for curves, the number of accidents will be fewer. For sharp curves, the accident rate more than doubles when few other curves are present in the road.

One might also add to this discussion consideration of the driver's expectancies regarding enforcement at crossings. As will be discussed in the section on "Compliance," police enforcement actions are perceived as very unlikely at grade crossings. This too might influence driver decisions.

"Costs" of Compliance

"Safe" decisions may have a cost involved for the driver. The most obvious cost is delay. If the driver decides not to attempt to cross in front of a visible train, he is committed to waiting until it has passed, however long that might be. If the driver slows on the approach to a crossing, he may feel he is enhancing his chances of having to stop, should a train be approaching. Since the delay associated with any approaching train is generally not known, the driver's expectations about delay will be a critical factor. Sanders et al. (1973) found that unsafe drivers at passive crossings reported significantly longer typical delays than did safe drivers. In general, motorists anticipate "typical" delays that are quite long (e.g., the majority of Sanders et al.'s respondents said in excess of five minutes), and the decision at a crossing may be more impacted by the longest delays expected, not the average.

Delay, however, is only one potential cost of compliance. It fails to capture the emotional consequences of interfering with a goal-oriented chain of behavior. Stopping, or even slowing down, represents a disruption of normal driving that can be annoying. While this sounds trivial, the fact that such annoyance is minor does not mean it is insignificant. Other costs of compliance or "safe" behavior at a crossing may include subjecting oneself to pressure, ridicule, or aggressive driving by following vehicles, and to rear-end collision risks (these factors are discussed elsewhere in this list).

Temporal Constraints

Processing information, making a decision, and executing that decision takes time. The duration of that process can be long relative to the temporal constraints imposed at many crossing sites. The amount of time required to process and act on information is quite variable and dependent on many different factors, among them how prepared the driver is for the possibility of the event reacted to. Complex or unanticipated choice situations may require more time. There is also large variability between different drivers. Decision making time can be considerable. For the simple brake reaction time (where little choice or decision making is involved), AASHTO (American Association of State Highway and Transportation Officials, 1984) recommends an engineering design value of 2.5 seconds (though this is conservatively long relative to most drivers and most situations). When more complex driving situations are involved, with more response options, longer information-processing times are required. For example, AASHTO design assumptions for decision sight distance computations, presuming a design speed of 40 miles per hour, indicate a detection-and-recognition time of 1.5-3.0 seconds, and a decision-and-response initiation time of 4.2-6.5 seconds, to yield a total premaneuver time of 5.7-9.5 seconds. Being intended for traffic engineering design practices, these are probably long relative to the average driver's performance, but they give an indication of the magnitude of time that may be required for decision processes. Whatever value one presumes, however, the major point here is that simply making a driving decision takes real time, and for some drivers in some situations, that time can be quite extended.

Sight distance problems at many rail-highway crossings may place severe limitations on the amount of time available to the driver for making a decision. By definition, inadequate sight distance means that there is not adequate time for decision making, once a train becomes visible. The frequency of inadequate sight distance crossings depends to a certain degree on the definitional criteria, but Schoppert and Hoyt (1968) found only 1 of 31 passive crossings studied to have adequate quadrant sight distance for all four quadrants based on design criteria (increased to 9 of the 31 using more liberal assumptions). Limited quadrant sight distance is also found to be a contributing factor to many crossing accidents (e.g., Knoblauch et al., 1982). Furthermore, less than optimal actions on the part of the driver -- too high an approach speed, failure to search for trains efficiently, attention to competing inputs -- can functionally reduce the available time. Under time pressures, people will make decisions more quickly, but at the cost of committing more errors. In choice response time tasks, where input must be classified and the appropriate response selected, there is a well known speed-accuracy trade off (Pachella, 1974; Wickelgren, 1977). When a deadline is imposed for making a choice, error rate increases as a function of the time limitation. Furthermore, conditions that produce a higher state of arousal in the decision maker appear to result in faster, and more error-prone responses (Wickens, 1984). For example, if a driver detects an approaching train at a passive crossing, and is stressed by the need for a rapid choice of stopping or crossing in front of the train, he is likely to make more errors. Thus it is very well established that temporal constraints cause more decision errors, and grade crossing situations often impose significant time constraints.

Competing Inputs

As drivers, we are always coping with a variety of inputs, and must share attention and cognitive resources across various driving subtasks. Thus at the approach to a rail-highway crossing, consideration about the likelihood or closing rate of a train is never the driver's sole concern. Occasionally, other inputs may be especially commanding. For example, one such competing consideration is negotiating the crossing itself. There is evidence that the tracks themselves command attention and modification of vehicle control. Sanders et al. (1973) found that nearly half of their respondents who reported having slowed down at the crossing site gave as their reason for doing so the probable bumpiness of the tracks. Crossing speed was in fact correlated with the smoothness of a crossing. Thus a driver's attention may well be drawn to the tracks, rather than being directed up-track. Other competing inputs may come from demands of vehicle control due to other traffic, roadway geometrics, or slippery road surfaces. Of course, competition can come from distractors unrelated to driving, coming from either inside or outside the vehicle. In their analysis of rail-highway accident causation, Knoblauch et al. (1982) identified competing inputs, internal distractions, and external distractions as contributing factors in various accident sequences.

Thus, while the driver should be directing his attention to the decision making problems facing him regarding train collision hazards, other factors will compete for his attention.

Decision Making as a Disruptive Activity

The "mental work load" is a factor which can impact complex task performance. Such work load effects are extensively studied in the aviation area (e.g., Wierwille, Rahimi, and Casali, 1985), and analagous concerns exist for driving (e.g., Moran, 1982). While trying to make a complex decision about an approaching train, simultaneously facing competing inputs at the crossing, the driver may disturb his guidance of the vehicle. This in itself could lead to an accident or conflict with another vehicle, but a more likely problem is that it would force the driver to suddenly switch his attention to the greater primacy task of maintaining vehicle control, and away from his decision problem. Beyond this, Konecni, Ebbesen, and Konecni (1976) have raised the very interesting idea that a driver unconsciously slows his vehicle while dealing with the conflict of a decision, but that the decision may not take this slowing into account. They studied decision processes at signalized intersections, and found the decision to stop or proceed at the yellow phase was related in an orderly way to vehicle speed and distance from the intersection. However, for those instances where a violation occurred (vehicle violated the red phase), it was usually the case that the vehicle was within a critical distance (40-60 yards) of the intersection, and the driver's initial reaction was to briefly slow the vehicle. These authors argue that the "go" decision may have been based on the speed prior to the decision conflict (which caused the slowing), and the final decision may have been correct had the speed remained constant. Thus the decision may fail to take into account the concurrent effects of the decision making. At rail-highway crossings, where the perceptual judgments may be particularly difficult, this sort of decision error factor could be an important consideration.

Recognition of Capabilities and Biases

In judging whether a gap is acceptable, the driver must estimate the moment of arrival of the oncoming train, the moment of arrival of the driver's own vehicle at the crossing, and the acceleration capabilities of the driver's own vehicle (especially if stopped or greatly slowed). In making a decision to go or to stop, the driver incorporates an assessment of how accurate and how variable his estimates are, so that there is some margin of error. Thus recognizing one's own abilities and limitations are important to proper judgments. For rail-highway crossings, drivers are apt to consider these judgments to be more precise than is the case. This is probable for various reasons:

(1) As discussed in the section on perception of trains, there are visual factors which bias judgments of the speed and distance of the train. These "illusions" are not something humans have conscious awareness of.

(2) Most feedback about the accuracy of gap judgments comes from vehicle traffic situations, which are not subject to the limitations and biases of the train situation. Furthermore, if there is a judgment error made in traffic, corrections made by the approaching vehicle can obscure the magnitude of the misjudgment. Therefore when judging an approaching train, a driver's experience will suggest he is more accurate than is so.

(3) The roughness of the crossing can influence the speed with which the vehicle clears the tracks. The driver may not appreciate the influence of this until after a commitment is made. Furthermore, since this is not a factor in highway gap acceptance, the bulk of the driver's feedback will not incorporate this factor.

(4) Small increases in perceptual variability can lead to a many-fold increase of "extreme" errors. This will be discussed further in the section on "Impairment." The key point here is that even if a driver has some awareness that his judgments of trains are not as precise as his judgments of vehicles, he may not recognize the degree to which this enhances the chance of a serious misperception.

If the driver fails to recognize and appreciate the limitations of his perceptual judgments, he cannot appropriately factor them into his decision.

Conflicting Messages

The roadway provides many messages to the driver, both formal (e.g., signs, markings) and informal. Rail-highway crossing signs and signals are only part of the total message the motorist receives. Sometimes the message implied by the roadway itself contradicts the intent of the crossing TCD's. The result is conflict and confusion. Consider the driver on a major suburban arterial with moderate, flowing traffic, and traffic signals every quarter-mile or so. What if the driver comes to a single crossing, with severely limited sight distance? Should he slow to a near stop in mid-block so he can look up track and be able to stop if necessary? The "message" of the whole road and its traffic control operations is "keep moving." Traffic signals ahead, and the actions of other vehicles may reinforce the perception that decelerating to a low speed is just inappropriate here. If the crossing is passive, the formal obligation to slow may be greater, but the perception that this is not a significant crossing may enhance the dominance of the "keep going" message. This sort of situation is not uncommon.

Other Safety Concerns

Collision with a train is not the only hazard at rail-highway crossings. Collisions between two vehicles occur much more frequently (Mortimer, 1988). A driver who acts safely with respect to trains may be subjecting himself to other risks. Sanders et al. (1973) found that following headways became short when a vehicle slowed and stopped at a crossing. Speed variability between vehicles becomes greater at the approach to a crossing (e.g., Schoppert and Hoyt, 1968) and such variability has been related to accident rate. Thus a driver must show enhanced caution with respect to other vehicles in the vicinity of a crossing. A driver may judge it safer to move in a manner consistent with nearby vehicles than to react to an unseen and improbable train. Vehicles with special stopping requirements (e.g., school buses, trucks) may face particular safety conflicts of this sort, as discussed in the section on "Compliance." There are also safety concerns for single-vehicle accidents. For example if roads are slippery, a driver may choose not to risk a skid by braking. Thus while the traffic engineer is formally warning the driver about one hazard, the driver may be more acutely aware of other immediate hazards.

Effort

Safety behaviors are sensitive to the degree of effort involved. While it would seem that something as significant as preventing personal injury would make actions resistant to minor inconvenience, this does not appear to be the case. A number of studies outside of the highway area have demonstrated how dramatically safe actions can drop off if the required effort is increased to a minor degree (e.g., Wogalter, McKenna, and Allison, 1988). An example in the grade crossing situation appears to be the case of oblique crossings. Where the track crosses the road at an angle, the driver must turn considerably to look up the track in one direction. Given the visibility limitation, one might expect more looking than for a normal, right-angle crossing. However, the opposite appears to be true (e.g., Aberg, 1988).

Social Influences

A variety of driver actions and decisions may be usefully viewed in the context of social interactions (e.g., Wilde, 1976). Driving, like many other human activities, is influenced by the presence and actions of others. These "others" may be passengers in the car, or the occupants of other vehicles. In general, drivers tend to make more conservative judgments when there are other passengers in the car with them. For example, drivers with passengers do not as readily accept small gaps after waiting for an opportunity to enter traffic at an intersection (e.g., Ebbesen and Haney, 1973), and drivers with passengers allow longer following headways in freeway traffic (e.g., Evans and Wasielewski, 1983). However, an exception may be when both the driver and passenger are males, in which case riskier decisions may occur (e.g., Jackson and Grey, 1976).

A driver's decision may also be influenced by other motorists, in various ways. First, an aggressive or impatient following driver can pressure the lead driver, through tailgating, sounding the horn, etc. But even in the absence of such overt actions, the mere presence of following traffic can alter driver decision making. For instance, it has been found that shorter gaps for entering a traffic stream are accepted when there are other cars behind the decision maker (e.g., Ebbesen and Haney, 1973). Another way a driver's decision can be influenced by others is through social facilitation. Seeing another driver violate the crossing without negative consequence provides a model and weakens the barrier against breaking a "rule." Thus, for example, when one driver goes around a lowered barrier, others will be more likely to. Finally, other drivers can exert influence through the development of local norms and customs. If in some area the local populace routinely ignores a certain grade-crossing TCD (or indeed any TCD or traffic law), then the everyday social processes of conformity encourage the individual to do the same. As will be discussed in the "Compliance" section, routine local practice inconsistent with crossing controls certainly does happen.

Thus, a driver's decisions at a crossing can be influenced in a variety of ways by the actions of others. The social setting, as well as the physical setting, of a crossing will impact decisions.

Emotional Reactions

A driver's decision making at a crossing can be influenced by his emotional state. The frustrations of driving in traffic can lead to impatience and aggressive driving. The influence of impatience has been demonstrated in the study of gap acceptance in traffic. For instance, Ebbesen and Haney (1973) found that drivers turning into a stream of traffic were dramatically more likely to accept short gaps after they had been forced to wait. It is reasonable to presume that the driver at a grade crossing is likewise susceptible to the frustrations and emotional consequences of the surrounding driving environment. For some drivers, too, an approaching train might represent a challenge, which they are motivated to try to beat; train crews describe frequently experiencing drivers who try to race the train.

3.4.4 Decision Factors: Summary

This list of factors should make clear that the driver faces a variety of conflicts and difficulties in decision making at rail-highway crossings. While an accident victim might be described as foolish or incautious (after the fact), this should not obscure the problems faced. Without too much overstatement, we can draw from the list above, and say that the decision making problem is this:

A driver facing various distractions encounters a crossing with limited information of questionable credibility and, not really expecting any trains or visual limitations, must disrupt his normal driving activity and make a rapid judgment, based on difficult visual and temporal perceptions whose accuracy the driver overestimates, about the relative costs, risks, and appropriateness of alternative actions, which may impact other traffic as well as himself.

3.5 COMPLIANCE

A driver may fail to comply with required actions through error or intention. If the driver does not perceive the TCD's, trains, or the crossing itself, if he does not comprehend the situation, or if he does not know the required actions, the non-compliance cannot be considered intentional. Errors of these sorts were addressed by previous sections. This section concerns driver decisions not to comply with crossing requirements. The types of behaviors that constitute non-compliance depend upon the type of crossing protection provided, so that violation rates for crossings with different types of TCD's cannot always be meaningfully compared.

Non-compliance can often be difficult to define in a field setting. For example, vehicles often come to a "rolling" stop, rather than complete stop, at signals. It may be difficult to classify a given vehicle's action as a stop or not, and even if a stop is not complete, the driver's action may be adequate for safety. Even for a clear stop, its location may not be appropriate (e.g., too close to the tracks). When vehicles are traveling in a platoon, there are also issues in determining whether a particular vehicle has an opportunity for violating the warning. For passively-protected crossings, "compliance" is even more difficult to define. No overt vehicle action is required unless a train is in "hazardous proximity." Furthermore, in simply observing driver actions, it is not possible to determine whether any particular driver fails to comply through intentional decision or through a failure to see or understand the requirements. However, discussions of non-compliance usually carry the implication that the act is intentional, and this is probably a reasonable assumption for the majority of cases.

3.5.1 Non-Compliance with Grade Crossing TCD's

No study identified was explicitly concerned with estimating the typical or overall rate of non-compliance at crossings of various types. There was never any attempt to representatively sample sites in order to generalize to the broader population of crossings. Rather, study sites were usually selected on the basis of criteria defined by the research objective (e.g., evaluation of a new TCD or study of sight distance problems) and often "problem" sites were selected. Thus the reader needs to be cautious in generalizing specific violation rates from these studies.

Non-compliance with flashing signals is clearly an important accident factor. In their study of accident causation factors, Knoblauch et al. (1982) determined that in more than half of the cases at flashing light crossings, the driver had seen the signal sufficiently in advance, but did not stop. Excessive warning time was found to be an important factor in many of these accidents. A similar conclusion emerged in Bowman's (1985) field observational study of constant warning time devices. Numerous violations were observed at sites without constant warning time devices, but only about one-third that rate was seen at sites with constant warning time devices. Most of the violations occurred when the warning time was long (more than 50 seconds in 72% of cases).

Stopping requirements are also frequently violated at crossings equipped with stop signs. Sanders et al. (1978) found that only about 60% of drivers showed "acceptable" stopping (full or rolling stop) at crossing stop signs, in contrast to 80% acceptable stops at nearby intersection stop signs. Stopping rates were, however, sensitive to such grade crossing factors as train volume, train speed, and advance signing. Parsonson and Rinalducci (1982) evaluated compliance at a rural crossing in Alabama used almost exclusively by local traffic. Although severe site problems prompted the use of the stop sign, violation rates were very high. No stop was made by 71% of drivers in one direction of travel, and by 39% in the other direction. Beyond this, 18% of drivers in one direction, and 8% in the other, did stop, but did so hazardously close to the track. This study found that applying "positive guidance" principles at the site, including installation of rumble strips, reduced failures to stop to levels of 5% and 12% in either direction; however, other safety problems emerged as a result of this treatment.

Heathington et al. (1988) evaluated a site where a flashing light system was replaced by a traffic signal (equipped with a strobe as well). These authors felt that the high credibility of the standard traffic signal, and the respect drivers show it, would discourage motorists from crossing the tracks. The authors did not compute violation rates for the flashing lights (due to the difficulty of defining a "stop"), but since a "violation" is defined differently for flashing lights and signals, these would not be directly comparable in any case. However, the finding of interest here is that even with a traffic signal, violations (crossing during the red phase) remained frequent, and this was so even though a "predictor" was installed to minimize the warning delay. A violation occurred for about 36% of the vehicles that had an opportunity, and multiple violations during a red phase were frequent. There was a mean of 0.68 violations per train arrival at the crossing.

In contrast to lights, signs, and signals, automatic gates tend to be violated less often. This is unsurprising since they present a physical barrier. The normal "two-quadrant" gate can be driven around (or into), and this constitutes a violation. Berg (1985), citing a 1966 study he conducted, found 90% compliance at crossings with gates. Bowman (1985) observed very few violations at gated crossings equipped with a constant warning time feature, but considerably higher rates without this feature. Even with an automatic gate, violation rates can sometimes be quite high. In their study of innovative crossing devices, Heathington et al. (1988) evaluated a site with standard gates, and found a violation rate of 2.6 violations per train arrival. There was at least one violation in 84% of the cases where there was an opportunity for a violation.

"Four-quadrant" gates block the entire roadway, and so are difficult or impossible to drive around; violation rates are therefore at or near zero (Heathington et al., 1988).

For passively-protected crossings, as stated earlier, it is difficult to objectively define "compliance" in terms of overt driver behavior. Therefore no studies report rates of "non-compliance" at such sites. However, based on driver behaviors (such as looking up the track) and speed profiles, it is reasonable to speculate that many motorists do violate the more subjective safety behavior components of many state laws. For example, Tidwell and Humphreys (1982) evaluated the behavior of drivers at two passive crossing sites with restricted sight distances. Based on driver "looking" behavior and speed (relative to sight and stopping distances), they found only 5 of 89 drivers to be performing safely. Thus while compliance at passive crossings cannot be well defined, a frequent failure to observe appropriate behaviors is reported in various studies.

Because a violation is defined differently for each type of crossing TCD, violation rates cannot be meaningfully compared. Further, since some violations do not really constitute safety risks, such a comparison might not reflect safety differences anyway. However, one may look at the frequency of "close calls" as an index of significant acts of non-compliance. Such comparisons have been made, and this aspect of driver behavior does appear related to crossing characteristics. However, the critical determinants are not just the physical aspects of the crossing and its TCD's, but also such factors as warning delay, traffic operational characteristics, train schedules, etc. Some of these factors are discussed further below. As an example representative of this type of research, Heathington et al. (1988), in their field study of various innovative active warning devices, categorized the clearance time (time between the last vehicle to cross and the arrival of the train) under various conditions. "Risky" actions (clearance times under 10 seconds) occurred during roughly 10-20% of the train arrivals at one site where various flashing light signal systems were evaluated. At another site, risky actions were observed during 26% of train arrivals when a flashing light signal was present, but during only 5% of arrivals when the flashing lights were replaced with a traffic signal (with a "predictor" to reduce inappropriate warning times). In another study, Bowman (1985) found a considerably lower incidence of brief (10 seconds or less) clearance intervals, around 5%, at sites with flashing lights. Despite such differences, studies such as these indicate that "close calls" occur with a meaningful frequency. While such behavior does not necessarily indicate a traffic violation, it does suggest a high incidence of non-compliance with the cautiousness required by typical crossing regulations.

It should be pointed out that studies that have examined motorist non-compliance have compared observed behavior to that actually required by law. But as discussed earlier, many drivers do not accurately comprehend the legal requirements. Many in fact believe that a stop is required at passive crossings, or that it is never legal to proceed after stopping if the flashing lights remain active. To the extent drivers believe this, intentional non-compliance as defined by the driver must be even more frequent than objectively defined non-compliance.

3.5.2 Factors in Non-Compliance

It is apparent that drivers do not respect rail-highway crossing devices to the same extent of some other traffic control devices. Numerous contributing factors to this have been pointed out. These will be briefly indicated here; some have already been discussed in more depth in previous sections. Note that each of these factors can be viewed as applied to a motorist's experience with a particular crossing, or as a more general perception based on overall experience.

Reasonableness of Warnings

Warning times may be unreasonably long in a particular situation, and may be perceived as even longer and more unreasonable by the driver. Because engineering practice requires that the "design driver" represent operators and vehicles with the greatest (or at least near-greatest) limitations, the warning parameters will be overly conservative for the majority of drivers encountering the site. For example, the "Railroad-Highway Grade

Crossing Handbook" (Tustin et al., 1986) discusses some vehicle characteristics important to crossing protection design, such as vehicle length, braking performance, and acceleration performance. Such characteristics relate to the necessary warning time and the required sight distances.

It is quite clear that drivers are sensitive to the length, and reasonableness, of the warning times. For example, Bowman (1985) found that (a) providing a constant warning time capability to eliminate unduly long warning times led to greatly reduced violations; (b) in the absence of constant warning time features, most violations occur during objectively long warning periods (72% of violations at flashing signal sites, and 88% of violations at automatic gate sites, occurred during train arrivals in which the warning time exceeded 50 seconds); (c) most crossings made at flashing light sites or in violation of lowered gates were objectively safe (58% at flashing light sites and 71% at gated sites were made more than half a minute before actual train arrival).

Furthermore, motorists' subjective impressions of the "typical" warning time are unduly long. For example, in their field study Sanders et al. (1973) observed actual warning times that seldom exceeded 70 seconds (though occasional long and erroneous signals did occur). But when asked "How long does it generally take a train to reach a crossing after the warning signal goes on?," more than 15% of the drivers questioned at these sites indicated times in excess of 2 minutes, and more than 40% in excess of 1 minute. Similarly, Tidwell and Humphreys (1981) found 30% of those they surveyed indicated times more than 1 minute, and Richards and Heathington (1988) found 22.5%. So drivers clearly see the "typical" warning time as quite long, and thus the apparent reasonableness of the warnings must suffer.

An even greater threat to credibility than long warning times are "false alarms," signals that are never followed by a train. Where false alarms occur frequently, compliance may suffer badly. Cunitz and Koenig (1977 unpublished; personal communication from author) studied one site in Boutte, Louisiana which was the scene of a tanker truck accident where the vehicle drove around a lowered gate. In observing the site 24 hours a day for a week, it was found that there was about a 50% false alarm rate. Most drivers were familiar with the site, and the gate and warning was routinely ignored by traffic; almost no one waited at the gate if a train was not in view.

Inconvenience

The delay of waiting for a train imposes an inconvenience on the motorist. In determining whether the probable delay merits violating the crossing, it is the driver's subjective judgment about potential delays that is critical. Unlike the case for warning times (where the driver may perceive the distance and speed of the train), the driver facing a decision at a crossing typically cannot directly perceive information predicting the impending delay. Therefore pre-established beliefs and/or direct experience with the crossing may importantly control the motivation to violate the warning. Sanders et al. (1973) found that

54% of their respondents reported experiencing an average delay in excess of 5 minutes. Furthermore, given the variability in delay times, drivers' actual decisions may not be based on the "average" delay, but at least in part on the longest anticipated delays. This can be contrasted with the duty cycles for traffic signals, which are relatively brief and predictable. Yet even for the less severe situation of traffic signals, "unnecessary delay" can "breed gross disrespect towards signals" ("Traffic Control Devices Handbook," 1983), and the warrants and phasing of traffic signals have evolved so as to insure that respect and compliance remain high. Traffic behavior is sensitive to the parameters of traffic signal timing, as well as to the parameters of train operations, and therefore familiar drivers may be assumed to be influenced by the duration of previously experienced delays at a given crossing.

Driver Familiarity with the Crossing

The role of the familiar driver's expectancies regarding the arrival and speed of trains has been previously discussed. There is another important point to note about familiarity as it relates to the problems of warning validity and period of delay. It is the frequent road user, highly familiar with the crossing, who will most often experience the invalid warning or long delay and learn to ignore or violate the TCD. Thus those most exposed to the signal will be least likely to comply. Through their actions, these frequent users can also influence the actions of drivers less familiar with the crossing (see next paragraph). Hence if a site is primarily used by local traffic, familiarity is a factor which can amplify the problems of long warning times and delays.

Social Behavior and Norms

A driver may be influenced by the actions of other motorists. This especially may be the case for urban crossings on high-volume arterials, where vehicles tend to travel in platoons and where driving behavior is more aggressive (Berg, 1985). For instance at a flashing light signal, a frustrated driver is not only more likely to cross, but may feel pressured to by the line of vehicles behind him. When one vehicle crosses, others may follow in a caravan even as the train draws quite near. Also, there may be some crossings or areas where local practice is to routinely ignore a crossing TCD. If this is the perceived norm, a driver is likely to comply with it. As an example, Parsonson and Rinalducci (1982) observed more than 70% of drivers ignore a particular stop sign at a crossing at a local road in a rural location.

Enforcement

In general, crossing-related laws are not rigorously enforced. Sanders et al. (1973) found that only 3-8% of the drivers he surveyed personally knew of someone who had gotten a ticket for a crossing violation. Sander's review of enforcement effects indicated that citations, or the presence of an officer, did reduce violations, but the effects appear typically transient.

Conflicting Concerns

Sometimes the appearance of the roadway and the traffic operational environment may suggest to the driver that slowing or stopping is inappropriate or risky. For example, a wide arterial road that carries substantial traffic and is periodically controlled by signals would not appear to be an environment where a motorist should slow drastically in mid-block. If a passive crossing is encountered at such a site, the driver may be unsure of what action is most reasonable.

3.5.3 Special Vehicles

The discussion of compliance to this point has concerned the general driving public. Special grade crossing requirements (depending on the state) are applied to certain classes of vehicles: school buses, commercial buses, hazardous cargo carriers, and certain trucks. There are known to be substantial degrees of non-compliance for these special cases as well. Typically, these "special vehicles" must stop at passive crossings, and in some states, they must also stop at active crossings even when the light is not flashing or the gate is not lowered. In a field observation of vehicle actions at crossings, Sanders (1972) estimated that 53% of school buses, and 88% of commercial buses, did not stop at the crossings observed. Furthermore, these vehicles traveled at such speed (mean speed of 25 mph) that Sanders inferred that therefore many of them had "no intention or capability of stopping." For school buses, Sanders distinguished active and passive crossings: 85% of the school buses stopped at passive (crossbuck only) crossings, but only 25% stopped at active crossings. Bowman and McCarthy (1985) looked at stopping by various categories of vehicles with special stopping requirements at a total of 12 sites with active crossing protection. They found that 49% of 278 observed tank trucks did not stop, and 21% came to only a rolling stop, to yield a violation rate of 70%. For 40 other placarded carrier trucks observed, 90% did not stop, and only one truck came to a full stop. School bus compliance was better. Of 44 buses, 64% did come to a full stop, and the remaining 36% came to a rolling stop. While studies such as these indicate non-compliance is high, one may question to what extent this represents unsafe behavior. For these vehicles to stop when other traffic is not required to raises the problem of traffic conflicts. Compliance may lead to more non-train involved accidents at crossings, since following vehicles may not anticipate the stop. Bowman and McCarthy cite statements from the trucking industry's perspective, that "from the motor carrier's point of view, the grade crossing problem is greater in terms of vehicle-to-vehicle collisions than from train-vehicle collisions... The trucking industry believes that each time a stop can be eliminated, an accident-producing situation can also be eliminated." Thus the high violation rate of drivers of vehicles with special stopping requirements may reflect these drivers' resolutions of a conflict between two opposing safety concerns.

In summary, there are substantial rates of motorist non-compliance with grade crossing requirements. While the type of TCD is an important factor, other contributing factors have also been identified. Under some conditions, non-compliance could even be considered the norm. Undoubtedly the factors which lead to serious non-compliance at some sites must contribute to a more generalized lack of respect and compliance with crossings in general; however, the extent of this general non-compliance is not clear.

3.6 IMPAIRMENT

Various forms of transient impairment can degrade driving performance. Alcohol use is certainly the major problem of this sort, but drug use (both licit and illicit) and fatigue have received attention in the highway safety literature. Unfortunately, there is relatively little direct information bearing on the role of these forms of impairment on driver safety at rail-highway crossings.

3.6.1 Alcohol Incidence

Alcohol plays a critical role in highway safety in general, and in fatal accidents in particular. Recent data from NHTSA's Fatal Accident Reporting System (1986 FARS Report) indicated that alcohol involvement has been dropping in recent years. Nevertheless, in 1986 an estimated 51% of all single vehicle accidents involved a driver who was legally intoxicated, and about 62% of the drivers showed some level of alcohol use (some degradation of driving ability is known to occur at levels well below the legal blood alcohol limit of 0.10% BAC). For multiple-vehicle accidents, about 32% of the accidents involved a driver who was legally intoxicated, and about 43% involved a driver who was alcohol positive. Alcohol involvement rates may be sharply higher for specific times of day, driver categories, accident types, etc. Clearly, alcohol is a major factor in traffic accidents in general.

There is a huge technical literature including both statistical studies of accident involvement and experimental studies of alcohol effects on aspects of human performance. Undoubtedly alcohol plays a role in a significant number of rail-highway crossing accidents, yet surprisingly little information was found regarding this. Much of what literature does exist is quite limited in terms of sample size and geographic region. Some of the research is now rather dated, which may be important given the recent attention given to alcohol education and enforcement efforts. Based on the information available, the general conclusion appears to be that while alcohol is a significant factor in rail-highway accidents, especially at night, the frequency of alcohol involvement may be lower than for injury or fatal traffic accidents in general.

McGinnis (1979) reviewed the literature on alcohol involvement in grade crossing accidents and found that only "limited data" was available. His review focused on three studies. A study of fatal accidents from 1956 to 1967 in Dade County, Florida found (based on BAC levels) that alcohol was present in 29% of drivers, and in excess of 0.10% BAC in 18% of them. This incidence was lower than for the county's fatal traffic accidents overall, where alcohol was detected in 49% of drivers, and exceeded 0.10% BAC in 38%. A 1968 analysis of seven years data on fatal accidents in two California counties found (based on BAC levels) the presence of alcohol in 28% of accident-involved drivers and BAC's in excess of 0.10% in about 22%. A Pennsylvania study of 1976 state accidents found 274 that occurred at grade crossings; the alcohol involvement rate (based on police accident reports) was 5.3% for fatal accidents, 4.1% for injury accidents, and 1.3% for property damage accidents. These may be compared with the corresponding rates for Pennsylvania accidents of all types (13.8%, 3.2%, and 1.6%, respectively). McGinnis was interested in nighttime accidents in particular. His evaluation of these accident studies led him to estimate that "between 30 and 40 percent of the drivers who were killed between 6 p.m. and 5 a.m. had blood alcohol levels of 0.10% or higher. It is unclear whether or not these statistics are representative of the nation as a whole."

Sanders et al. (1973) discussed a 1972 study of fatal accidents in Michigan. Alcohol or drugs were reported involved in 12.6% of the rail-highway crossing accidents, versus 26.6% of the fatal accidents in general. Sanders et al. point out that the higher proportion of daytime accidents for grade crossing fatalities (63.9% vs. 44%) may at least in part account for this, since alcohol involvement is more strongly related to night accidents. More recent findings by Wigglesworth (1979) in Victoria, Australia found similar results. BAC tests were conducted on the drivers in 80 of the 85 grade crossing fatal accidents he studied. Of these, 90% showed 0% BAC; only 9% showed a BAC of 0.05% or higher. Wigglesworth contrasts this with a figure of more than 25% positive blood alcohol found in a study of drivers admitted to hospitals in Victoria. Again, rail-highway accidents did not show as high an incidence of some other accident factors known to be correlated with alcohol use (e.g., time of day, sex).

The National Transportation Safety Board (NTSB, 1986) investigated 75 accidents occurring in 1985 that involved passenger/commuter trains. Despite NTSB's requests, toxicological tests were conducted in only 19 cases. Alcohol was detected in 11 of these, and exceeded 0.10% BAC in 9. However, it is probably unwarranted to assume that the 19 cases tested were representative of the total group of accidents; it could well be that a test was more likely where alcohol use was suspected. However, taking the positive blood test results as indicating the minimum number of alcohol-involved drivers in the 75 accidents, this study suggests that at least 15% of the drivers were alcohol positive, and at least 12% had a BAC in excess of 0.10%; the actual incidence could be much higher.

Because the published information on alcohol involvement was so limited, a very restricted examination of more recent fatal accident data was conducted for this report. Although suffering serious limitations, it was felt to be useful, given how out of date available accident information was. This analysis involved records in the Fatal Accident Reporting System (FARS) files for the years 1982-1986. Pedestrian accidents were excluded from consideration. "Alcohol involvement" for any driver was defined as any case in which the driver showed a positive BAC value, or there was police-reported alcohol involvement, or a citation for DWI was given. This provided a crude but expedient index of alcohol involvement, which may be useful for comparative purposes. It will underestimate the actual frequency of alcohol involvement because so many cases are coded as "unknown" for alcohol and no blood test results are reported. NHTSA has developed a complex algorithm for estimating the true alcohol incidence, which it uses in its formal analyses of FARS data. The analysis presented here was simply to provide a quick and informal "snapshot" of relatively current alcohol incidence in rail-highway accidents, and should be viewed as appropriate for rough comparative purposes.

For all fatal accidents at grade crossings, 20% of drivers were positive for alcohol involvement, 14% were negative, and 66% were unknown. This rate of alcohol involvement was somewhat lower than for other fatal accidents, where 28% were positive, 10% were negative, and 62% were unknown. Of course, the large number of "unknowns" makes such comparison tenuous. The 28% alcohol-positive drivers identified in this analysis may be contrasted with the 36% positive cases identified by NHTSA (in the 1986 FARS report) for the same period, using NHTSA's more sophisticated methods for estimating involvement rates. Thus rates generated by the present method appear about 25% low.

Alcohol involvement rates at grade crossings appeared to be much higher at night than in daytime (35% positive vs. 9% positive). For non-crossing accidents, the comparable figures were 39% and 16%. As is typically found in alcohol studies, incidence was tied to age and sex, with males aged 20-35 showing the highest involvement rate, about 30%. Little difference was evident between urban and rural locations. It was felt that there may be differential rates of alcohol involvement for different categories of crossing traffic control device. However no major difference was evident here. In the daytime, the percentage of alcohol-positive drivers was: active TCD's, 10.3%; passive TCD's, 7.5%; no TCD, 10.5%. At night, the comparable figures were 38.3%, 30.0%, and 34.4%. Rates for gates and flashing light sites were similar. For all these conclusions, the reader is reminded to view them tentatively, recognizing the large number of "unknown" codings.

In summary, the available information on alcohol involvement in rail-highway crossing accidents suggests that alcohol is an especially significant factor in nighttime cases. Involvement rates may be somewhat lower than for other traffic accidents, but are still high. Based on limited data, it does not appear that crossings protected by one sort of TCD are any more susceptible to alcohol-involvement accidents than are other kinds of crossings.

3.6.2 Alcohol Mechanisms

Although the degree of alcohol involvement in crossing accidents is not clear, many of the mechanisms through which alcohol might influence such accidents are well researched. It would not be appropriate here to review the large literature on the human factors implications of alcohol impairment. In one of the early major papers on rail-highway crossing safety (Schoppert and Hoyt, 1968), Hulbert and Burg (1968) wrote a lengthy appendix on "Application of Human Factors Research in Design of Warning Devices For Highway-Rail Grade Crossings." This analysis remains useful after 20 years, including discussion of how various alcohol-related detriments may impact crossing safety. Extensive research since that review has further established that alcohol has detrimental effects on virtually all aspects of driver performance. We will only briefly mention some of the general aspects that clearly relate to grade crossings (specific documentation of the literature can be found in reviews by Allen, Schwartz, Hogge, and Stein, 1978; Barry, 1973; Johnston, 1982).

Alcohol interferes with visual perception. It disrupts normal visual scanning patterns, eye movement frequency, and functional field of view. It distorts distance judgments and timing judgments. It reduces dynamic visual acuity. Decrements such as these obviously relate to the detection of signals and trains, as well as judgments about available gaps.

Alcohol causes information processing and decision making to be slower and less efficient, and suffer more errors. Intellectual performance and short term memory suffer. A particularly important deficit is in attention. Not only may the drunk driver suffer attention "lapses," but routinely he will have difficulty in sharing attention between different tasks. This may be critical at a site such as a grade crossing, where off-road search for trains must be accomplished while the driver negotiates the roadway, notices signs and signals, and adjusts speed for the crossing itself.

Alcohol influences a host of motivational factors. These include assertiveness, self-destructiveness, dissociation from sober habits, decreased fear, and overconfidence. These factors may be particularly destructive when combined with the objectively decreased cognitive and perceptual abilities.

Alcohol increases risk taking. There is an unresolved controversy over whether this is because it interferes with risk perception or increases risk acceptance (Lerner et al., 1988). In either case the consequence is the same.

Alcohol also interferes with gross motor coordination. This is probably not a direct factor in most rail-highway crossing accidents. However, this problem could force the driver to devote more of his attentional resources to vehicle control and path maintenance; hence less attention is devoted to the search for and interpretation of TCD's or trains.

A final aspect of alcohol effects is on the variability of behavior. Allen, Schwartz, Hoggs, and Stein (1978) and Allen and Schwartz (1978) have shown how this can have particular highway safety consequences. They argue that relatively small increases in the variability of perception or behavior can lead to drastic increases in accident probability. This is because a small increase in the standard deviation of a distribution can lead to many more cases exceeding some value at the extreme "tail" of the distribution. Thus while still "rare," extreme errors will occur much more often. A driver may have difficulty in directly perceiving the variability of his performance and beyond this may not appreciate how a small change in variability increases risk. Thus he is unlikely to attempt to compensate for this enhanced risk.

In summary, alcohol interferes with driving performance through many mechanisms. These may be especially relevant to hazards at rail-highway crossings.

3.6.3 Drugs

There is very little information available on the involvement of drugs other than alcohol in rail-highway crossing accidents. The role of various drugs in highway safety in general is much more ambiguous than for alcohol. This was carefully documented in an NHTSA report to Congress on the current state of knowledge (Compton and Anderson, 1985). Among the many problems in determining the magnitude of drug-related traffic-safety concerns are: There is relatively little data on the incidence of drug use in traffic victims, with small sample sizes in many studies; there is no good "exposure" data (rate of drug use in the non-accident population), so that increased risk is difficult to determine; the dose-response relationships are often not well understood and may be subject to large individual differences; a very high percentage of drug-positive victims are also alcohol-positive, so that drug effects cannot be isolated; there are numerous drugs with potentially detrimental effects, but the toxicological tests may be drug-specific; toxicological tests for even the most common drugs are not routinely conducted; the change in the level of the drug in the blood as time passes may be poorly understood, variable, and not conducive to determining the level of intoxication at the time of the accident; and various other problems. While there is certainly laboratory evidence for driving performance detriments under various drugs, some of the better-controlled accident investigation studies have failed to firmly establish any evidence of enhanced risk as a result of, for example, marijuana use (e.g., Donelson, Haas, and Walsh, 1986). Given this state of affairs for traffic safety in general, it is not too surprising that little can be said about drugs as a contributing factor at rail-highway crossing accidents in particular.

Certainly the most prevalent and well-studied illicit drug is marijuana. Moskowitz (1985) has provided a good review of experimental studies examining the relationship between marijuana dose and some area of performance related to driving. Impairment is seen in coordination, tracking, perception, vigilance, certain cognitive activities, and overt driver performance (in simulators, on closed-courses, or on the road). However, performance decrements are not universal, and in fact Stein, Allen, Cook, and Karl (1983) found some evidence that there may be decreased risk taking after marijuana use.

Whatever its risks, drug involvement in accidents appears much more limited than alcohol use. The Compton and Anderson (1985) report found that perhaps 10%-15% of fatally injured drivers show some evidence of drug use (for all drugs combined). Most of these drivers were also alcohol intoxicated. It cannot be assumed that in all cases the level of the drug at the time of the accident was significantly detrimental to the driving task.

Thus while many illicit drugs, medications, or other drugs have demonstrated degrading effects on a least some aspects of human performance, there does not appear to be any adequate basis for assuming drugs play a prominent role in many grade crossing accidents.

3.6.4 Fatigue

A final transient impairment considered here is fatigue. Fatigue can influence both perceptual performance and the speed and quality of decision making. Again there is minimal information on the role of fatigue in rail-highway crossing accidents. Because, relative to other categories of serious accidents, grade crossing accidents have a low percentage of nighttime occurrences, and frequently involve local drivers, it may be presumed that fatigue plays less of a role than for fatal accidents in general. However, the nature of fatigue effects are such that they might be especially critical at grade crossings. Short of actual dozing at the wheel, the fatigued driver shows occasional attention lapses, delayed reaction in making vehicle speed adjustments, fewer steering corrections, and less "reactivity" or "arousal" in response to environmental events. Fatigued drivers show less efficient visual search for hazards, since their gaze tends to fixate on the near right road edge, rather than uproad (Shinar, 1978). There appears to be less ability to share attention between various aspects of the driving task. While fatigued drivers show some awareness of their declining abilities and judgment (Fuller, 1984), there is also evidence that they may be more likely to make risky maneuvers, such as risky passes of other vehicles (Brown, Tickner, and Simmonds, 1970). All of these effects would suggest that the fatigued driver may be especially susceptible to the hazards of grade crossings, even though the magnitude of the problem is unknown.

In summary, the contribution of various forms of transient impairment to rail-highway crossing accidents is not well defined. Alcohol is certainly present in many cases, although perhaps not to the same degree as for other traffic accidents of similar consequence. The incidence of drug involvement and driver fatigue is undoubtedly lower, but the increased risk associated with these factors is unknown.

4. DRIVER CHARACTERISTICS

This section addresses the characteristics of drivers that relate to their behavior at rail-highway crossings. A number of these characteristics have already come up in the course of discussing the factors that contribute to crossing safety. They will just be summarized in this section. The concern here is with who has what problems at grade crossings. To a large degree, the characteristics of drivers involved in rail-highway accidents parallels the characteristics of accident-involved drivers in general, and are not unique to crossings.

4.1 FAMILIARITY

Familiarity with the particular crossing has been related to both dangerous actions and actual accident involvement. One of the prominent characteristics of drivers involved in rail-highway accidents is their familiarity with the specific crossing. For example, Gossard (1987) indicated that the 1986 NTSB study of 75 accidents involving high-speed passenger trains found that 85% of the drivers were familiar with the crossing. This may even be somewhat conservative, since the NTSB (1986) report also indicated that 92% of the accidents involved a driver making a trip to or from work, school, or shopping. Wigglesworth (1979) found similarly high percentages for Australian accidents, and Knoblauch et al. (1982) implicated familiarity as a contributing causal factor in their accident study. While accident data suggest the accident-involved driver is typically familiar with the crossing, this in itself does not necessarily imply the familiar driver is at special risk. It may simply be that the majority of drivers exposed to a crossing are familiar. For example, in their field study Sanders et al. (1973) could classify only 9% of drivers at their sites as "unfamiliar" (crossed only once or twice before, or never), and well over 75% of the drivers indicated that they first became aware of the crossing because they remembered it was there. However, mere exposure is probably not the sole explanation for the role of driver familiarity. It has been identified as a probable contributing factor in accident studies (e.g., Wigglesworth, 1979; Knoblauch et al., 1982). Also, familiar drivers have been found to behave differently at crossings. In Coleman, Koziol, and Mengert's (1977) field evaluation of passive crossing signs, it was found that out-of-state drivers showed significantly more safety behavior such as head movement and speed reduction. Sanders et al. (1973) found that the frequency of using the crossing was inversely correlated with looking behavior and speed reduction.

The probable reasons for the familiarity factor's influence on behavior include: low expectancy of trains at the time and/or place; low credibility of warnings; and benign experience with careless actions in the past.

4.2 AGE AND SEX

The demographic characteristics of age and sex have been strongly related to accident involvement rates, and this is also true for rail-highway crossing accidents in particular. Male drivers predominate in accident data, and this is also true for rail-highway crossing accidents. However, there is some indication of greater female involvement than for all accidents in general. For example, Sanders et al. (1973) cited a Michigan study which found about 23% of the drivers in fatal rail-highway accidents to be female, vs. about 17% in all fatal highway accidents. Very similar proportions were reported by Wigglesworth (1979), 24% vs. 15%. Peterson and Boyer (1975), cited data showing 39% vs. 29% females when truck accidents are excluded. However, in reviewing more recent data (excluding pedestrian accidents) from the Fatal Accident Reporting System for the years 1982-1986, we did not find this difference in the proportion of female drivers. For fatal accidents occurring at rail-highway crossings, 22% of involved drivers were female; for fatal accidents where the first harmful event involved collision with a train, this figure was again 22%. This can be compared to the 1986 FARS report, which shows that for all fatal accidents, a very similar number (21%) of drivers were female.

Both young and old drivers have accident involvement rates that are substantially higher than for the middle-age population of drivers. The above FARS data were also examined for age distribution. About 17.5% of drivers involved in fatal accidents at rail-highway crossings were age 20 or less; about 17% were over age 56, and about 9% were over age 65. These figures are quite comparable to the 1986 FARS figures for all fatal accidents: about 17%, 14%, and 8%, respectively.

Because of substantial differences in the amount and type of driving done ("accident exposure"), the relative frequencies of accidents for various age groups do not necessarily reflect the relative risk. More sophisticated indices of accident risk, reflecting a per mile involvement rate, have been computed for various kinds of accidents (e.g., Maleck and Hummer, 1986). Unfortunately, no such analysis was found for rail-highway accidents. However, a number of authors have pointed to special concerns for older drivers in crossing situations. Decrements in certain perceptual, cognitive and physical abilities suggest that older drivers ought to experience more difficulty at crossings. The literature on aging is very extensive, and changes in abilities related to driving include many aspects of visual perception, auditory detection, information processing rate, attention sharing, reaction time, agility (especially ability to turn head or torso), temporal judgments, and so forth. Some of the age-related deficits related to driving have been recently discussed in an extensive Transportation Research Board review (1988). There are even notable age differences in the comprehension of signs in general, and rail crossing signage and knowledge of requirements in particular (e.g., Fambro and Heathington, 1984; Richards and Heathington, 1988). Detailed accident investigations (Knoblauch et al., 1982; NTSB, 1986) have identified age effects as contributing factors to some crossing accidents. However, despite these concerns, the degree of enhanced risk incurred with age, and the mechanism of this problem, remain a question.

4.3 ALCOHOL

The alcohol impaired driver accounts for a substantial portion of rail-highway accident victims, particularly at night. This problem has already been discussed in Section 3.6. No information was found specifically on how the behavior of alcohol-impaired and non-impaired drivers differs at grade crossing sites. However, based on the more general literature on alcohol and driving, a number of the expected mechanisms of interference with driving were already indicated in Section 3.6.2.

4.4 RISK TAKING

The tendency to commit a risky driving behavior of one sort is often correlated with the tendency to engage in other risky driving actions. Driver risk taking has been correlated with certain personality characteristics, as measured by various tests of risk taking propensity and impulsivity (e.g., Shoptaugh, 1988). Section 3.4.2 has already discussed some aspects of driver risk taking at rail-highway crossings. As indicated there, risky actions at crossings are correlated with other risk taking behaviors. Thus unsurprisingly, more general driver personality traits appear related to behavior at grade crossings.

5. COUNTERMEASURES

As the body of this review has indicated, there are numerous factors that contribute to inappropriate driver behavior at rail-highway crossings. Unsurprisingly, then, there have been many different safety countermeasures implemented, pilot tested, or suggested. In this section there will be a discussion of countermeasure approaches intended to influence driver performance.

The effectiveness of many of these approaches in actually reducing accidents is not known, and cannot be evaluated here. A particular countermeasure may or may not be effective in substantially modifying driver behavior in a desirable way. If effective in modifying behavior, this change may or may not result in a significant reduction of actual accidents; and if significant reduction in accidents does occur, the countermeasure still may or may not be cost-effective. Most countermeasures only address some limited accident scenarios. Since no single scenario dominates the rail-highway crossing accident cases, this limits the potential of any given countermeasure to reduce accidents, even if it is quite effective in modifying driver behavior for the specific scenario it targets. As an example, the cost-effectiveness of reflectorizing the sides of rail cars has been analyzed in some detail (e.g., McGinnis, 1979). Retroreflective markers on the sides of rolling stock would certainly improve the conspicuity of trains (especially slow-moving trains) already present in the crossing as a vehicle approaches at night. However, considering the particular subset of accidents which even have the potential to be influenced by this factor (based on illumination level, speed and angle of vehicle approach, train location and speed, etc.), other contributing accident factors, installation costs, continuous maintenance needs, and so forth, the cost effectiveness of this countermeasure is questionable. Furthermore, for many sorts of accident countermeasures, site-specific warrants will determine cost effectiveness. The concern in this review is with how a particular countermeasure may influence driver perceptions and actions. The important considerations of cost effectiveness are beyond the scope of this evaluation of driver behavior factors.

The basic traffic control devices and strategies for grade crossings have been in effect for many years; therefore the driver problems involved are not new. Perhaps unsurprisingly then, most countermeasure strategies suggested are also not new. Some technologies and concept feasibility may have advanced, but the underlying countermeasure concept remains. NCHRP Report 50, "Factors Influencing Safety At Grade Crossings" (Schoppert and Hoyt, 1968) is now 20 years old. But the analysis of the driver problems, information needs, and countermeasure concepts remains quite current. The dramatic reductions in grade crossing accidents perhaps are therefore not so much the result of improved methods as the result of more extensive implementation of higher-level protective systems.

Before discussing specific countermeasure ideas, the rather obvious distinctions between the major levels of crossing protection should be mentioned. Elimination of the rail-highway crossing, either through closing it or by means of grade separation, removes the issue of driver behavior from the problem. The only related accidents are those that involve collision with crossing-related structures. If the crossing cannot be eliminated, active protection by automatic gates is most effective, because it simplifies driver options and reduces decision making. Active crossing signals are more effective than passively protected crossings, which place the most demands on driver understanding, perception, and decision making. Estimates of the relative effectiveness of each of these alternatives exist (e.g., Eck and Halkias, 1985; Farr and Hitz, 1985). The issues involved in the selection of these countermeasures primarily involve cost (of installation and maintenance), cost effectiveness, and resource allocation. The relative virtues in terms of driver behavior are clear.

This section will describe the countermeasure concepts that have been suggested for addressing each of the contributing driver behavior factors reviewed in the previous sections. These concepts vary from vague suggestions about some novel approach to specific devices that have been subjected to systematic laboratory or field testing.

5.1 COMPREHENSION

Section 3.1 indicated that a significant number of drivers did not adequately comprehend the meaning of crossing-related TCD's, the required driver actions, or important accident factors. Various suggestions for better educating the driving public on these matters have been made.

Richards and Heathington (1988) suggested that: state highway departments work with state departments of education to incorporate a rail-highway crossing module into the high school driver education curriculum; material on grade crossing requirements and TCD's be upgraded in driver licensing handbooks and included in written licensing examinations; public service activities (e.g., Operation Lifesaver) should give more attention to TCD's, and should devote more effort to educating the law enforcement community. Tidwell and Humphreys (1981) suggested that public education efforts (e.g., driver training, driver handbooks, safety campaigns) specifically convey the following: Only the more hazardous crossings have active protection; standard TCD's should be shown and discussed; passive crossings require slowing and looking/listening, but not stopping; a stop is not required when a signal is not activated; knowledge concerning grade crossing hazards does not need to be overly emphasized. Knoblauch et al. (1982) argued that education efforts might be more effective and efficient when targeted to specific types of accidents involving specific driver groups. For example, older drivers could benefit more from an approach that emphasized recognition of signals or trains, while truck drivers could benefit more from statistics on certain kinds of truck accidents. Haga (1988), particularly addressing Japanese concerns, suggested that emphasis be placed on the need to not proceed across tracks at congested sites until there is adequate space on the other side of the crossing; he also recommended improving knowledge of "emergency skills" (e.g., use of smoke candles).

Several authors have argued that motorists should be educated about their own perceptual limitations. Knoblauch et al. (1982) and Leibowitz (1985) suggested informing drivers about their inabilities or "overconfidence" in judging approach rate or time intervals. Leibowitz and Owens (1986) stressed that drivers need to be educated about their nighttime visual limitations, including factors that deceive people into overestimating their ability to detect targets at night. McGinnis (1979) felt that public education campaigns on rail-highway crossing safety should inform drivers of the need for use of high-beam headlights in the vicinity of crossings.

Despite the frequent and varied recommendations regarding driver education, its influence on driver behavior at rail-highway crossings is not well understood. The best-known and most-widespread educational effort in this area is "Operation Lifesaver." This program has grown from an effort initially adopted in one state under the auspices of a single railroad in 1972, to an essentially nationwide non-profit organization. Operation Lifesaver, Inc. is widely believed to have had beneficial effects, and is frequently cited as a factor in the decline of rail-highway crossing accidents. However, no formal evaluation of the program appears to have been done. A number of important questions need to be answered, including the following: What is actually learned and retained? How does the course actually alter driver behavior? What portions of the presentation are most effective/ineffective? What types of accidents will most likely be influenced? What is the expected effect on accident reduction?

Consistent with this need for evaluation of the effects of an education program, some studies (e.g., Sanders et al., 1973; Tidwell and Humphreys, 1982) have reported a failure to find any positive correlation between actual safe driver behavior at crossings, and the individual's knowledge of sign meaning, required behavior, accident causes, or estimated number of fatalities. Thus while improved driver knowledge of these factors would appear worthwhile, the actual effectiveness of educational countermeasures is undemonstrated.

Driver comprehension may also be improved by measures other than education. In particular, signs and signals could be designed to more effectively convey the intended message. Various authors (e.g., Schoppert and Hoyt, 1968; Ruden et al., 1982) have argued that a yellow diamond-shaped sign field for the railroad advance warning sign would be consistent with coding convention for other advance warning signs, and hence be better comprehended. Similarly, Ruden et al. suggested incorporating the "Yield" sign into the railroad crossing (crossbuck) sign, to convey that the driver requirements are the same as for a yield situation. Other sign concepts (discussed further in subsequent sections) include explicit statements about required driver actions (e.g., "look for trains"). Another sign-related problem, discussed in Section 3.1.2, is that advance signs and markings, and crossbucks, do not in any way distinguish active from passive crossings. This may contribute to a driver's failure to comprehend that different driver actions are required in approaching and traversing the crossing. Countermeasure proposals related to sign and signal design will be discussed in more detail in following sections.

5.2 DETECTION AND RECOGNITION

Efforts to improve the detection and recognition of TCD's, of the crossing itself, and of trains have focused on increasing their conspicuity, by manipulating such properties as signal intensity, signal size, brightness contrast, color contrast, number of signals, configuration of signals, supplementary flashing lights, and placement relative to expected driver line of sight. For each component device that the driver may encounter on the roadway approach, methods to increase its attention-getting potential and its recognizability have been applied and sometimes tested.

5.2.1 Advance Warning Signs

Although experimental advance warning signs with different colors and a diamond shape have been tested, it is unclear whether they are effective in alerting the driver sooner or more reliably to the presence of the crossing. The Texas system advance warning sign differs from the standard advance sign in that the top and bottom quadrants are red rather than yellow. Koziol and Mengert (1978) did not find significantly more head movements or greater speed reductions in response to the Texas advance sign than to the standard advance sign, when both signs were paired with a standard crossbuck. Ruden et al. (1982) used several alternative advance signs with a diamond shape and a flattened (60-degree) red X, instead of the 90-degree black X utilized in the standard advance sign. The upper and lower quadrants formed by the red X were bounded by a white stripe. When it was viewed on a yellow background in direct sunlight, the flattened red X was reported as detected earlier by subject drivers than the standard black X. The degree to which color, as opposed to angle of the X, accounted for increased conspicuity of the experimental advance warning sign cannot be determined from the data. Diamond-shaped advance warning signs utilizing symbols (black silhouette of a train, or of a track crossing a road) were tested in conjunction with diamond-shaped crossing signs containing a superimposed crossbuck (Dommasch et al., 1976). Color of the experimental signs was also manipulated, and was either yellow or brilliant yellow-green. However, it is unclear whether the experimental sign combinations produced significant increases in braking or greater reductions in spot speed, when compared with standard advance warning and crossbuck signs. Although color contrast within the sign, and against its background, is an important determinant of sign conspicuity, the color combinations tested do not appear to have clear-cut advantages over the standard black and yellow advance warning sign. Two of Ruden et al.'s experimental advance warning signs and a 48-inch standard advance warning sign were field-tested in a study of active advance warning signs (Bowman, 1987a); there was an opportunity to compare their effect on driver behavior during the unactivated state, when yellow beacons mounted above and below the signs were not flashing. Although there may be differences in how drivers respond to advance signs with and without unactivated flashers, the unactivated condition gives some indication of the relative conspicuity of the advance sign component of the AAWD. At most test sites, under both day and night conditions, Bowman observed no significant differences in mean approach speeds among the different advance signs. Thus, two field studies that evaluated advance signs with red features (Koziol and Mengert, 1978; Bowman, 1987a) failed to demonstrate an increase in their attention-getting value over the standard advance warning sign. Similarly, evidence concerning the diamond shape is inconclusive. On the basis of preliminary study, Schoppert and Hoyt (1968) reported that the "average driver" associates rectangular and diamond-shaped yellow signs with the function of advance warning for a hazard. It is unknown whether the association between the diamond shape and its general warning function is strong enough to facilitate recognition of the advance warning message.

Since detection of the advance warning sign depends on the driver's eyes being oriented in the proper direction, the use of more than one advance sign on the approach roadway (e.g., on both sides of the road) has been suggested as a way of decreasing the probability of missing the advance warning (Mortimer, 1988; Schoppert and Hoyt, 1968; Hulbert, 1972). In Israel, it is standard practice to use three pairs of advance warning signs, that are also coded for distance from the crossing: The number of diagonal stripes on each advance sign decreases from three to two to one as the distance between each sign pair and the crossing decreases (Shinar and Raz, 1982). The general principle that redundancy of information increases the likelihood of detection has been well-supported (e.g., Schoppert and Hoyt, 1968), and has been applied at intersections with multiple highway traffic devices installed on each approach. However, the type of redundancy that is most advantageous for advance warning of a crossing has not been systematically evaluated: The optimal configuration for presenting multiple advance warning signs is unknown, and cross-modality redundancy, such as that achieved through rumble strips, may be more effective than repeated visual presentations, especially at crossings with visibility restrictions. The use of auditory advance warnings will be discussed in subsequent sections.

In summary, a variety of alternative advance warning sign designs have been suggested to increase conspicuity. While some enhancement may occur, substantial effects on driver performance have not been shown, and potential effects on accident reduction are unknown.

5.2.2 Active Advance Warning Devices

Various designs and modes of operation for active advance warning devices (AAWD's) have been proposed for both active and passive crossings, particularly those with limited sight distance and high vehicle speeds (Hopkins and Holmstrom, 1976; Ruden et al., 1982; Raab, Brooker, Ryan, and Waechter, 1977; Sanders et al., 1973; Tustin, 1975). Ruden et al. (1982) recommended that AAWD's be installed at active crossings with visibility restrictions due to the following conditions: vertical or horizontal alignment of the roadway such that an activated crossing signal would not be bright enough and/or close enough to the driver's line of sight to be readily detected before the non-recovery zone; crossings that require extended braking distances (e.g., because of downgrades); crossings that often have poor visibility due to weather conditions (e.g., fog, blowing dust). Flashing lights on AAWD's at active crossings can either flash continuously to alert drivers to the presence of a crossing, or be activated just prior to or simultaneously with activation of the crossing signal and thus provide advance warning for the presence of a train and the need to brake to a stop. The effects on overt driver behavior of adding flashing warning beacons in other traffic situations (e.g., school zones, rural intersections) have been mixed (e.g., Warren, 1982; Hagenauer, Upchurch, Warren, and Rosenbaum, 1982). Peterson and Boyer (1977) speculated that, if a pair of continuously-flashing amber lights were placed adjacent to a standard advance warning sign, drivers unfamiliar with the crossing might be more effectively alerted to its presence than with the standard advance warning sign alone; however, the effect of the AAWD on drivers would be difficult to determine from observable measures.

The rationale behind activating the AAWD prior to activation of the crossing warning 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 (Wilde et al., 1975). In field studies, Ruden et al. (1982) and Bowman (1987a) utilized delays between activation of the AAWD and the crossing signal; they recommended that at sites where a queue of stopped vehicles must be cleared after the train has passed, the AAWD remain activated for a period of time after deactivation of the crossing signal. This measure would alert vehicles approaching the crossing after passage of the train to the presence of the queue. AAWD's at active crossings have taken the form of a standard advance warning sign with yellow flashing lights mounted above and below the sign or in the upper and lower quadrants of the sign (Butcher, 1973; Ruden et al., 1982; Bowman, 1987a); a neon "R X R GATE" sign with a flashing yellow light (Dejaiffe, 1961, cited in Butcher, 1973); and a "TRAIN WHEN FLASHING" sign containing a symbol of active flashers, with a pair of yellow flashers mounted above and below the sign (Texas Highway Department, 1974, cited in Humphreys and Heathington, 1981). Raab et al. (1977) have suggested the following designs: a variation of the standard advance warning sign, with the R's in the upper and lower quadrants and flashing lights in the right and left quadrants; a diamond-shaped "LOOK FOR TRAINS" sign with flashing arrows pointing to the left and right; a blank yellow crossbuck with four flashing lights mounted on the arms. They recommended that the same basic advance warning sign be used for both activated and passive advance warning devices. Finally, Urbanik (1971) proposed the use of an overhead variable message sign as a train-activated AAWD. The standard advance warning "R X R" symbol would be present and illuminated at all times; the message "TRACKS AHEAD" would flash continuously in amber when it is safe to cross, and would be replaced by a "TRACKS BLOCKED STOP AHEAD" message, flashed in red, when the crossing signal is activated.

When AAWD's have been tested at active crossings with limited sight distances, they have appeared to facilitate driver detection of the activated crossing signal, but primarily under daytime viewing conditions. As part of an outdoor laboratory test, drivers were exposed to activated advance warning signs on the approach to crossings, and then asked about the meaning of the flashing lights (Ruden et al., 1982). About half of them seemed to recognize that the flashing lights signaled the approach of a train; the other half wanted to know whether or not the lights flashed continuously. Perhaps the pervasive use of continuously flashing amber lights as warning signals (e.g., construction hazards) contributed to the subject drivers' uncertainty about their specific meaning in the crossing situation. Another factor that may have contributed to their uncertainty was that they were never exposed to advance warning signs with inactivated flashers. Ruden et al. (1982) also field-tested the use of flashing yellow beacons above and below a standard advance warning sign and a number of experimental advance warning signs. They found earlier activation of brake lights and more speed reductions in response to crossing signal activation when the AAWD was activated than when it was not activated, under daytime viewing conditions. When Bowman (1987a) used one of Ruden et al.'s prototypes for an experimental advance sign as the basis for an AAWD with two yellow flashers, he observed significantly lower speeds (about 10 mph lower) near the AAWD when it was activated than when it was not activated during the day. Two studies have presented subjective evaluations of the effectiveness of train-activated AAWD's in alerting drivers to the crossing signal. Based on informal reactions of diagnostic team members and state safety agencies to the installation of "TRAIN WHEN FLASHING" AAWD's at seven Texas crossings, the Texas Highway Department (1974, cited in Humphreys and Heathington, 1981) concluded that the AAWD's were "more effective" than the standard advance warning sign. Dejaiffe (1961, cited in Butcher, 1973) reported a substantial reduction in annual collisions at a gate-protected crossing in California after an AAWD had been in operation for three years; he credited the improvement to the AAWD, which was based on a neon "R X R GATE" sign.

Although a continuously flashing AAWD has been suggested for use at passive crossings, only one systematic test of its effects on driver behavior was found. Sanders et. al (1973) attached two yellow flashers to the left and right sides of a standard advance warning sign, and installed it at a crossing with limited sight distance. They observed an increase in driver looking behavior and larger speed decreases in response to the AAWD, relative to a standard advance warning sign without flashers.

All of the AAWD's discussed above have utilized a visual signal, typically the addition of alternately flashing yellow lights to a standard or experimental advance warning sign. Cox (1972) proposed that an audible warning device be installed at the location of the advance warning sign, and activated both on the approach and departure of the train from the crossing. The cost of this acoustic AAWD was estimated to be 10% of that for an active crossing signal, and the AAWD was targeted for passive crossings on roads with low traffic volume. In general, auditory stimuli are responded to more quickly than visual stimuli, and may draw one's attention to the source of the sound, an advantage if the driver's eyes do not happen to be oriented toward the advance sign. Although the acoustic warning provides information about the presence of a train, while the advance warning sign indicates the presence of a crossing, there is some redundancy between the two sources of information, which should increase the likelihood of alerting the driver to an upcoming hazard. However, constraints on the effectiveness of auditory signals from trains also apply to their use in an AAWD: There are limitations on the intensity of an acoustic warning that will be tolerated by nearby residents; the strength of the signal is attenuated as a function of distance from the source, and by such objects as the driver's vehicle; the auditory warning must compete with other background noises from both inside and outside the vehicle.

Various authors (e.g., Butcher, 1973; Peterson and Boyer, 1975 and 1977; Heathington and Urbanik, 1972) have suggested that in-vehicle, real time information systems would be applicable to rail-highway crossing problems. This concept would employ communications technology whereby information is transmitted directly to receiving systems in individual vehicles. The potential of such warning systems, in terms of conspicuity, credibility, and information content, are obvious. To be effective as a general motorist warning system, the presence of such devices in private vehicles must be widespread. However, this sort of radical change in vehicle, roadside, and trackside technology clearly cannot realistically be driven primarily by the safety concerns of rail-highway crossings. To the extent that emerging in-vehicle technologies and "smart roadway" concepts become developed and used, these can be taken advantage of for grade crossing applications. The literature review did not uncover any indication of near-term rail-highway applications.

It therefore appears that active advance warning devices do improve driver performance. For signals which are only active when a train is present, this could be due in part to the information properties of the signal. However, since even in a passive crossing situation there was more slowing in response to the signal, conspicuity improvements presumably are part of the reason. However, it is not known whether the benefits of advance beacons are transient, particularly for the passive crossing situation where they do not provide additional information.

5.2.3 Rumble Strips

Rumble strips on crossing approaches are intended to increase the probability of drivers detecting visual advance warning signs, auditory warnings, and the presence of the crossing. The well-established principle behind their use is that presenting redundant information to several sense modalities increases the likelihood of detecting an event. The vibratory and auditory stimulation produced by rumble strips when the driver travels over them is well-suited for alerting him to an imminent hazard. Whereas detection of visual crossing cues depends on the driver's eyes being oriented properly, rumble strips capture his attention, even if he is distracted from other warning signals by competing visual or auditory inputs. At high speeds, vibratory stimulation from rumble strips cannot be readily ignored, and continues to be uncomfortable for the driver, even on repeated exposure. For this reason, rumble strips may be more resistant to familiarity effects than other countermeasures (Schoppert and Hoyt, 1968; Zaidel et al., 1986). Rumble strips have also been used to control vehicle speed at stop-sign controlled intersections, traffic circles, and tollgate plazas. In summarizing the traffic and safety effects of rumble strips installed on residential streets, Warren (1982, Table 15) reported that they produce speed reductions, improve safety, are unlikely to cause traffic volume reductions, and increase noise.

Rumble strip installations, in general, have varied widely in dimensions, number, spacing, and distance of surface treatment. Zaidel et al. (1986) reported that strips are typically from 3/8- to 3/4-inch in height, and from 4 inches to 3 1/2 feet or more in width; in pilot tests, drivers objected to rumble strips from 5/8- to 3/4-inch in height. More than one strip is typically used. Zaidel et al. concluded that, for intersection applications, there is currently no evidence to support any one spacing of strips or distance of treatment over others. Based on a comparison of two treatment distances at a stop-controlled intersection, they recommended installing two or three strips at regular intervals over a distance equal to the deceleration distance required for the 85th-percentile speed. For crossing applications, Schoppert and Hoyt (1968) proposed installing rumble strips at the point where the driver should begin to slow down. Parsonson and Rinalducci (1982) used rumble strips at three locations on each crossing approach: in advance of a "STOP AHEAD" sign; before an advance warning sign; and in advance of either a "LOOK FOR TRAIN" sign or an at-crossing stop sign. Bellis (1969, cited in Hulbert, 1972) compared the installation of rumble strips with a "rumble area," about 25 feet wide, and found the strips to be more effective.

Other forms of rumble strips have been used, in addition to the strip of rough pavement material described above, including grooves in the pavement, quiet strips, and an open graded asphalt friction course. As of 1985, grooves or indented rumble strips were reported to be in use in a number of states for rail-highway crossing applications (NTSB Safety Study of Passenger/Commuter Train and Motor Vehicle Collisions at Grade Crossings, 1986). Peterson and Boyer (1977) reported that the sensation produced by traveling over grooved pavement is less abrupt than that produced by tacked-on rumble strips, but the implication of this finding for the relative alerting function of strips and grooves is unknown. Quiet strips, or areas of unusually smooth pavement immediately preceding each rumble strip, were proposed by Schoppert and Hoyt (1969). The rationale behind the use of quiet strips is that the contrast between the sudden reduction in tire noise, associated with quiet strips, and noise caused by rumble strips would increase the probability of detecting rumble strips. Also, sudden quieting due to smooth strips was thought to have alerting properties, in and of itself. Peterson and Boyer (1977) studied the effect of an open graded asphalt friction course, applied over areas from 6 to 8 feet in width, and alternated with areas of normal pavement. This type of pavement treatment produces an acoustic signal, like a rumble strip. Relative to typical pavement surface, the porous structure of the open graded friction course resulted in better braking in wet weather. Painting the open graded friction course produced markings that were visible from a greater distance than normal road markings, and this superiority was even more pronounced under wet conditions. The alerting effectiveness of the open graded friction course, compared to rumble strips, was not evaluated.

Field tests of rumble strips at stop-controlled intersections and rail-highway crossings have shown reductions in accident frequency, stop sign violations, and approach speed. However, these results have not been consistently demonstrated, and unsafe driver responses, such as avoidance maneuvers, have been reported. When Zaidel et al. (1986) installed reflective yellow rumble strips on the minor leg of a stop-controlled rural intersection, they observed earlier deceleration and lower approach speeds in the treatment than in the no-treatment condition. Moreover, much of the deceleration occurred in advance of the first rumble strip, indicating that visual detection of rumble strips contributed to their alerting effectiveness. One year after installation, rumble strips maintained their ability to reduce approach speeds. In a 1981 field test (cited in Pinell, Mason, Berg, Coleman, and Rosenbaum, 1982), rumble strips at selected crossings in Louisiana were observed to increase looking behavior and complete stops, and to reduce approach speed. After rumble strips were installed at 30 crossings in Kentucky, fewer accidents and near misses were reported than before treatment, but these improvements were not quantified (Skinner, 1971).

Although Parsonson and Rinalducci (1982) found fewer stop sign violations after rumble strips were installed at a rural crossing, they observed no change in speed profile, and a significant decrease in looking behavior. Since both rumble strips and new advance warning signs were added to the crossing at the same time, results may be due to either or both treatments. On average, 12 drivers per day were seen driving into the opposing lane in order to avoid the rumble strips. Because of these unsafe maneuvers by drivers familiar with the crossing, Parsonson and Rinalducci recommended that rumble strips be used only at crossings in nonresidential locations, where unfamiliar drivers can be targeted. Bellis (1969, cited in Hulbert, 1972) also raised the issue that familiar drivers may swerve into the oncoming lane to avoid rumble strips, and pointed out that non-local drivers may follow suit. To control for avoidance maneuvers where shoulders are wide, Zaidel et al. (1986) recommended that rumble strips be extended onto the shoulder. Other possible disadvantages of rumble strips include driver surprise and possible loss of vehicle control (Bellis, 1969, cited in Hulbert, 1972; Pinnell et al., 1982). When rumble strips were used on a straight stretch of highway in Wyoming to counteract driver fatigue, a small percentage of drivers stopped their vehicles because they attributed the vibratory-auditory stimulation from rumble strips to tire or engine trouble (Skinner, 1971). However, rumble strips were installed in increasing numbers in the 1970's (Zaidel et al., 1986), so problems due to driver unfamiliarity are less likely to occur.

In summary, rumble strips have important advantages over visual warning signals in alerting the driver to the crossing, and also facilitate detection of other warning signals. Painted rumble strips were effective in reducing approach speed at a stop-controlled intersection; speed reduction was largely in response to visual detection of the strips, before the driver experienced their vibratory and auditory stimulation. Field tests specific to crossings have yielded mixed results. The most serious disadvantage appears to be the unsafe avoidance behaviors exhibited by drivers familiar with the strips. There is consensus that rumble strips should be used only at crossings with special hazards, such as limited sight distance, unusual highway-roadway alignment, or excessive vehicle speeds. They have also been recommended at crossings where vehicular traffic volume is low.

5.2.4 Crossbuck

Low conspicuity of the white and black standard crossbuck, particularly when viewed against a light background, has led to the evaluation of alternate crossbuck designs. These experimental prototypes may differ from the standard in color, angle between crossbuck blades, addition of a contrasting background and/or flashing lights, or absence of the "RAILROAD CROSSING" legend. In several studies, combinations of experimental advance warning and crossbuck signs have been tested, making it impossible to isolate the effects of the at-crossing component (Dommasch et al., 1976; Coleman et al., 1977; Koziol and Mengert, 1978). In general, the use of different contrasting backgrounds and borders, and blank crossbucks, has yielded mixed results, which are sometimes difficult to interpret due to methodological limitations.

Coleman et al. (1977) field-tested seven different combinations of advance warning and crossbuck signs, under both day and night conditions. Crossbuck prototypes included the following: a blank yellow crossbuck with a black border; a bright yellow-green crossbuck; a flattened blank white crossbuck with a red border (the International Swiss Crossbuck); the red and yellow Texas system crossbuck, a standard crossbuck superimposed on a circular red and yellow background with a square black border. Since the crossbucks were paired with different advance warning signs at test installations, the advance and at-crossing signs could not be evaluated independently. Nevertheless, it is interesting to note that, although all experimental sign systems, taken together, produced significantly more head movements than standard advance signs and crossbucks, no significant differences in head movements, speed reduction, or speed near the crossing were found among the experimental systems. In addition, no differences in speed profile were observed among any of the sign systems. The extent to which the significant increase in head movements was due to the novel appearance of the signs is unknown: Coleman et al. did not report how long the signs had been installed before their two-day observation period began. As part of a follow-up study, Koziol and Mengert (1978) observed driver responses to the Texas system crossbuck, a blank yellow and black crossbuck, and the standard crossbuck, each paired with the Texas system red and yellow advance sign. The experimental crossbucks did not produce more head movements or greater speed reductions than the standard crossbuck. Significantly more head movements were observed with the combined Texas system advance sign and crossbuck, relative to the standard advance and at-crossing sign combination. Although it is possible that the Texas system crossbuck, with its red, yellow, and black background, was more conspicuous than the black and white standard, the increase in head movements could also be a function of the difference in advance signs between conditions.

In a laboratory study, Ells et al. (1980) found faster classification of a blank white crossbuck with a red border than a blank yellow crossbuck with a black border. The yellow and black crossbuck was classified more quickly than the then-standard Canadian crossbuck. These results were specific to conditions in which signs were viewed against a sky-blue background; classification times did not differ when a grass-green background was used. Both blank crossbucks were identified from significantly greater distances than the standard, but only against the blue background. Finally, crossbucks with 90-degree angles between the blades were identified from farther away than flattened (45-degree) crossbucks. On the basis of subject-provided definitions of alternate crossbuck designs, Kemper (in press) concluded that shape alone may be sufficient for correct identification of a crossbuck. He recommended further testing of crossbucks with a two-inch black border, either with or without the standard legend.

Raab et al. (1977) noted that a blank, bright yellow-green crossbuck with a black border would not provide good contrast against a background of foliage. Although Schoppert and Hoyt (1968) reported that, under low levels of illumination, bright yellow-green is visible at greater distances than other colors, they suggested that this color be reserved for some other type of highway signage required at unilluminated, rural locations. For a crossbuck prototype, they instead recommended superimposing a standard crossbuck on a triangular yellow background with a black border. This background provides better contrast than the standard crossbuck against a light background, such as sky or pavement. Schoppert and Hoyt's recommendation was based on judgments by the study staff and on subject preferences for crossbuck designs, and not on objective tests of sign conspicuity. In a field test of pairs of advance warning and crossbuck signs, Dommasch et al. (1976) superimposed crossbucks on diamond-shaped yellow and bright yellow-green backgrounds. It is unclear from their report whether the bright yellow-green signs had a greater effect on driver behavior than the yellow signs, or whether any of the experimental signs were significantly more effective at alerting drivers than the standard signs.

At trial installations, a number of states have attempted to increase the conspicuity of crossbucks by adding continuously flashing yellow lights. In Missouri, two 12-inch yellow flashers were mounted above and below a standard reflectorized crossbuck at four crossings. The flashing crossbuck sign was reported to be ineffective relative to the standard (Hartsell, 1967, cited in Butcher, 1973). Ohio also added continuously flashing yellow beacons above and below a modified crossbuck sign at some passive crossings; a white crossbuck was superimposed on a rectangular red background, and a 12-inch letter "R" was placed on either side of the crossbuck. However, an evaluation of the experimental sign indicated that it was ineffective (Traister, 1965, cited in Butcher, 1973). It is unclear from Butcher's review of the Missouri and Ohio flashing crossbucks what criteria were used to judge their effectiveness. Finally, Butcher (1973) reported on Arizona's proposal to modify the standard crossbuck for use as a cantilevered active warning device. For this purpose, a standard crossbuck would be superimposed on a black background, with a pair of standard railroad flashers to the left and right of the sign. This train-activated device was intended for use at passive crossings, and as an adjunct active system at crossings already equipped with flashing lights.

In summary, the standard crossbuck has limited conspicuity, and a variety of new designs have been suggested. Bright yellow-green crossbucks, blank black and yellow or red and white crossbucks, and the Texas system crossbuck have had undemonstrated effects on driver behavior in field tests (Coleman et al., 1977; Koziol and Mengert, 1978). Ells et al. (1980) found evidence for the superior recognition and identification of blank red and white or black and yellow signs, but only when viewed against a blue background. Although a strong rationale exists for superimposing a standard crossbuck on a yellow background, very little formal evaluation of the potential improvement in external contrast has been carried out.

5.2.5 Active Warning Devices

Even under ideal viewing conditions (e.g., straight and level approach, proper aiming), the standard narrow-beam lights used for active crossing signals are not readily detected by drivers at short distances from the crossing (e.g., Hopkins and White, 1977; Lindberg, 1971). Efforts to increase the conspicuity of crossing signals have focused on manipulating signal intensity, size, color, flash rate, placement, and source of light (incandescent vs. strobe). Such variables have been investigated in connection with the detectability of signal lights, in general, or flashing emergency beacons (e.g., King et al., 1975; Brown and Cole, 1969; Gerathewohl, 1953; Rumar, 1974), as well as railroad crossing signals. Ruden et al. (1977) conducted extensive indoor laboratory tests of potentially attention-getting properties of both incandescent and xenon flashing lights. They found that, although increases in signal intensity made flashing lights more conspicuous during the daytime and in the fog, increasing lens size from the standard 8 3/8-inch roundel to a 12-inch roundel produced greater improvements in conspicuity than increasing luminance alone, when other distractor lights were present. Other researchers have recommended the use of 12-inch roundels (Berg, 1985; Tustin, 1985). However, when Heathington et al. (1988) implemented 12-inch lenses in tests of experimental flashing light signals, they found no significant differences from the pre-existing 8 3/8-inch signals on indirect measures of driver detection, such as PBRT, speed profiles, and maximum deceleration rates.

Ruden et al. (1977) reported that red and blue incandescent lights were more conspicuous during the daytime and nighttime, respectively, a finding that is consistent with the different peak sensitivities of day and night visual systems to wavelength. Both Hopkins and Holmstrom (1976) and Ruden et al. (1977) recommended that current flash rates, typically between 35 and 55 cycles per minute, be increased. Ruden et al.'s laboratory tests showed that an optimal range for increased conspicuity was between 70 and 90 cycles per minute. The use of flashing lights for various marine, aviation, and highway applications, as well as for on-train warning signals, led Hopkins and White (1977) to conclude that the optimal flash rate falls between 90 and 150 flashes per minute. However, Hopkins and White's flash rate recommendation was based on experience with strobe lights. In principle, flash rates higher than 90 cycles per minute may attract attention better than lower flash rates; however, at these higher flash rates (up to 120 cycles per minute), incandescent lights are dimmer, and therefore not as effective as when they flash at 70 to 90 cycles per minute (Ruden et al., 1977). Ruden et al. reported that conspicuity of strobe lights increased with increases in flash rate, up to the maximum rate tested (110 cycles per minute). Thus, the higher flash rates which increase the conspicuity of strobes are not practicable for incandescent lights. There is consensus that, since cantilevered signals fall closer to the driver's line of sight than post-mounted signals located on the right roadway, they have a higher likelihood of detection (Tustin, 1985; Berg, 1985). As Berg (1985) and Mortimer (1988) pointed out, cantilevered signals are particularly well-suited for crossings with high vehicle approach speeds, multiple lanes, or restricted visibility, due to highly competitive or cluttered backgrounds. Haga (1988) recommended the addition of cantilevered signals to improve the visibility of flashing signals at gate-protected crossings in Japan.

Given the limitations of incandescent lights, particularly their poor coverage at short distances from the crossing and flash rate constraints, alternative roundels with more efficient beam patterns have been evaluated. Lindberg (1971) demonstrated that a multiple-beam roundel, designed for placement on the right side of the road, was effective in making an 18-watt reflectorized bulb visible to the driver at all positions that he is likely to occupy on the approach. He suggested that the same design principle be used to optimize signals for cantilevered and left side of the road placement.

The bulk of proposals for improving the conspicuity of standard flashers have involved the addition of one or more strobe lights to the cantilevered or roadside signal system. Laboratory and field studies suggest that add-on flashing strobes, mounted directly above or below conventional flashers, increase the conspicuity of the active warning device, but much of the evidence is based on subjective judgments. Ruden et al. (1977) demonstrated that the effectiveness of one or more strobes depends on the color of the lens: A pair of red strobes was less conspicuous than a pair of 8 3/8-inch narrow-beam incandescent flashers; blue strobes attracted attention more readily than standard red flashers; one, two, or three white strobes were much more conspicuous than standard flashers. Multiple add-on strobes significantly improved the conspicuity of standard flashers under both rural (noncompetitive background) and urban (highly competitive background) daylight conditions, and under nighttime urban conditions. There was some indication that irregular flash patterns and flash patterns that produced apparent movement improved the conspicuity of multiple strobes. Raab et al. (1977) also noted the potential of a flash pattern that simulates movement to attract the driver's attention.

Some field tests have supported the higher visibility of active warning devices equipped with add-on strobes, but have relied on subjective reports rather than quantitative measures of driver behavior (Hopkins and White, 1977; Bates, 1985). Heathington et al. (1988) upgraded two-quadrant flashing light signals at a crossing to four-quadrant flashing light signals with red strobes centered over each traffic lane, but found no effect on behavior. When four-quadrant flashing light signals with overhead red strobes were compared to flashing signals without strobes, there was no indication that strobes alerted drivers earlier to the crossing signal (Heathington et al., 1984). There is limited evidence that strobes mounted on gate arms facilitate detection of the active signal system. When Ruden et al. (1977) added a red, white, and blue strobe to the gate arm at a rural desert crossing, they reported earlier deceleration on the approach to the crossing in daylight, but not in darkness. On the basis of field test and laboratory results, Ruden et al. recommended the evaluation of two small white strobes, mounted on a gate arm, with a flash rate of at least 110 cycles per minute per light and an irregular flash pattern. They suggested that the add-on strobes would be more effective at urban crossings, where other lights compete for the driver's attention at night. When Russell (1974) added automatic gates to an active crossing, mounted six red strobes on the gate arms, and increased the size of the standard flashers to 12 inches, he observed slower approaches to the crossing than with the pre-existing system. However, the improvement in driver behavior was not necessarily due to alerting properties of the gate arm-mounted strobes; higher conspicuity of the automatic gates relative to standard flashers may have accounted in part or in whole for the result (e.g., Butcher, 1973).

Raab et al. (1977) have pointed out some possible drawbacks of using strobes to increase the conspicuity of active crossing signals. One disadvantage appears specific to crossings protected by flashers only: After the driver becomes alerted to the crossing signal, he should be attending to the train, and strobes may distract him from this task. To compensate for this problem, Raab et al. suggested that the strobe light housing be designed such that strobes appear brightest when viewed from directly in front on the approach, but appear less bright from the sides, to a driver stopped at the crossing. Ruden et al. (1977) reported that drivers approaching or stopped at an active crossing with add-on strobes did not appear to stare at the strobes, although only overt head movements were used as an index of driver eye fixation. A more precise measure of whether drivers were staring at the strobes would be required to assess the validity of Raab et al.'s objection. Raab et al. considered, but could not recommend, the addition of one white strobe to the top of the crossing signal post, because it would divert driver attention from the red flashers which convey the message to stop for trains. They instead recommended that red strobes be substituted for conventional flashers at active crossings. However, given that xenon light has limited output in the red portion of the spectrum, and the laboratory finding that standard red flashers were more conspicuous than a pair of red strobes (Ruden et al., 1977), the sole use of red strobes may not improve the detectability of crossing signals. The use of light red lenses for the strobes would not attenuate their output as much as dark red lenses would (Hopkins and Holmstrom, 1976). Finally, Raab et al. recommended that strobe lights visible to the driver be restricted to use on highway warning signs and public safety vehicles; otherwise, wide usage in advertising signs may reduce their effectiveness as warning signals. This suggestion is supported by Brown and Cole's (1969) conclusion that irrelevant background lights reduce the detectability of signal lights, particularly if the flashing of irrelevant lights is not obviously different from the flashing signal. The issue of whether strobes will maintain their alerting advantage over standard flashers with more extensive use is an important one, and long-term installations of crossing signals with add-on strobes should be evaluated.

The addition of safe-to-proceed indicators to active crossing signals has been proposed to increase the conspicuity of unactivated signals, especially at night. This measure is intended to bring about earlier detection that the crossing is safe, by providing the driver with a clear signal to discriminate between the absence of trains at or approaching the crossing and a signal failure. The signal also indicates the presence and location of the crossing, and that the active crossing device is operating (Mortimer, 1988; Shinar and Raz, 1982). Another function is to facilitate the distinction between active and passive crossings, since the safe-to-proceed signal helps the driver to discriminate between the presence of an unactivated active warning device and the absence of an automatic signal (Hopkins and Holmstrom, 1976). Specific recommendations for safe-to-proceed indicators are discussed in section 5.4.2.

Hopkins and White (1977) recommended that a steady amber signal be activated at the crossing for a brief interval prior to activation of conventional flashers. The proposed warning signal has the potential to facilitate detection of the activated red flashers, a function that can also be served by an active advance warning sign with amber lights that flash just before the active crossing signals are activated. The active advance warning signal may have the advantage of being detected earlier than the at-crossing signal, particularly if vertical or horizontal curves on the approach, or other obstructions, limit visibility of the crossing signal.

Highway traffic control signals have received consideration as replacements for flashing light signals. In a 1985 NTSB report on passenger train and motor vehicle collisions, the point was raised that a steady red light may provide a stronger signal for the driver to come to a complete stop than the standard flashing red light. Moreover, the green signal can be activated after the train has passed, so that the driver is no longer responsible for determining when it is safe to proceed. The amber light can serve as advance warning for activation of the red signal. Because of their experience with traffic signals at highway intersections, drivers will recognize blank signals at the crossing as a malfunction indicator (Heathington et al., 1988). Butcher (1973) noted that one rationale for using highway traffic signals at crossings is that drivers pay more attention to these devices than to flashing light signals. However, with regard to conspicuity or ability to attract the driver's attention, highway traffic signals have not been demonstrated as superior to standard flashing signals. In an outdoor laboratory test, Heathington et al. (1984) evaluated the effects of highway traffic signals on driver crossing behavior, relative to other active warning prototypes. One or three white bar strobes were placed in the 12-inch red lenses of the traffic signal, and flashed at the rate of 60 times per minute when the red signal was illuminated. The highway traffic signal conditions were always in the group of active signal conditions associated with the longest PBRT's. In fact, when the stop-for-train signals were activated, and the driver was 330 feet or 670 feet away from the signals, highway traffic signals produced significantly longer PBRT's than four-quadrant flashing light signals. When Heathington et al. (1988) field-tested highway traffic signals, similar in design to the ones previously studied, they found no significant changes in PBRT, speed profiles, or maximum deceleration rates in response to highway traffic signals, relative to pre-existing standard flashers. Although highway traffic signals were superior to standard flashing signals on measures of safe crossing behavior, such as the number of vehicles crossing within a short time of the train's arrival, their conspicuity was not demonstrably higher.

Raab et al. (1977) argued against the use of highway traffic signals at crossings for the following reasons: The effectiveness of the traffic signal per se will not be maintained once it is placed in the context of a crossing signal system; highway traffic signals lack the redundancy that alternating flashers have; in practice, extinction of the red light, rather than illumination of the green light, can serve as the all clear signal, and so the green light is unnecessary. The problem of redundancy could be readily solved by using multiple highway traffic signals; for example, when Heathington et al. (1984; 1988) evaluated highway traffic signals, they used both cantilevered and post-mounted signals on each approach. The potential benefits of a safe-to-proceed signal were discussed earlier in this section. The issue of whether traffic signals will become less effective when they are paired with crossbucks at crossings has not been addressed. Raab et al. favored adaptation of the crossbuck as a train-activated crossing device, over other active warning signals. Alternating red flashers would be mounted in the arms of the crossbuck, or in the arms and center, and the supplementary message "STOP WHEN FLASHING" would be placed below the crossbuck. One disadvantage of the flashing crossbuck, noted by Raab et al., is that red flashers may be less conspicuous when viewed against the crossbuck than against the black discs used to improve background contrast in standard flashing signals.

Ideas for improving the conspicuity of gate arms have included four-quadrant systems with and without skirts (Heathington et al., 1984; 1988), and the use of such materials as metalized mylar and light tube material in the construction of gate arms (Peterson and Boyer, 1977). When they reviewed crossing signal practices in Germany, Heathington et al. (1981) reported that the majority of gate systems were four-quadrant systems, many of which utilized skirts. A direct comparison of four-quadrant gates with and without skirts revealed no significant differences between the two systems in PBRT, or maximum deceleration rate (Heathington et al., 1984). Moreover, when four-quadrant gates with skirts replaced two-quadrant automatic gates in a field test, the experimental system did not lead to lower PBRT's or approach speeds, or more gradual deceleration rates (Heathington et al., 1988). Thus, limited data on four-quadrant gate systems with skirts do not support their higher conspicuity, in comparison to two-quadrant systems. The use of add-on strobes to improve the detectability of gate arms was discussed above.

In summary, most studies of designs to improve conspicuity of active warning devices have focused on parameters of flashing signals and strobes, and on the use of strobes to supplement standard flashers. Although the effect of individual parameters, such as color and flash rate, on the detection of light signals and strobes is fairly well understood, there is little objective evidence from field tests that optimizing these parameters increases the alerting potential of active warning devices. Whether strobes will maintain their attention-getting properties with more widespread use is unknown. Safe-to-proceed indicators, amber lights that signal imminent activation of red flashers, enhanced gate systems, and highway traffic signals to replace flashing signals have been proposed, but have received limited attention. Active advance warning devices may be more readily detected by drivers than an at-crossing advance warning light. One study indicated that highway traffic signals may be less conspicuous at a crossing than four-quadrant standard flashing signals (Heathington et al., 1984). The addition of skirts to four-quadrant gate systems did not appear to improve their conspicuity, although the higher conspicuity of gate systems per se, relative to highway traffic signals and standard flashers, may outweigh any improvements that can be achieved by adding features like skirts or strobes to gate arms.

One caveat should be noted regarding field studies that have not shown improved driver behavior as a result of some signal conspicuity enhancement. The logic of measuring vehicle speed profiles, PBRT, deceleration, etc., is that the improved devices will be noticed and responded to earlier. The absence of significant changes in driver behavior could be due in part to the drivers not responding immediately to the noticed device, but rather relating braking and slowing to the site geometry itself. More basically, however, conspicuity is related to the probability, as well as speed, of detection. A few drivers may simply fail to notice the signals, and these are the motorists at greatest risk. The primary safety effect of enhanced signal conspicuity countermeasures may be in reducing the probability of such an event. However, since this sort of severe perceptual failure may be relatively infrequent, countermeasure effects may be difficult to detect in the field.

5.2.6 Trains

Countermeasures for increasing the conspicuity of trains vary, depending on whether one is addressing the problem of detecting a train at the crossing, or before it reaches the crossing. Analyses of crossing accident data indicate that in about 10% of all crossing accidents, the driver could have stopped safely if he had detected the train when it was at the crossing (McGinnis, 1979; Schoppert and Hoyt, 1968). This type of accident can be targeted by increasing the visibility of trains at, or about to enter, the crossing; illumination of crossings and reflectorization of railcars have been proposed as countermeasures (McGinnis, 1979; Mortimer, 1988; Poage, Pomfret, and Hopkins, 1982; Sanders et al., 1973). On the other hand, in the majority of crossing accidents, the train was still approaching the crossing when the driver was at his decision point, and the most frequently recommended measures include improving quadrant-sight distance and using on-train illumination devices or painting schemes to increase train conspicuity (Berg et al., 1982; Hopkins and Newfell, 1975; Aurelius and Korobow, 1971). Reconstructions of where the train was when the driver was at his decision point are subject to inaccuracies (e.g., Sonefeld, 1979); moreover, it is difficult to ascertain whether a given accident was primarily due to a detection or recognition failure, as opposed to a decision error (see discussion in section 3.4.1). However, even if failing to detect the train in sufficient time was not a primary factor in a given accident, increasing the probability of detecting trains sooner has the benefit of giving drivers more decision time. The major categories of countermeasures for improving train conspicuity are discussed below.

Illumination of the Crossing

Passive crossings appear to be stronger candidates for the benefits of illumination than crossings with active warning signals. In a before-and-after evaluation of illumination at crossings in Houston, Texas, an 85% reduction in mean accident rate was observed at passive crossings, compared to a 13% reduction for active crossings (cited by Russell and Konz, 1980). Knoblauch et al. (1982) estimated that, at passive crossings, about one-quarter of all accidents attributed to driver recognition error involved late recognition of a train already at the crossing. A primary contributing factor in these cases was limited visibility due to darkness, a problem that can benefit from crossing illumination.

In their list of conditions under which illumination can be effective, Tustin et al. (1986) included the following: nighttime train activity; low train speeds; blockage of crossings for long periods at night; accident history of drivers failing to detect trains or warning devices at night; horizontal or vertical curves on the approach, such that the train is not illuminated by vehicle headlights until after the vehicle has passed a safe stopping sight distance; restricted stopping sight distance in rural areas; low ambient light levels. Tustin et al. recommended that at least one lamp be positioned on each side of the track, and that a distinctive color or distribution of illumination be used to distinguish crossing lamps from street intersection lamps. Russell and Konz (1980) also suggested the use of a distinctive color, such as that of high-pressure sodium lamps, following similar recommendations that emerged from field studies of crossing illumination in Oregon and Lincoln, Nebraska (Russell, Pelter, and Mather, 1979, cited in Russell and Konz, 1980). Based on subject rankings of lighting conditions at scale-model crossings, Russell and Konz (1980) concluded that lighting boxcars from the far side of the tracks (silhouetting) was ineffective. The impact of different lamp positions on the detectability of trains is unknown.

At rural crossings, particularly those with high train speeds, installing lights along the tracks, as well as at the crossing, may help to illuminate a train about to enter the crossing (Russell and Konz, 1980; Tustin et al., 1986). However, no quantitative data were available to support this recommendation. Other variations on crossing illumination have been proposed, but not evaluated: train-activated, rather than continuous, illumination (Tustin et al., 1986; Butcher, 1973); flooding the crossing with alternating red and white lights, in areas with no competing background lights (Peterson and Boyer, 1977); street lighting on crossing approaches (Tustin, 1985); wheel-level illumination on the far side of the crossing (Sanders et al., 1973).

In summary, crossing illumination has been shown to reduce the frequency of accidents at passive crossings at night, presumably by facilitating detection of trains at the crossing. An added benefit of illumination is alerting drivers to the crossing and its features. However, systematic comparisons of different sources, intensities, numbers, and positions of lights at crossings and their impact on train detectability have not been conducted.

Reflectorization of Railcars

Adding reflectors to the sides of railcars can increase the conspicuity of trains, but their effectiveness is limited to trains at, or about to enter, the crossing. McGinnis (1979) examined the conditions under which high-intensity reflectors would be detectable as cues for the presence of a train. First of all, unreflectorized railcars, illuminated by low-beam headlights, are not likely to be visible at an adequate distance for safe stopping, even for a vehicle traveling at 20 mph (McGinnis, 1979). Since a large percentage of drivers may not use high-beam headlights when it is appropriate to do so (Hare and Hemion, 1968, cited in McGinnis, 1979), it is important that reflectors be detectable under low-beam headlights. McGinnis calculated that a reflector (.25 feet square), located one foot above the plane of headlights at a 90-degree intersection, is likely to be visible from 500 to 1,000 feet in front of a vehicle with low-beam illumination, and from 100 feet to the right and 50 feet to the left of the projected path of a vehicle. Factors that increase the probability of train detection include appropriate spacing of reflectors, so that more than one reflector is in view at the same time, and observing reflectors on a moving train. However, raising the position of reflectors on railcars decreases their visibility range under low beams, and vertical curves on the approach roadway may further increase the vertical separation between the headlights and the reflector. In addition, intensities of reflectors decrease rapidly as a function of their lateral distances from the headlight axis, and, for this reason, Lepkowski and Mullis (1973) recommended increasing the contrast between reflectors and their immediate background. Other variables that reduce the visibility of reflectors are adverse weather conditions, such as fog and haze, and the rapid degradation of the reflective intensity of reflectors due to accumulation of dirt (Poage and Hopkins, 1983). Finally, reflectors will not be illuminated by headlights at an adequate stopping distance, when crossing visibility is restricted, due to visual obstructions or the roadway-crossing alignment.

Leibowitz and Owens (1986) recommended that trains be required to show reflective materials at night, to help compensate for reductions in visual acuity that occur under low illumination levels. Since 1959, a reflectorization program has been in effect for Canadian freight cars; however, an estimated 20% of cars in Canadian trains are owned by U.S. railroads, and are not typically reflectorized (Poage and Hopkins, 1983). A Wisconsin state law, enacted in 1971, has required the reflectorization of all train cars built or repaired in Wisconsin. Some railroads have voluntarily reflectorized railcars--for example, as of 1981, Santa Fe had added 6-foot-square reflective panels to an estimated 20,000 new and rebuilt units ("NTSB Report on The Improvement of Nighttime Conspicuity of Railroad Trains", 1981). One problem in evaluating the effectiveness of reflectors is that reflectorized and unreflectorized equipment is typically combined to form trains that are not 100% reflectorized (NTSB Report, 1981).

Specific parameters of reflectors that may enhance train conspicuity, such as spacing and size, have not received much attention. Lepkowski and Mullis (1973) proposed that the spacing of reflectors be determined by the widths of grade crossings. Assuming a 30foot width for a "typical worst case" passive, rural crossing and an average 50-foot width for a railcar, they estimated that each railcar would require a minimum of two reflectors in order to be visible if the car was stopped at or moving through the crossing. Lauer and Suhr (1956) presented evidence that drivers are better at detecting simulated reflectors when the same area of reflective material is concentrated in a few reflectors per car, than when it is widely distributed as eleven reflectors along the sill of the car. An analysis of effective reflector area as a function of washing interval was undertaken by Poage and Hopkins (1983). Reflective intensity of engineer-grade reflectors on Canadian freight cars was observed to deteriorate rapidly because of dirt accumulation. For example, a reflector's reflective intensity declined to 14% of its original value after only one year in service. Poage and Hopkins concluded that the area required for reflectors will increase as a function of washing interval. They estimated that a reflector area of 1.5 feet square would be sufficient for a one-year wash interval, with reflector replacement after 10 years; for a wash interval of two years, the reflector area would have to be increased to more than 3 feet square. Thus, adequate maintenance of reflectors is necessary for their continued effectiveness after installation, and frequency of washing must be considered in determining adequate reflector size. Poage and Hopkins also had observers rate the visibility of reflectors on freight cars passing through crossings at night. When subjects were expecting trains to pass, and viewed them under high-beam illumination, 61% of reflectors were judged as barely visible or not visible at all.

In summary, reflectorization can improve the visibility of trains at the crossing, even under low-beam illumination. However, reflective intensity of reflectors has been found to deteriorate rapidly with the accumulation of dirt, and so washing intervals have an impact on the minimum detectable reflector size. Estimates of reflector visibility have been based on measurements of the reflective intensity of reflectors on stationary freight cars, and on FAA standards for the detection of lights in darkness. The extent to which reflectors on moving trains are detectable by drivers, who are approaching a crossing and have a low expectancy of trains, is unknown.

Reflectorization of Trackside Objects

Reflectorizing the backs of crossbucks or other crossing hardware on the far side of the tracks has the potential to increase train conspicuity, because passage of railcars would intermittently break the reflected light from a vehicle's headlights. The resulting flashing effect would serve as an attention-getting cue for the presence of a train. Schoppert and Hoyt (1968) proposed this countermeasure for use at 90-degree crossings, since more acute crossing angles (less than 80 degrees) would cause the flashing effect to be obstructed by the train. This treatment is thought to be effective for train speeds higher than 30 mph, but not for very slow-moving trains, which represent a greater hazard at night.

On-Train Devices

On-train devices -- such as oscillating headlights, roof-mounted xenon strobe lights, outline lights, illuminated panels on the sides of railcars, and areas of contrasting colors -- have been proposed as measures to improve the conspicuity of an approaching train. Because of its narrow beam width, the standard locomotive headlight is not readily visible during the day, unless the driver is stopped at the crossing (Aurelius and Korobow, 1971; Mortimer, 1988). The probability of detecting the headlight is higher at night than during the day, if atmospheric conditions like rain or fog scatter the light in different directions to make it more visible, or if the headlight illuminates trackside objects (Mortimer, 1988). However, Hopkins and Newfell (1975) have estimated that horizontal beam widths must be as wide as 150 degrees to be visible from most viewing angles, and under conditions in which the ratio of vehicle speed to train speed is high. They recommended horizontal beamwidths of 360 degrees for roof-mounted xenon strobe lights. Oscillating headlights, consisting of one or more standard headlights mounted on a plate that moves in a figure eight, circular, or oval pattern, have been used (Tustin et al., 1986). However, the effectiveness of the spatial sweep of the oscillating headlight, relative to fixed headlights with wider beam widths, is unknown.

Because the standard locomotive headlight is not readily visible from viewing angles likely to be in effect when the driver approaches a crossing, other on-train warning light systems have been proposed. A pair of alternately flashing, roof-mounted xenon strobes may be detectable from larger viewing angles, and at greater distances, than the standard headlight, but much of the evidence supporting their effectiveness consists of subjective judgments of conspicuity (Hopkins and Newfell, 1975; Devoe and Abernethy, 1975; Aurelius and Korobow, 1971; Sanders et al., 1974, cited in Hopkins and Newfell, 1975). Moreover, observers in these studies were expecting to see locomotives equipped with strobes, whereas, under normal driving conditions, drivers often do not expect to encounter a train, and do not have advance knowledge of what cues to look for. Therefore, the reliability and validity of these results, and their generalizability to normal crossing conditions, are questionable. Potential benefits of strobe lights for train detection, that emerged from subjective observations in the Devoe and Abernethy study (1975), include the following: At a distance of several miles, flashing strobes were reported to be visible in the form of a pulsating environment, well before they were detectable as points of light; the pulsation of strobes was detectable in peripheral vision, an important advantage for detecting an approaching train at night; when strobes illuminated reflectorized highway signs and license plates on either side of the tracks, the reflected light appeared to serve as an additional cue for the train's approach. It is not known whether the pulsation effect of strobes, or the pattern of illumination of reflectorized trackside objects by strobes, is distinctive in appearance from the effects of other potentially distracting sources of illumination near the crossing.

Other suggestions for on-train warning light systems include amber incandescent outline lamps, and internally illuminated panels located on the sides of locomotives. Hopkins and Newfell (1975) proposed that outline lights be located at the front corners, and along the top and side frame of a locomotive, for a distance of at least 40 feet from the front of the locomotive, at 12-to 20-foot intervals. Outline lights have been installed on a trial basis (Hopkins and Newfell, 1975), but their effectiveness in improving train conspicuity has not been demonstrated. Schoppert and Hoyt (1968) pointed out that illuminated panels on the sides of freight trains may make them more conspicuous at night, by simulating the appearance of illuminated windows in passenger cars. Passenger cars appear to be more detectable at night than freight trains. When Sanders et al. (1974, cited in Hopkins and Newfell, 1975) evaluated a number of warning light systems installed on a locomotive, strobe-illuminated panels were given low conspicuity ratings. Aurelius and Korobow (1971) had observers rate photographs of scale model locomotives displaying various warning light devices. The criteria used by observers to judge the effectiveness of devices were not specified. Aurelius and Korobow concluded that one-foot-by-six-foot illuminated panels, mounted above or below the cab windows, along with omni-directional roof-mounted strobes, had the most potential for alerting effectiveness.

Reflective side panels and color schemes for trains have been recommended to increase their contrast with the surrounding area (Sanders et al., 1973; Aurelius and Korobow, 1971; Mortimer, 1988). Painting schemes have involved contrasting areas of light fluorescent colors and dark colors. Mortimer (1988) suggested painting each railcar with three horizontal bands of color, each 5 feet in height, in order for the band of color to be detectable at a distance of 1,000 feet. A bright yellow middle band would provide good contrast against dark backgrounds, while dark upper and lower bands would provide good contrast against bright backgrounds. Mortimer pointed out that illuminating the central section with lamps on the side of the locomotive would improve its detectability at night.

In summary, the standard locomotive headlight is inadequate as a cue for an approaching train, under typical viewing conditions. Evidence supporting the effectiveness of roof-mounted xenon strobes consists primarily of subjective judgments of conspicuity, made by observers who were expecting to see a strobe-equipped train. The conditions under which roof-mounted strobes may facilitate detection of an approaching train under normal crossing conditions have not been systematically investigated.

The alerting effectiveness of alternative on-train auditory warning signals has received little study, perhaps because of practical limitations on the level of signal intensity that will be tolerated by nearby residents, and because a number of factors, such as physical barriers, wind, and background noise, attenuate the sound level at the ear of the listener. (Refer to section 3.2.8 for a discussion of constraints on the effectiveness of auditory train signals.) Specific recommendations have been made for improving the detectability of railroad horns, but there appears to be consensus that auditory signals cannot adequately serve as primary warning devices.

Aurelius and Korobow (1971) found that existing railroad horns did not meet the performance levels required for reliable advance warning of drivers, when train and vehicle speeds exceeded 50 mph. For example, Amtrak air horns produced 109.5 dB of sound at 100 feet in front of the train, measured from a 90-degree angle, a level that just meets the estimated requirement of 109 decibels for a vehicle traveling between 51 and 65 mph. However, one must consider that, if a train's horn is barely detectable when it is only 100 feet from the crossing, or about a second from the crossing for a 60 mph train, it cannot alert the driver in sufficient time for him to stop. Moreover, even higher horn levels may be required to compensate for the sound-attenuating effects of higher winds or higher levels of background noise. Aurelius and Korobow made the following recommendations for the use of horns: a five-chime high-output horn should be adopted, because its multiple frequencies help to make it distinctive from masking sounds; horns should be located on a high point at the front of the locomotive; where auditory warning signals must serve a primary alerting function (e.g., at crossings with severe visibility restrictions), highway approach speeds should be low.

Based in part on Aurelius and Korobow's findings, a 1985 NTSB Safety Study of Passenger/Commuter Train and Motor Vehicle Collisions at Grade Crossings concluded that current FRA standards for horn performance levels were inadequate, and recommended that they at least be raised to the decibel warning levels associated with the Amtrak train air horns. The Safety Board also proposed that truck drivers be informed of the unreliability of train horns as advance warning signals, and be advised to roll down their windows, and turn off radios and CB units, when listening for trains at passive crossings. Cox (1972) suggested that all drivers be required to lower their windows and reduce their speed when approaching crossings. The recommendation to roll down the vehicle window to make the train horn more audible does not seem realistic, and may actually lead to vehicle-vehicle collisions. Cox also made the point that a horn signal that is focused towards the crossing, rather than projected over 360 degrees, may have a higher peak intensity and be less disruptive to local residents.

5.3 PERCEPTION

Countermeasures for improving perceptual judgments at crossings can target either the driver's visual judgments of his own vehicle's speed and distance from the crossing, or of the train's speed and distance. Studies discussed in section 3.3 indicated that drivers can be inaccurate at judging their own speeds, may not take sufficient account of the speed of on-coming vehicles, and are likely to underestimate train speed and overestimate the distance of trains from the crossing. The principle behind proposed countermeasures is to make the driver's perceptual judgments more accurate or more conservative, sometimes by utilizing built-in perceptual biases to counteract the unconscious perceptual illusions that can lead to misjudgments.

5.3.1 Perception of Own Vehicle Speed and Distance

Where a signal or stop sign requires a driver to stop at a crossing, perceived speed and braking distance are important, as in any stopping situation. At passive crossings where a driver is not required to stop, perception of the speed of one's own vehicle becomes a more significant consideration. The judgment about whether one can beat an approaching train requires an estimate of the time of arrival of both the vehicle and the train. Some have suggested the use of perceptual illusions to "trick" the driver into sensing that he is going faster than is actually the case (e.g., Schoppert and Hoyt, 1968; Hulbert and Burg, 1968; Peterson and Boyer, 1977).

Suggestions include progressively decreased spacing of transverse lines, modifying the size of signs or markings to make them appear nearer, and the spacing and density of roadside objects. The logic behind these countermeasure ideas is that if the driver perceives himself as going too fast, or as being nearer the crossing, he may decelerate more and sooner. In other highway safety applications, the use of perceptual illusions has been generally effective in reducing speeds (e.g., Triggs, 1988; Warren, 1982). However, the magnitude of this effect appears to diminish with time, and in some studies the speed reductions appeared quite minor (e.g., Zaidel et al., 1986). No studies of driver behavior at rail-highway crossings were found which employed speed/distance perceptual illusions. Where the crossing is actively protected, or is stop-sign controlled, this application parallels other applications (intersections, end of roadway) where such treatments have been found to improve driver behavior. However, the logic of this type of countermeasure for passive crossings must be questioned. While a slower approach speed may be desirable, the distorting perceptual effects may disturb the driver's judgment of the likelihood of collision of two moving objects, his vehicle and the train. While the effects of this altered perception are not known, perceiving one's vehicle as moving faster or being closer to the intersection could actually encourage the driver to try to beat the train across the tracks. Thus countermeasures aimed at altering the driver's perception of his speed must be viewed skeptically for grade crossing applications.

5.3.2 Perception of Train Speed and Distance

Although several methods for improving the accuracy of train speed and distance judgments have been proposed, they have not been systematically tested. Since apparent velocity is known to decrease as a function of increasing target size, Leibowitz (1985) suggested a method for increasing the perceived velocity of the large target represented by a train. The more the reflexive visual system is involved in executing smooth eye movements in automatic response to a moving target, the slower the perceived velocity of the target. Leibowitz suggested that the presence of special markings or lights on trains may reduce involvement of the reflexive system, in favor of the voluntary system that controls pursuit eye movements, and thereby increase perceived velocity. However, Leibowitz did not provide specific examples that might be used. A second mechanism which contributes to underestimations of train speed is that, at the distances at which train speed must be judged, the rate of growth of the expansion pattern on the retina is slow (Leibowitz, 1985). The implication is that a measure which somehow exaggerates the looming appearance of the train, even when it is relatively far from the crossing, will make judgments of train speed more accurate. For example, a light pattern projected from the front of the train, that regularly radiates outward in concentric circles, may increase the train's perceived velocity. The flashing effect created by this light source may have the added advantage of increasing train conspicuity per se.

Since the apparent convergence of railroad tracks may help to create the illusion that the train is farther from the crossing than it really is, the addition of cues to counteract the depth cues associated with distance may be helpful. For example, the contours of the track bed can be made to diverge from the vantage point of the crossing, by gradually widening the textured surface on either side of the rails. This treatment might be most effective under daytime conditions at crossings where rail-highway alignment permits uptrack visibility of the tracks. There is some indication that a blue light appears closer than it actually is, while a red light appears farther, and so a blue light may make the train appear closer to the crossing. (See discussion in section 3.3.3.) Although this measure might be most effective at night when other cues for the train are absent, the magnitude of the effect may not be large enough to have an impact on distance perception.

Meeker and Barr (in press) presented evidence that drivers are fairly accurate at judging train speed and distance, and the time until train arrival. For example, they found that the probability of crossing in front of an approaching train increased as a function of the time until train arrival, and as a function of the distance of the train from the crossing. They concluded that, when a crossing afforded an unobstructed view of the tracks, estimates of safe time intervals for crossing ahead of the train did not appear to be a problem for the driver. Meeker and Barr's dependent measures may not reflect any perceptual biases that may have contributed to their drivers' decisions to cross ahead of the train; moreover, their results are based on a small sample of drivers, and so may not be reliable. Meeker and Barr suggested that the flashing rate of active warning signals increase as the train gets closer to the crossing, to help drivers estimate the time available before train arrival. However, the driver would be required to learn the precise correspondence between changes in flash rate and the distance of the train from the crossing, in order to effectively utilize this crossing cue.

In summary, measures proposed to counteract perceptual factors that distort judgments of vehicle and train speed and distance have not been tested in crossing situations, and so the magnitude of the perceptual effects and potential safety benefits are unknown.

5.4 DECISION MAKING

Decision making problems concern the manner in which the driver deals with the information available to him in a rail-highway crossing situation. Issues involve the kind of information presented or not presented, its credibility, when and where it occurs, and what the results of alternative decisions will be. Many different countermeasure ideas have been offered in terms of information and decision making. For convenience of discussion, these countermeasures will be categorized into five groups: enhanced information content in advance warnings; enhanced information content at the crossing; information credibility; the distribution of information; and the "costs" of alternative actions.

5.4.1 Enhanced Information Content: Advance Warnings

The standard railroad advance warning sign (W10-1) provides an indication that there is a crossing ahead. No other information is conveyed to the driver. Many authors have suggested that driver decisions and actions could benefit from additional advance information. The various types of additional information are discussed below.

Active vs. Passive Crossing Warnings

Probably the most frequently mentioned improvement would be to discriminate active from passive crossings. As illustrated by Figure 2-2, and repeatedly noted in the literature, drivers must take different actions depending upon whether they are approaching an active or passive crossing. Although the case for this accident countermeasure was made strongly by Schoppert and Hoyt in 1968, recommended repeatedly by others since then, and is standard practice in a number of other countries, it does not appear ever to have been fully evaluated. For intersection-related advance warnings, the parallel distinction between signal, stop, and yield controlled intersections is reflected in unique advance signs for each case. The logic and needs are similar for the grade crossing situation.

The use of only one type of advance warning may contribute to a driver's failure to recognize that different driver actions are called for at different crossings. Even where the driver is fully aware of the importance of the distinction, the only means for identifying the crossing type is to detect the lamp housings, or their absence, at the crossing itself. This clearly is a cue without conspicuity or discriminability. Educational and other countermeasures designed to get drivers to do more looking or to reduce approach speed may be hindered if drivers find such behaviors superfluous, either because they fail to appreciate the active/passive distinction, or because they cannot make the discrimination on the road.

Design suggestions for advance signs for active crossings have been presented by Schoppert and Hoyt (1968) and Ruden et al. (1982), among others (sometimes in conjunction with active advance warning systems). Sign content suggestions include images of red lamps, verbal messages, color coding, and adjacent active signals. Examples of foreign practice (e.g., Heathington et al., 1981; Hopkins and White, 1977), such as European standards, discriminate active and passive crossings diagrammatically. For example, Shinar and Raz (1982) show a locomotive silhouette (on a triangular field) as the advance warning for a passive crossing; the same image with a red dot added to indicate flashing light protection; and an image of a gate (with a red dot) to indicate automatic gate protection.

The effectiveness of distinct advance signs for different crossing types in actually altering driver behavior may be difficult to evaluate, because its full effect may not be realized until such practice is widespread and reliable. Nonetheless the argument for this practice can be made simply because it provides an item of information that the responsible driver requires, and does not now get, which can be readily and clearly provided to him.

Active Advance Warnings

Active advance warnings may use flashing beacons, illuminated signs, strobes, variable message signs, etc. These have been discussed previously. The active advance warning provides enhanced information over typical current practice only in that it provides the information sooner, so that the driver (particularly where sight distance is limited) can adjust his behavior and expectancies more appropriately. The active advance warning sign can also be viewed as a special case of a device for discriminating active from passive crossings.

Another possible countermeasure that might be mentioned under the heading of "active advance warnings" is the optically programmed signal. While located at the crossing, this may be considered an advance warning in that a signal head can be specifically programmed to provide information to distant vehicles (providing sight distance is adequate). This countermeasure is discussed further in Section 5.4.4.

Sight Distance and Search Behavior

Many authors have noted the deficiencies in typical driver search behavior, and have suggested advance signs to facilitate proper search. One strategy is to indicate the need to search, through a description of the problem: "hidden crossing," "blind crossing," "view of trains limited," "limited sight distance," or even a pictorial sign (e.g., Knoblauch et al., 1982; Lunenfeld and Powers, 1985; Schoppert and Hoyt, 1968). Another strategy is to explicitly state the need to search: "look for trains" (e.g., Lunenfeld and Powers, 1985; Schoppert and Hoyt, 1968). Others have emphasized that signs should indicate where and when to search, in particular for sites with limited visibility (e.g., Schoppert and Hoyt, 1968), or which illustrate the crossing geometry at sites with acute crossing angles that require more deliberate looking (e.g., Knoblauch et al. 1982). Mortimer (1988), noting that drivers often search in only one direction, suggested signs that indicate the need to look in both directions.

The logic behind using signs such as these as countermeasures is that driver performance appears to be quite poor in this respect, and that drivers appear to be relatively unaware of the existence of sight restrictions. However, there is reason to be somewhat skeptical of their effectiveness, particularly over the long term. They may be useful to the motorist unfamiliar with the site, but familiar drivers typically represent the bulk of the accident cases. For these drivers, the signs might only serve as a "reminder," which may lose its effectiveness over time. In fact, in their field study, Parsonson and Rinalducci (1982) actually found a worsening of "looking" behavior after the installation of "hidden Xing" and "look for train" signs as part of their positive guidance demonstration project. Furthermore, in other highway contexts, the effectiveness of "limited sight distance" signs has been questioned; in fact, the section on this sign (2C-39) was dropped from the Manual on Uniform Traffic Control Devices in 1985. Freedman, Staplin, and Decina (1985) found in a field study that neither the "LIMITED SIGHT DISTANCE" sign nor alternative "improved" sign versions for this message had any appreciable effects on traffic speed or braking. However, there was some indication that drivers did show more awareness of the hazard. For the railroad crossing situation, the use of signs related to visual search may merit consideration because they address a real limitation in driver behavior, but pending further research, there is reason to be skeptical of the ultimate level of effectiveness that may actually be achieved.

Approach Speed, Path, Braking

Drivers may approach a crossing at a speed that does not permit adequate decision sight distance or stopping distance. They may also be unaware of the roadway geometry, which could interfere with effective visual search for trains. Some authors have suggested providing the driver with explicit information regarding these vehicle control aspects. Speed control information includes advisory speed signs, regulatory speed signs, or warnings to reduce speed (e.g., Knoblauch et al., 1982; Tustin et al., 1986; Schoppert and Hoyt, 1968). Tidwell and Humphreys (1982) argued that a regulatory speed sign may be more effective, since it can be used to designate "the point where the lowered speed is needed for effective looking." In contrast, the advisory speed plate is generally used in advance of the point (hazard) at which the lower speed is required, e.g., in advance of a curve. Thus it is not spatially precise for application to the problem here. However, one might question whether motorists are actually sensitive to this distinction in the use of advisory and regulatory speed signs.

Sanders et al. (1973) included the countermeasure suggestion of indicating the distance to the crossing. Shinar and Raz (1982), illustrating Israeli practice, showed markers that code the distance to the crossing: Three stripes indicate 250 meters to the tracks, two stripes indicate 170 meters, and one stripe indicates 100 meters. The degree to which drivers might make use of this distance information is unclear. However, it might be argued that the information the driver really needs is not distance per se, but decision sight distance or stopping sight distance. These, after all, are the critical distances in terms of vehicle control and collision avoidance. It is conceivable that new markings or signs could be developed to convey this information to drivers; however, no discussion of this concept was found.

Ruden et al. (1982) argued for including a directional arrow to indicate the roadway path as an integral part of the advance warning sign. This would indicate to the driver where to anticipate the crossing. In laboratory tests, subjects were found to comprehend the meaning of these directional arrows. However, the effectiveness of this information in improving driver performance, and any advantage over the use of an independent curve warning sign or a supplemental sign plate, is not known.

Train Operations

Hulbert and Burg (1968) felt that a driver's expectancy about trains could be modified at least in part by signs or markings describing train operations at the crossing. These devices could indicate "the average speed and relative frequency of train traffic at each crossing." However, it is not entirely clear how this would benefit overall driver behavior at rail-highway crossings. If some crossings were highlighted as carrying significantly more or faster train traffic, perhaps drivers would respond with more caution. However, it would be reasonable to also suppose that there would be decreased caution at the larger number of sites that would appear relatively "safe." The same argument might be made for signs at crossings that indicated the periods of high train use. Since accident and field observational data suggest that it is the familiar driver -- who presumably has the most accurate expectancies about train operations -- who drives least safely, explicitly providing information on train operations appears a questionable strategy.

In summary, standard advance warning information is very limited in content. Enhancements may improve driver decision making, and a variety of ideas have been suggested. Of these, distinguishing active from passive crossings meets a general driver need, and would be consistent with practice in many other countries. Most of the other information enhancements would be potentially most useful on a site-specific basis, although their ultimate effectiveness is generally not known. To the extent that multiple additional messages are provided, there must be concern with information overload and distraction from other tasks and messages. Section 5.4.4 addresses this concern further.

5.4.2 Enhanced Information Content: At Crossing

Currently the typical information provided at the crossing itself consists of: the crossbuck, which identifies the location of the crossing; an auxiliary sign indicating the number of tracks, if more than one; a stop line, indicating the hazard zone; a pair of flashing red lamps, if an active crossing, to indicate the approach or presence of a train; and the gate at automatic gate crossings. Supplementary signs may be included, such as an "Exempt" to inform special vehicles that a normally required stop is not required here, or "Do Not Stop on Tracks" sign where vehicles are likely to queue on the track.

A number of suggestions have been made for additional information which would aid or direct the driver. Most of these suggestions are specific to active crossings. Various countermeasure ideas are described below; some of these strategies overlap to a degree in terms of the information needs they are trying to address.

Safe To Proceed

While flashing red lights indicate that the driver must stop, the absence of the lights provides a more ambiguous message. The fact that the crossing is actively protected may not be obvious. There is no distinction between a safe condition and a signal failure. Some drivers may slow on approach, causing traffic conflicts. Both green lights (e.g., Mortimer, 1988) and flashing amber lights (e.g., Hopkins and Holmstrom, 1976) have been suggested. There are two potential disadvantages of using amber for the safe-to-proceed signal. If amber signals are placed in close proximity to standard red flashers, color-blind individuals may not be able to discriminate between the two colors and between their very different messages (Raab et al., 1977). In addition, since amber flashers have strong associations with a caution or slow message, their use as a safe-to-proceed indicator may be confusing to drivers. Therefore, a green rather than amber safe-to-proceed signal would be more consistent with driver expectations. A safe-to-proceed message may also be useful at multitrack crossings, as further protection against the situation where the first passing train obscures the approach of a second train (e.g., Butcher, 1973). However, the key to effectiveness for this scenario would be getting drivers to attend to the signal as opposed to the passing train itself. An explicit message regarding "two trains" has also been suggested (Butcher, 1973).

Malfunction Indicator

Some have argued that it would be useful to provide the driver with an explicit indication when the track circuitry is malfunctioning. Currently, the "fail safe" mode presents flashing red lights in a manner identical to when a train is approaching. Raab et al. (1977) proposed using an array of two vertically arranged amber flashers, as distinct from the horizontal array of red flashers. Some form of malfunction indicator would have the presumed advantages of: clarifying the hazard; removing the "false alarm" and eliminating the need for all traffic to stop when there is a malfunction; and clarifying for the driver that there is an explicit malfunction indication, so that the absence of flashing red lights is more clearly identified as meaning "safe." For the latter consideration, the malfunction indicator has an advantage over a safe-to-proceed signal in that it does not require constant power.

Signal Phasing

Hopkins and Holmstrom (1976) have drawn the analogy between a grade crossing signal and a highway intersection signal in which the green and amber displays have burned out. The unexpected onset of the red phase can lead to sudden braking, and to particularly variable driver actions (with resulting traffic conflicts) in the area of the crossing. An amber phase was suggested as a countermeasure. Another suggestion (Peterson and Boyer, 1977), discussed further in Section 5.4.4, uses a phased sequence of optically programmed signals. Of course, suggestions of these sorts make the grade crossing signal progressively more like the standard traffic signal. This raises the controversial problem of breeding motorist disrespect for traffic signals used in other applications. While the actual benefits of signal phasing at grade crossings are not clear, to the extent this idea is employed it may be beneficial to keep the actual signal displays distinct from traffic signals.

Train Direction

Because motorists often do not show good scanning behavior, and sometimes search in only one direction, it has been suggested (e.g., Mortimer, 1988) that an indicator be used to show the direction of approach of the oncoming train. Directional arrows are used for this purpose in some foreign countries (e.g., Haga, 1988; Heathington et al., 1981). Raab et al. (1977) even suggested use of a dynamic arrow display, as in sequential arrow panels used for construction and maintenance sites. Train direction information may not only improve search by reducing choice options, it may also be a means of informing the driver about the situation where trains may be coming from both directions on multiple tracks.

While train direction information would be helpful to the driver, some limitations of this concept may be noted. First, Raab et al. (1977) pointed out a potential confusion (which may be a particular concern for the dynamic arrow display). Does a left-facing arrow mean that the train is located to one's left, or moving toward the left? The direction of search will be different for either interpretation. Although the logical possibility of this confusion exists, it is not clear whether it would actually happen with significant frequency. Another potential problem of unknown significance concerns the case where trains are approaching from both directions. If the sooner arriving train activates one arrow, the driver may not continue to monitor the display, and so will be unaware when the second arrow goes on. Thus he might focus his attention in only one direction, and fail to see the second train. A final concern is whether the arrow application may be ambiguous, particularly at night or in limited visibility. For example, it could be taken to represent the roadway path, or lane closure (especially for the dynamic display idea). Such a misinterpretation could lead to serious errors. If train direction indicators are used, consideration should be given to making the appearance and meaning of the display unique and unambiguous.

Train Time, Speed, or Distance

At a rail-highway crossing, the driver deciding whether to proceed when a train is approaching faces a difficult perceptual judgment. Suggestions have been made to assist this decision by providing information about the train. For example, Meeker and Barr (in press) suggested that the rate of flashing of the signal be made to correspond to the time it will take for the train to reach the crossing. Sanders et al. (1973) suggested assisting the motorist in the estimation of train speed. Such supplemental information might be particularly useful at night or when visibility of the train is limited. While a variety of means for presentation of information to the driver about train characteristics could be offered, there are some potential problems with this countermeasure. It is not clear how drivers would use this information, and if it would cause them to be more or less cautious. What values subjectively connote "fast," "close," or "brief" to the typical driver? For example, would a 15-second gap time be viewed as adequate or inadequate? It would be quite important to understand how the additional information maps onto driver decisions. Another question is whether the presentation of such information would encourage approaching drivers to try to beat the train to the crossing; this is analogous to an approaching driver accelerating when a traffic signal turns yellow. It must be recognized that even though many drivers cross in front of trains, and allow less of a safety margin than may be desired, field studies indicate that very few of these crossings actually come very close to a collision. For example, while Meeker and Barr (in press) found that although two-thirds of drivers crossed in front of the train at a flashing signal, none of their 57 drivers crossed with less than 14 seconds of available time. Therefore even if additional information on train characteristics is often useful to the driver, if it does encourage risk taking in some situations this could result in a net loss in safety. Another possible problem is that where warning times are unduly long, signaling this fact could further reduce respect for crossing signals in general. A final point is that since the information needed to compute this message for the driver may be essentially the same as that needed for constant warning time systems, one must ask whether presenting such information is preferable to the use of a constant warning time system. If the warning time is fixed and reasonable, there is no need for indicating the train's speed or time to arrival.

Yield

The crossbuck at a passive crossing may not adequately inform the motorist of the appropriate actions and responsibilities. Although many drivers fail to slow down and search the tracks, studies described in Section 3.1 indicate that some drivers think that stopping is actually required. Because the crossbuck essentially functions as a yield sign, Schoppert and Hoyt (1968) argued for the inclusion of a more explicit "yield" message at crossings. These authors suggested incorporating the crossbuck itself into the yield sign field to better inform the driver of his obligations. While providing "yield" information or other messages related to driver responsibility might result in greater comprehension, any effects on general driver performance remain to be demonstrated.

In summary, several enhancements to information provided at the crossing have been suggested. These relate to appropriate driver actions, signal system status, and information about the approaching train. None of these appear to have clearly demonstrated behavioral, safety, or operational benefits, and so must be viewed somewhat skeptically at this point.

5.4.3 Information Credibility

In making a decision, the driver (with or without conscious awareness) will be influenced by the perceived credibility of the information he receives. This section addresses countermeasures which make the information more credible.

In a formal sense, signs for passive crossings do not have a credibility problem: They alert the motorist to the presence of a rail-highway crossing, which is in fact there. However, as warning signs, these TCD's carry the implication that there is a potential hazard, and that some driver action is warranted. The low frequency of encountering trains is the major credibility problem, particularly since sites with higher train and traffic volumes are more likely to be actively protected. Countermeasures appear limited, since the driver may have an essentially accurate perception. However, countermeasures can be suggested for some particular situations. First, the track should look like it carries rail traffic. If it appears unmaintained, overgrown with brush, and in poor condition, risks may appear negligible. Second, where a crossing is in fact abandoned, its existence contributes to the general expectancy of very rare conflicts with trains, particularly for local residents who may be well aware that the track is unused. At abandoned crossings, signs and signals should be removed, or at least covered (Coleman, 1980), to help protect general credibility.

For actively protected crossings, there are two primary causes for lack of signal credibility: extended warning times and false alarms.

The primary countermeasure suggested for unduly long warning times is the use of constant warning time (CWT) circuitry. Wider use of this technology has been recommended by numerous authors (e.g., Berg, 1985; Coleman, 1980; Bowman, 1987b; Raab et al., 1977). CWT circuitry uses the train's speed and location to determine when it will reach the crossing, and activates the signal or automatic gate when the estimate reaches a criterion time (e.g., 25 seconds away). In the absence of such circuitry, the train's distance from the crossing at which the signal is activated must be based upon the maximum timetable speed for the crossing, in order to provide adequate warning time for all trains. To the extent train speeds are variable, warning time will also vary. Extended warning times have been identified as a contributing factor in decision error accidents.

The general effectiveness of CWT on driver behavior and on accident rates has been demonstrated (e.g., Halkias and Eck, 1985; Heathington et al., 1988; Bowman, 1987b). Halkias and Eck's evaluation of before/after effects found that upgrading from fixed distance to CWT circuitry reduced accident rates by about 20% for flashing light sites and about 28% for automatic gate sites. Effects were greatest where there were large differences in train speed.

Bowman (1985) investigated the reasons why CWT systems were not more widely used. He concluded that the problem, at least in part, was that perceived problems of reliability, cost, and compatibility were based on outdated products. Bowman states (page 43) that: "Many of the problems that are identified in the literature are problems that existed with the early CWT models. The majority of these problems have been eliminated and are not more prevalent in the current CWT models than in any other type of track circuitry."

CWT systems are a countermeasure that can influence driver behavior where installed, although warrants for use may not be clearly defined. However, it has been pointed out (e.g., Tustin, 1985) that excessive warning time at some site can lead not just to credibility problems at that site, but also to a more generalized disregard of crossing signals. The corollary of this, however, is that improving credibility through CWT at one site may lead to improvements in driver behavior at other sites as well. This "system" view of credibility may be important in evaluating the benefits and cost-effectiveness of upgrading sites by use of CWT technology. In contrast, site improvements such as installing a gate or signal cannot be presumed to have similar generalized benefits.

Another suggestion to improve signal credibility where warning times are variable is to provide an indication of how far away the train is. For example, Meeker and Barr (in press) suggested that the approximate time to train arrival could be indicated by the rate at which the signal lamps flash. The effectiveness of this concept would depend on how well drivers can learn the meaning (expected time) associated with a given flashing rate, how discriminable different flash rates are, and how well the driver can use the temporal information in making a safe decision. Given that any particular individual may have very limited exposure to the activated signals, opportunities for learning might be limited.

Whether signals are controlled by CWT systems or less sophisticated fixed distance systems, the system is broadly based around some minimum warning time that will be provided to the driver. Since the warning interval cannot be targeted to each individual driver, vehicle, and environmental condition, it must be based on conservative assumptions. Some have recommended that the changing characteristics of the vehicle fleet (e.g., double bottom trailers) or the driving population (e.g., age-related effects) may warrant extending the length of the warning period (e.g., Bowman and McCarthy, 1985; Gordon, McGee, and Hooper, 1984). However, it should be recognized that as a countermeasure against certain types of accident scenarios, this approach could also lead to a more general loss of warning reasonableness to other drivers. As the already conservative warning times become extended, it is increasingly likely that a typical driver may perceive the train to be too far away to actually warrant stopping. The resulting loss of signal credibility could reduce, perhaps even eliminate, the net safety gain of providing greater protection for special situations. We know of no data on the possible magnitude of such effects, nor any systematic investigation of the crossing signal warning parameters that drivers will find acceptable or invalid. Thus it can only be pointed out that as a safety countermeasure, extending the warning time could have negative consequences on signal credibility.

In addition to extended warning times, the major credibility problem for active crossings is the false alarm. This refers to the signal or gate being activated when no train arrives. This could arise through an equipment malfunction, or from properly working devices that sense stopped rail cars or irrelevant switching activities. In either case, from the driver's perspective, this is a false signal. Countermeasures to insure signal integrity include improvements to track circuitry (e.g., Berg, 1985), timely detection and repair of signal malfunctions (e.g., Coleman, 1980), or the use of flagmen where switching operations are underway (e.g., Coleman, 1980). Section 5.5.2 will describe a public reporting system that may help reduce false alarms.

One source of false warnings, from the driver's perspective, is in the "fail safe" mode of operation of crossing signals. If any malfunction is detected, or primary power is lost, the signals go into the flashing mode. As a better safety countermeasure, Raab et al. (1977) recommended instead the use of a "signal malfunction indicator." This would provide the driver with a more accurate indication of the hazard, and would eliminate the false alarm situation.

<u>5.4.4 Information Distribution</u>

Most of the countermeasure suggestions regarding driver information deal with the information content and credibility. However, it is also important that the entire assemblage of crossing-related information and its manner of presentation be treated in a systematic, effective manner. This need becomes even more acute if additional kinds of information, of the sort described in previous sections, is added to the information array.

The "positive guidance" method (e.g., Post et al., 1981) is a set of procedures, based on traffic engineering and human factors principles, that defines a driver information system that is matched to the nature of the roadway and its hazards. It is a systematic approach to determining the driver's information needs (related to all aspects of the site, not just the rail-highway crossing), the priority of various information aspects (related to the concept of primacy), driving task demands, the proper location of the information, its spatial and temporal relationship to the hazards, the distribution of information and the driver's ability to manage it. Parsonson and Rinalducci (1982) applied the positive guidance method to a problem rail-highway crossing site in a demonstration project. The project was only partially successful in improving driver behavior at this site. However, the authors did feel that the project demonstrated the applicability of the positive guidance technique to the grade crossing situation.

The positive guidance method would appear to be a useful tool for systematically insuring that the driver traversing a grade crossing gets the information he needs in a manner that effectively supports his decision making. It may be particularly advantageous at problem sites. It should be noted that some of the underlying aspects of the driver behavior model (e.g., definition of information handling zones) are already incorporated into recommendations regarding crossing TCD's.

Another proposed countermeasure that has to do with the distribution of information is the use of optically programmed signals. Such signals use special lenses to sharply limit by optical means the viewing angle through which the light can be seen. Peterson and Boyer (1977) have described a hypothetical system which uses an array of four optically programmed signal heads to provide different messages at different zones on the approach roadway. This system recognizes that the active flashing signals at crossings can be ambiguous as to driver actions. When the signal begins to flash, some vehicles may be too near to safely stop; some may be near enough to safely proceed anyway; some will be sufficiently far so that they clearly must stop; and some may be in a "gray area" where the appropriate actions are unclear. Peterson and Boyer describe a possible optically programmed signal configuration for a sequence of three conditions:

(1) No train is approaching. Two signal heads present a flashing amber signal to both near and far approach zones.

(2) Train detected (e.g., about 30 seconds away). The far zone receives a red stop signal; the nearer zone receives a continuous amber signal.

(3) Train near (e.g., about 10 seconds away). A red signal is presented to all zones.

This general scheme is further refined by the use of two "red" signals, a solid red ball and a red crossbuck shape. The uniqueness of the red crossbuck signal would reinforce the association with the railroad crossing, and could be used to reduce possible confusions about the signal sequence. Peterson and Boyer indicate that field testing would be required to determine what the characteristics of an optimal system actually would be.

There does not appear to have been any further application of the optically programmed signal sequence to the rail-highway crossing problem. Its particular virtue is in allowing for an appropriate spatial distribution of active warning information, based on zones defined by driver needs. It is not apparent if this potential countermeasure has not been pursued because of technical or economic infeasibility, or simply has not been followed up.

5.4.5 Costs of Decisions

Alternative driver decisions will carry potential "costs" to the decision maker. These may range from the nuisance of slowing down to the disaster of colliding with a train. These costs vary widely not only in the magnitude of their consequences, but also in the likelihood of their occurrence. Some countermeasure ideas attempt to alter driver decision making by changing the costs of some decision. One class of potential costs is the consequence of police enforcement actions for non-compliance. Enforcement is discussed separately in Section 5.5.1.

If a driver behaves cautiously and waits for a train which he might have been able to beat across the tracks, he incurs the nuisance and time cost of waiting for the train. To remove the incentive for not stopping, Peterson and Boyer (1977) suggested placing a barrier or red light on the far side of a crossing. Then even if the driver did "beat" the train, he would have to wait anyway. Of course this only makes sense for active crossings, where the barrier or signal following the crossing is tied to the signal at the crossing. While this is a clever approach, the authors provide no details, and a number of problems would be significant. One is the cost involved in essentially doubling the number of crossing TCD's. Another is the operational and safety concern caused by the downroad signal. If close to the crossing, vehicles might queue up, and some vehicles in a queue may find themselves trapped on the track. If farther from the track, operational problems with other roadway features may occur. Finally, and perhaps most basically, what reason is there to assume the driver will comply with the second signal or barrier, if he was willing to violate, or at least take a risk, at the first signal or gate?

Other than this "second barrier" idea or suggestions regarding police enforcement, no other countermeasure concepts were identified that concerned increasing the costs of non-compliance. Also, it does not appear that much can be done to decrease the relative costs of compliance or caution; the disruption and wait must be incurred. Since many drivers appear to have exaggerated expectancies about the duration of delays, there might be some benefit in trying to better inform the public about typical waiting times. However, this would also be drawing attention to the negative aspect of safe driver behavior (waiting), and so could be counterproductive. One could view the use of stop signs at rail-highway crossings as a countermeasure which has as one of it features the decreased relative cost of waiting for an oncoming train. Since the driver is already forced to stop, some interference with driving has already occurred anyway. This does not of course eliminate the aspect of cost due to delay while waiting for a train to pass. Many other safety and operational factors enter into the decision about whether to employ stop signs at crossings. The influence on the relative cost of alternative actions may contribute to the safety effectiveness, but it probably is not a major factor.

In summary, with the possible exception of police enforcement (discussed later), little has been identified in the way of promising decision-error countermeasures that address the relative costs of safe vs. unsafe actions.

5.5 COMPLIANCE

Four general countermeasure strategies for improving driver compliance with crossing laws and devices were identified: (1) enforcement; (2) crossing TCD validity; (3) use of intersection-related TCD's with better compliance rates; and (4) the perceived reasonableness of driver requirements.

5.5.1 Enforcement

Police enforcement of driver compliance at crossings is very low. The presence of a police officer can improve driver compliance, but the effect appears transient. Some problems in enforcement include the difficulty of defining a violation for many situations, and the low frequency of trains actually being present at a given crossing.

A variety of authors (e.g., Leibowitz, 1985; Richards, 1985; Tidwell and Humphreys, 1981; Tustin, 1985) have suggested that better enforcement be considered as a countermeasure strategy, although more specific recommendations are lacking. Knoblauch et al. (1982) suggested that enforcement may be particularly beneficial at flashing light sites where large vehicles are a contributing accident factor. However, they also point out that enforcement only has the potential for influencing certain accident scenarios (for example, at crossbuck-only sites, perceptual errors may predominate, and are unrelated to enforcement); furthermore, such enforcement may not be a priority from the enforcement agency's perspective. Sanders et al. (1973) point out that the use of police resources can be made more effective by increasing patrol specifically at those periods of greatest commuter and train traffic. In fact, it would seem that the railroad schedule would permit rather precise targeting of enforcement. Peterson and Boyer (1977) proposed the use of automatic cameras at crossings to record violators. However, the use of such automated surveillance techniques in traffic law enforcement in general remains highly controversial and limited in use.

One recent innovation is the "trooper on the train" concept. A police officer rides the train and identifies violators, and communicates with another "chase" officer who stops the violator. No formal evaluations of this concept were identified, and its influence on driver behavior is unknown. Based solely on the literature review of driver behavior, it may be questioned whether this is more effective than targeting a specific site. Since an exceptionally high percentage of accident victims are local drivers familiar with the crossing, it might be argued that a visible periodic threat of enforcement at the site would influence its frequent users. The "trooper on a train" method might cover a broader range of sites, and is efficient in that drivers are only observed at those times when the train is actually present. However, since the driving public perceives so little likelihood of enforcement, this less visible and more diffuse method may have less impact on driver behavior. The relative merits of alternative enforcement methods, as well as the effects of enforcement on crossing violations in general, do not appear to have been formally evaluated.

5.5.2 Crossing TCD Validity

Compliance is related to the perceived validity of the information presented to the driver. Unduly long warning times and false alarms increase non-compliance. Constant warning time devices reduce this problem and improve compliance, as already discussed in Section 5.4.

Another approach to improving perceived, as well as actual, warning device validity is the use of a "hotline" for the public to report crossing signal malfunctions. The state of Texas (Lamkin, 1985) implemented a program in 1983 in which actively protected crossings on state highways have a sign posted, which lists a toll-free "800" phone number, as well as a crossing number to identify the site. Motorists can then call appropriate authorities to notify them about the location and nature of the malfunction. The call goes to the state Department of Public Safety, who in turn inform the responsible railroad. No formal records of follow-up are kept, to promote railroad cooperation with the program. This program now averages about 5,000 calls per year. Its effectiveness is unknown, and is currently being evaluated. However, it would appear a promising means of influencing the driver's perception of signal validity. First, of course, it actually promotes greater validity in the rail-highway signal system. But beyond this, it may serve as a highly visible indication of efforts to insure validity, gives the motorist a sense of participation in promoting signal validity, and may even call driver attention to the high frequency of properly operating signals. Furthermore, 84% of the calls received concerned the problem of "signal operating - no train visible," the false alarm condition which is particularly damaging to the credibility of any warning signal. Finally, about 20-25% of calls received were for sites on city streets and other locations not part of the state system. Since there were no signs posted at these sites, this suggests public awareness of the program, and together with the total number of calls received, suggests reasonably good public participation and acceptance. Thus while a formal evaluation is not yet available, this countermeasure holds promise for improving signal validity and driver compliance. Lamkin (1985) has indicated that no additional staff were added as a result of implementing this program, with the major initial costs being those of installation of the signs and the phone line.

5.5.3 Intersection-Related TCD's

The suggestion is sometimes made that intersection-related traffic control devices be employed at rail-highway crossings, because of the greater respect drivers show these devices. These possible TCD's include traffic signals, stop signs, and yield signs. Two critical, but essentially unanswered questions are: (1) Would the devices used at crossing sites retain their greater respect in this setting?; and (2) Would the use of these TCD's at rail-highway crossings, where motorists might disregard them, lead to more generalized lack of respect and compliance with them as used in other settings? Some discussion of this may be found in section 3.1.2.

The influence of this countermeasure strategy on driver behavior is largely speculative, and quite difficult to answer definitively through research studies. That is because it requires a relatively long-term and system-wide measure of driver behavior, equally long-term and system-wide careful control for changes in traffic behavior independent of the treatment, as well as the difficulties of defining and measuring non-compliance.

5.5.4 Perceived Reasonableness

Compliance with warnings is better when motorists believe that the warning is warranted and the required actions are reasonable. For example, traffic engineers have repeatedly warned that the inappropriate use of stop signs (e.g., for speed control) can "breed contempt for other necessary STOP signs" ("Traffic Control Devices Handbook", 1983), and compliance with such signs is often low. The same concern exists with the reasonableness of crossing-related TCD's and required driver actions.

Various authors have suggested that unused crossings be eliminated. If local drivers know that trains never appear, or if the overgrown, weedy appearance of the track makes this obvious, then the crossing's signs and markings are unnecessary and compliance (e.g., slowing to search for trains) with them is not reasonable.

It has also been argued that some stopping requirements for special vehicles are unnecessary, and truck and bus drivers certainly appear to view them as unreasonable. Bowman and McCarthy (1985) have pointed to a particular problem of requiring special vehicles to stop at active crossings even when the signal or gate is not activated. This leads to increased accident risk, a fact perceived by the trucking industry. More specific requirements, related to crossing level of protection, and perhaps site features (e.g., sight distance, traffic operational characteristics), might lead to better compliance among special vehicle operators.

At some sites, a supplemental warning sign might provide a means for making appropriate slowing at passive crossings (particularly with limited sight distance) more reasonable to the driver. If the driver perceives the arrival of a train as extremely unlikely, he may not feel that it is reasonable to slow down to the extent required to search for trains effectively. However, if other, more likely factors also require slowing, this may improve compliance. As an example, where truck or bus traffic is frequent, a supplemental warning sign might indicate: "Caution: Trucks and Buses Stop for Rail Crossing." Since the hazard of such a traffic conflict may be perceived as much more likely than a train arrival, slowing and caution may be greater. This message might also enhance the general awareness of the crossing and the need for alertness, and might improve compliance by special vehicle drivers as well. However, these benefits are all speculative.

As discussed in Section 3.1, a significant number of motorists do not properly comprehend driver responsibilities at grade crossings. The nature of these misunderstandings is such as to make crossing-related laws appear unreasonable. Many drivers, and even a substantial portion of police officers (Richards and Heathington, 1988), believe that the law requires all vehicles to come to a stop at even passive crossings ("stop, look, and listen"), and do not realize that they may proceed after stopping at a flashing light if the train is at a sufficiently safe distance. If this promotes the attitude that crossing-related laws are unreasonable, it may help foster general non-compliance with crossing TCD's. Therefore education about what behaviors are actually required may not only have the specific effects of promoting those behaviors, but also the non-specific effect of improving compliance because the laws appear more reasonable. This aspect of driver education could be incorporated into existing or proposed educational efforts.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 SOME GENERAL CONCLUSIONS AND IMPLICATIONS

This section concerns some of the general conclusions and recommendations that emerged from the review of factors in driver behavior and the consideration of countermeasure concepts intended to modify driver behavior. These conclusions and suggestions have to do with driver behavior; the net operational and safety benefits, installation and maintenance costs, technical issues in use (e.g., power requirements), and ultimate cost effectiveness, are traffic engineering considerations not dealt with here.

Some countermeasure approaches broadly influence driver behavior and address a range of accident scenarios. Others target specific problems in driver behavior, and may only be expected to influence a particular accident scenario. It might be a useful generalization to characterize grade crossing safety measures into those that assist the driver in his task, and those that fundamentally alter the task. For example, conspicuity enhancements, rumble strips, or warnings about sight distance all attempt to improve driver performance of his task. In contrast, a change from passive to active protection means that the driver is now required to do quite different things. Changing the driver's task can broadly address accidents in general. Upgrades from passive measures to signals to gates to grade separation progressively simplify the task and reduce opportunities for error. For the less fundamental changes, countermeasures can only be effective to the extent that they address the problems of driver behavior that typify accidents at the site. Suggestions for general changes in practice, such as a new design for advance warning signs, may be broadly applicable, but still address only a subset of driver behaviors, and so impact only a fraction of the potential accidents.

As the previous sections of this report indicate, there are many means and opportunities for potentially improving driver behavior at rail-highway crossings. There is not always good data on the behavioral or ultimate safety benefits of a particular strategy. However, the expectations about safety benefits arising from any particular behavioral countermeasure should be realistic. There has been a dramatic drop in grade crossing accidents, and this success has implications for the magnitude of further expected gains. From the mid-1960's to the mid-1970's, the number of motor vehicle fatalities at crossings was reduced by about half. By the mid-1980's, these fatalities were only about one-third the number in the mid-1960's. There are now approximately 500 motor vehicle fatalities and 2,000 injuries annually at crossings. The implication of this is that even a new countermeasure which is quite effective in modifying the particular behavioral aspect it targets nonetheless may have effects on accident frequency that are statistically difficult to discriminate and quantify in any study of limited duration.

The sections that follow highlight some of the significant general conclusions and strategies regarding driver behavior.

6.1.1 An Appropriate View of the Driver

From a highway safety standpoint, drivers do not act in an ideal manner at grade crossings. Safety countermeasures are in part attempts to improve that behavior. How one views the driver -- in particular, the accident victim or violator -- may influence the manner in which the problem is approached.

The very fact of a rail-highway accident implies some probable error on the part of the driver. Descriptions of typical accident scenarios may use terms such as "disregard" of signals, "inattention," "impatience," or "inappropriate" approach speed. Drivers may be viewed as careless or reckless, or at the least uninformed and unappreciative of the risks. There may be an attitude that if we could only "reach" these people with the facts, their behavior would be more rational.

Certainly some drivers do act recklessly. Certainly there could be safety benefits if all drivers were better informed about hazards and laws. Certainly it would be desirable if motorists gave greater consideration to safety factors. However, it may be misleading, even self-defeating, to stereotype the victim of a grade crossing accident as an irrational or oblivious risk taker. Despite the post hoc obviousness that there was a driver error, one may fail to adequately appreciate the driver's problem by adopting a "blame the victim" perspective.

A quite different view of the motorist emerges from a detailed review and analysis of the literature on driver behavior at rail-highway crossings. The image of the more typical driver is that of a reasonably 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 by 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.

Consider the driver who commutes daily across a passive crossing site. If it is a typical passive crossing, based on data in the "Rail-Highway Crossing Accident/Incident and Inventory Bulletin," we can characterize it as carrying two trains per day, with a train speed of perhaps 20 mph. Like many familiar drivers (e.g., Sanders et al., 1973), this hypothetical driver may not adequately slow down and search along the track for trains. What risk does this entail? One way to address this question is to ask what the probability of a vehicle-train collision would be at the crossing if the driver showed absolutely no awareness of approaching trains. Presume all his attention is focused on the road ahead, he has tunnel vision, and cannot hear well. While he would notice a train already in the crossing, he would take no action in response to an oncoming train. Under these conditions, the probability of the vehicle and the train occupying the crossing at the same moment is less than about one in 10,000.[1] If the hypothetical driver made an outbound and return trip every day (730 crossings/year), and acted in a totally oblivious manner, he could expect a conflict about once every 15 years. Even this assumes that no leading vehicles had detected the train and already stopped ahead of him, which would obviously reduce the likelihood further. Of course, even the worst of drivers would not be "totally oblivious" to the extent of this hypothetical example, so that the actual risk of "carelessness" would be much lower. Thus, when it is pointed out that drivers may have a very low expectancy of a train at a crossing, this is not necessarily an "error" that needs to be "corrected." It may be a rather accurate and difficult to alter perception, and one which safe behaviors must be taken in spite of.

This perspective in no way minimizes the importance of preventing the approximately 500 annual deaths at grade crossings, but it helps one appreciate how the risk may look from the driver's perspective. It may also help explain why some studies have reported a failure to observe any positive correlation between safe behavior at crossings and driver knowledge about accidents and laws.

If a driver's only concern at a grade crossing was avoiding a train collision, behavior might be more readily influenced by traffic control measures. However, as Section 3.4 discussed, his decision-making, broadly viewed, is incorporating many factors. Even the role of minor, but certain, nuisances, such as having to slow and deliberately search, become more understandable when considered against the improbability of encountering a train in any given instance. In fact, in many ways drivers may be doing a better job than given credit for. Consider a "problem" crossing of the sort studied in various published investigations of driver behavior or safety countermeasures, where sight distance is severely limited on a roadway with at least moderate traffic. What would be the safety and operational consequences if most drivers took seriously the need to slow drastically and direct attention away from the road? Even without such "compliance," non-train involved accidents at crossings outnumber train-involved accidents by about 2-to-1. The problem becomes somewhat analogous to determining warrants for stop signs at minor intersections, where rear end collisions, traffic delays, wasted fuel costs, etc. might outweigh the benefits of reducing potential right-of-way collisions. The point here is not that drivers are optimizing system performance, but that their behavior is sensitive to these other considerations.

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[1]These computations were based on the collision of the first 100 feet of the train and a 22-foot-long passenger car. Considering a 10-foot-wide collision area, at 20 mph the initial portion of the train would occupy this area for 3.75 seconds, or at two trains per day, a total of 7.50 seconds per day. The car at 35 mph would occupy the area for 0.62 seconds per crossing.

Despite the occasional train collision, they may not be as irrational as sometimes portrayed.

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 options 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.

6.1.2 Sight Distance

Limited sight distance has been pointed to as a prime target for countermeasure action by author after author. All three relevant types of sight distance -- 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 -- warrant consideration. Sight distance has been implicated as an accident factor in numerous studies. But as Schoppert and Hoyt (1968) noted in their original analysis of this problem, even in the absence of strong empirical correlates with accidents, sight distance is accepted as critical on the bases of common sense and analogy with other traffic engineering problems.

Sight distance is a particular concern for a variety of reasons. Most obviously, it limits the view of the hazard, and reduces the time available for the driver to react. Complicating this is the finding that drivers seem relatively insensitive to the very existence of a sight limitation. Even if aware, they tend not to appropriately compensate by slowing the vehicle sufficiently. Search behavior is often not good at crossings, and where special search effort is required (sight obstructions or acute crossing angles) it is not given. Not only do sight limitations increase the problems of detecting and responding to trains, they may also cause vehicular traffic conflicts when different drivers respond to them differently, or when a motorist must react abruptly. Because of the restricted decision time associated with limited sight distance, drivers may make more erroneous decisions, rely more on preconceived expectancies, and feel more "committed" to initial decisions.

On the other hand, except for the most extreme cases, the sight distance problem can be recast as a speed control problem. The sight distance required by the driver is jointly determined by the train's speed, the vehicle's speed, and vehicle control characteristics (e.g., braking distance). Modifying one of these aspects also modifies the sight distance "problem," and some have argued that there in fact is no such problem. For example, Nichelson (1987) contended that there is a lot of confusion over the "required" sight distance "probably because there is no such animal.... It is the available sight distance which establishes the safe approach speed. The posted speed limit does not 'require' a predetermined sight distance." However, as an approach to crossing safety, this perspective puts critical reliance on driver perception, judgment, and compliance. Appropriate speed control efforts are a necessary traffic engineering measure for some sites, but this places additional responsibility and decision burdens on the driver, and is not ideal from the driver behavior standpoint.

A variety of specific countermeasure ideas and recommendations are directed at the sight distance problem. Generally, these could be classified as site physical improvements to remove barriers to visibility, or as efforts to modify driver behavior. Physical improvements relate to: removal or better maintenance of vegetation; elimination of standing rail cars; prohibitions against parking vehicles; removal or better placement of roadside hardware; changes in the crossing geometrics; removal of billboards or other obscuring objects not necessary at that location; regrading of small hills; and discouragment of locating buildings or objects (e.g., farm equipment) on private property where it can block the driver's view. In some cases sight distance improvements can be easily achieved, but in other instances improvement may be difficult or even undesirable. Barriers may be difficult to remove or relocate; extensive areas of privately owned property may be involved; and some objects (particularly vegetation) may serve as visual or acoustic barriers to residential intrusion by trains.

The efforts aimed at driver behavior are attempts to insure that the driver adequately compensates for visual limitations by modifying his search behavior or approach speed. These countermeasures include: speed control through regulatory, advisory, or warning signs; physical means of speed control (e.g., rumble strips); advance signs warning about limited sight distance; signs indicating where and when to look for trains; active advance warnings; and reduction of competing attentions demands (driving task requirements or extraneous attention-getting stimuli). Of course, sight distance limitations are also among the reasons for upgrading a crossing from passive to active protection.

Although there are no federal standards regarding sight distance, and there is controversy over the appropriateness of recommended methods for computing required sight distances (e.g., Tustin et al., 1986), the importance of this factor to visual search and decision making force its consideration. Countermeasures to address the problem need to adopt realistic expectations about what drivers will do, what information they need and will use, what expectancies they bring to the situation, and so forth. Systematic methods for dealing with these driver needs, such as Positive Guidance, may be a useful and sufficiently flexible means of addressing limited sight distance problems.

6.1.3 Driver Familiarity with the Crossing

Most grade crossing accident victims were familiar with the crossing. The kinds of trips on which these accidents occur tend to be recurring types, such as work trips and school trips. Higher level roads, which are more likely to be carrying unfamiliar drivers, are more likely to have grade separation, or at least more protection (e.g., automatic gates) at crossings. While it of course remains important to alert the unfamiliar driver, the nature of the rail-highway crossing problem demands consideration of the implications of driver familiarity with the site.

What are some of the implications of driver familiarity for countermeasure strategies? For one, it would seem to play down the significance of passive information. Passive devices will lose their salience with familiarity, and driver actions will be more habitual, and more influenced by expectancies based on direct experience. Another implication is that for a countermeasure of some sort to be most effective when it is introduced at a site, it may be necessary to break individual driver habits and alter inappropriate local norms and practices. For example, a police presence coinciding with the period of introduction of a countermeasure may give the countermeasure a better initial chance to influence behavior, as well as give greater subjective significance to the change. Also, because behaviors may be well established, and additional driver information of limited effectiveness, there may be greater emphasis given to strategies which more fundamentally alter the driver's task or change the relative costs of alternative actions. Thus while a "Watch for Trains" sign or more conspicuous advance signing might have lesser effects on the locally familiar driver, a change to active signals, or periodic police enforcement, might have more potential. In any case, whatever countermeasures are contemplated for a particular site should give consideration to the influence on familiar, as well as unfamiliar, motorists.

6.1.4 Directed Visual Attention

From a human factors standpoint, one limitation of the typical warning and informational system for grade crossings is the overwhelming reliance on visual detection of critical stimuli. Auditory cues frequently are presented by the train whistle, but the effectiveness of this signal is limited for a variety of reasons already discussed. Therefore detection of the crossing, the traffic control devices, and the train itself are all primarily by visual processes.

This very strong reliance on vision implies a number of limitations. Visual search, in contrast to other senses, requires that the receptors (eyes) be oriented toward the target. This puts more burden on the human to direct attention in an appropriate way. Poor visibility conditions (e.g., rain, snow, fog, darkness) can degrade communication. Also, because driving is a largely visual task, mutual interference between visual signal detection and other driving tasks is maximized. Redundancy of warnings, which is an important warning concept, is particularly effective with multiple sensory modes. In the driving situation, redundancy solely in the form of additional visual cues (while often desirable) may mean greater visual clutter and complexity. In other human factors applications, non-visual warning modes (particularly acoustic) have been widely used and recommended in preference to visual displays for certain alarm needs; in particular if the warning is infrequent, if false alarm annoyance is not recurrent and critical, and if spare visual attention is limited, then non-visual warning modes may be especially appropriate.

Given the limitations to visual warnings, it would be desirable if redundant information about crossings or trains could be effectively provided through other channels. Reliably detected acoustic signals from the train or crossing are difficult to achieve in a practical way. However, other means may warrant further consideration. Pavement treatments, such as rumble strips or open graded asphalt sections, provide both tactile and acoustic cues to the driver, regardless of driver orientation or visual attention problems. As discussed in Section 5.2, these treatments have some demonstrated effectiveness in gaining attention, slowing vehicle approach, and reducing the number of vehicles that fail to stop. They also suffer potential problems in driver avoidance, so that implementation and warrants for use must be carefully considered.

Of course, measures such as rumble strips suffer the limitation of being passive devices, unrelated to train presence. Consideration should be given to the technological feasibility of activating some auditory/tactile cue only upon train detection (e.g., raising or lowering some otherwise flush elements in the road, or highly focused acoustical signals that are less environmentally intrusive). Theoretically, if not practically, such a product might make an ideal active advance warning device. It would be effective regardless of driver attention and visual distraction, would provide redundancy with visual cues, would directly induce slowing (hence impact behavior early in the behavioral chain), would minimize driver annoyance and inappropriate reactions (since it would only be present occasionally), and like any active warning, would provide important information and define the appropriate response option.

6.1.5 A System Perspective

The problems of a rail-highway crossing site are typically addressed on an individual basis. However, there also may be some merit to a system view of the problem. A change at any particular site(s) may have repercussions throughout the local rail-highway system. For example, as has already been discussed, improving signal credibility at specific sites, such as by means of CWT systems, may more broadly improve respect for crossing signals. The improvement at a particular site may be "transparent" to the driver; he only experiences fewer long delays. At another crossing there may or may not be CWT circuitry, but his expectancy may have been altered. Generally, allocation of resources for crossing improvements is based on site-specific determinations of some hazard index. The suggestion here is that since certain countermeasures may influence behavior more broadly, there be some means for recognizing and incorporating this. A broader system perspective might permit questions such as: What would be the improvement in overall compliance if X% of signallized crossings were upgraded to CWT systems, and how might these sites be best selected to enhance motorist perception of general signal credibility? As another example, on a site-specific basis, there may be little direct safety benefit to maintaining the appearance or removing the signs and markings from an abandoned crossing, since there is no risk of a train collision anyway. Yet various authors have pointed out that this may be useful for maintaining general (i.e. system) credibility of passive warnings.

A system view would also lead to questions about negative consequences that might occur at unimproved sites. For example, as a higher proportion of crossings acquire active protection, driver behavior may change at remaining passive sites. Motorists may feel that unprotected sites must be "safe," or they may even suffer the potentially dangerous misperception that all crossings are actively protected. Similar types of arguments could be made for widespread use of other possible countermeasures, such as sight distance improvements, active advance warning signs, or warnings about limited sight distance. The changes in driver beliefs or attitudes could certainly influence safety behaviors, such as visual search or approach speed, at unmodified sites. In reviewing the literature, we specifically sought information on how driver behavior at passive crossings may have changed over the past decade as a result of the widespread upgrade of many sites to active protection. No information, or even discussion, of this was found.

In other highway safety applications, such a broader view and consideration of driver expectancies is taken. Further, recent interest in the apparent phenomenon of "accident migration" (e.g., Boyle and Wright, 1984) has focused concern on the mechanisms by which spot safety improvements might actually lead to increased accidents at surrounding locations.

It is suggested that the rail-highway crossing safety community consider the merits of a system view in the selection of countermeasures for site improvements, the determination of the cost effectiveness of countermeasures, and the evaluation of treatment effects. This perspective may or may not ultimately prove necessary, but it warrants greater attention.

6.1.6 Comparison of Railroad Crossing Flashing Light Signal vs. Traffic Control Signal

Analogies have frequently been drawn between the flashing light signals used at rail-highway crossings and traffic control signals used at roadway intersections. There are both important similarities and significant differences. Some authors have suggested using traffic control signals at railroad crossings (focusing on the similarities), while others have objected to this (focusing on the differences). Some of the differences highlight limitations to current signals. In this section of the report, we will summarize some of the major differences between the two types of traffic control devices, and indicate the implications of these differences for the rail-highway safety problem.

The comparisons are made in tabular form (Table 6-1). Each entry is based around a particular "factor" in signal use or design. For each factor, the table describes the relevant characteristics of traffic control signals, the relevant characteristics of railroad crossing flashing lights, and the implications of the differences between the two device types. There is some overlap between the "factors", but they are treated as distinct wherever this helps clarify the implications.

The comparisons made in Table 6-1 are based on <u>functional</u> differences between traffic control signals and railroad crossing flashing lights. The table does not consider current differences in motorist compliance, police enforcement, public attitudes, etc. Nor does it consider physical differences in hardware aspects, such as lens dimensions, photometric characteristics, etc. The point of Table 6-1 is to compare and contrast the informational and regulatory aspects of the two device types.

Review of Table 6-1 suggests that relative to the traffic control signal, the railroad crossing flashing light presents a more ambiguous message about appropriate driver actions. Some of these limitations are inherent in the nature of the rail-highway crossing situation. For example, even if traffic control signals were used for rail-highway crossings, the red phase would necessarily be of unpredictable length and occasionally quite long, and so compliance might be expected to suffer. Other differences between traffic control signals and railroad crossing flashing lights reflect deliberate decisions by the highway safety community about the nature of the warning system. These decisions may incorporate a variety of other factors, such as power requirements or protecting the integrity of the traffic control signal, but Table 6-1 helps make explicit some of the implications for driver information.

6.2 GENERAL SUMMARY

This section briefly highlights a few of the major points raised in the review of driver behavior and related countermeasures for rail-highway crossings.

- If a driver is to behave in a consistently safe manner at rail-highway crossings, he must: Understand the meaning, requirements, and implications of crossing-related features; readily detect and recognize all relevant stimuli; accurately perceive dynamic and spatial relationships; make decisions about alternative actions and conflicting demands; and show compliance with required actions. There are factors which significantly limit proper driver performance in all of these areas.

- Motorists understand the general meaning and requirements of crossing-related traffic control devices, but many suffer potentially serious misunderstandings of specific meanings. Many drivers also fail to appreciate important accident-related factors.

TABLE 6-1

TRAFFIC CONTROL SIGNALS VS. RAILROAD CROSSING FLASHING LIGHTS

Factor	Traffic Control Signal	Railroad Crossing Flashing Light	Implications
Meaning of Red Phase	A steady red indication requires the driver to stop and remain waiting until the signal changes to green. A flashing red indication requires the driver to stop, and proceed when safe.	The flashing red lights require the driver to stop; the vehicle may proceed only if no train is in hazardous proximity.	The regulatory meaning of the railroad crossing flashing red light is similar to that of the flashing red traffic control signal. However the meaning of the most frequently encountered red indication (steady signal) is not the same; but it appears that many drivers interpret the railroad crossing signal to also mean stop and wait for the red phase to terminate. The difference in meaning between the typical traffic control signal red indication and the railroad crossing signal may contribute to driver confusion. The steady red indication provides a more simple choice situation for the driver, with the appropriate action entirely specified by the signal phase.
Phasing	The typical traffic control signal has a sequence of three phases, green-to yellow-to red. Green and red define clear actions (go, stop) on the part of the driver; yellow is a transition phase.	The flashing signal has only two states: activated (flashing) or inactive (dark).	The absence of a transitional phase complicates the driver's decision if the flashing signal becomes active when the driver is near the crossing. If he is already in the non-recovery zone, the safer behavior is to continue through the crossing, and in fact the train detection circuitry should be timed so as to provide an adequate period for this. On the other hand, the driver's general experience with red signals is that is it both dangerous and illegal to "run" them. Furthermore, the time available before the train arrives is ambiguous, and the driver probably lacks knowledge of the typical warning interval. The absence of a transitional signal phase also makes it difficult to define a traffic

TABLE 6-1: TRAFFIC CONTROL SIGNALS VS. RAILROAD CROSSING FLASHING LIGHTS (Con't)

Factor	Traffic Control Signal	Railroad Crossing Flashing Light	Implications
			violation, since continuing through the crossing during the red phase is acceptable if the driver is sufficiently close when the signal activates. The fact that it is clearly most safe to continue through the red indication under certain conditions could conceivably reduce motorist respect for the signal, or contribute to confusion over what the appropriate response ought to be.
Duty Cycle	The signal cycles through a sequence of relatively brief phases. The onset of the red phase is reliably predicted by the yellow phase. The duration of the red phase is fixed, brief, and known (to an approximation) by the driver.	The flashing signal will activate at an unpredictable time. The duration of the cycle is unpredictable, and subject to very large variability, as a function of train length and speed.	The characteristics of the traffic control signal foster better compliance with the red phase because (a) the driver can predict its occurrence and adjust in advance, and (b) the "cost" of compliance is predictably low.
Absence of Signal	If the signal head is dark, the traffic signal is not operating. Traffic conflicts are highly probable, and caution is required. The driver should stop and proceed if clear.	A dark signal head means that the crossing is clear. The driver may proceed across the tracks.	At a rail-highway crossing, the absence of an illuminated signal is not fully informative. This may indicate a passively protected crossing, or the safe period for a signallized crossing. A driver also might consider that a signal malfunction could cause the flashing lights to be inactive. To recognize the absence of the signal as a "safe" indication, the driver must detect the unilluminated signal heads, which are low conspicuity targets. In addition to its poor target quality, the meaning of an unilluminated signal may be misunderstood by the driver, whereas an active signal is unambiguous.

TABLE 6-1: TRAFFIC CONTROL SIGNALS VS. RAILROAD CROSSING FLASHING LIGHTS (Con't)

Factor	Traffic Control Signal	Railroad Crossing Flashing Light	Implications
Immediacy of Conflict	The onset on the red phase is closely followed by the green phase for the intersecting road (after a brief clearance interval). The probability of a traffic conflict is very high just after the signal turns red.	The relation of signal onset to the arrival of conflicting traffic (the train) is unpredictable. CWT systems improve predictability, but the driver has know way of knowing if such a system is in effect. Objectively, the period immediately following the onset of the signal (about 25 seconds for typical CWT applications) reliably indicates the non-presence of the train.	Violating a red traffic control signal, and in particular entering the intersection early in the red phase, is very likely to result in a conflict; this is less true for a railroad crossing. This may contribute to disregard of the railroad crossing signal or to attempts to beat the train when the signal becomes activated. CWT systems reduce the uncertainty somewhat. Briefer periods between signal onset and train arrival would make signal activation more informative of risk, but conservatively long warnings may be required by "worst case" conditions.
Malfunction	A malfunction of a traffic control signal will be indicated by an unilluminated signal head or a fail-safe flashing mode. If a driver is forced to wait an unusually long time for a red signal, this may indicate a failure of the controller to cycle through the signal sequence.	Railroad crossing flashing signals are backed up by supplementary power sources, and go into a failsafe flashing mode if normal power is terminated.	The public is probably not aware of the fail-safe mode of the railroad crossing signal. There may be uncertainty as to whether a dark signal means "safe" or "malfunction." If a signal is flashing because it is in a failsafe mode, the driver will not recognize this and may wait indefinitely; this could impact the perceived credibility of crossing signals.

TABLE 6-1: TRAFFIC CONTROL SIGNALS VS. RAILROAD CROSSING FLASHING LIGHTS (Con't)

Factor	Traffic Control Signal	Railroad Crossing Flashing Light	Implications
Presence of Signalized Intersection	Since some phase of the traffic control signal is always activated, the presence of a signallized crossing is indicated in advance by the illuminated lens.	If the flashing light is activated, the crossing is obviously signallized. If the lamps are not activated, only the unilluminated lamp housings indicate that there is active control at the crossing.	The driver approaching a rail-highway crossing may have no conspicuous cue that there is active protection. Even cues to the existence of the crossing itself, whether signallized or not, are usually passive signs and markings. Thus the approaching driver may be less prepared to take appropriate action if the signal activates. The absence of a conspicuous and unambiguous indication of the kind of traffic device ahead may also contribute to greater variability among drivers on approach to the crossing.
Nighttime Perception	Virtually all of the information available in daytime remains available at night with adequate conspicuity, since at least one signal head is always illuminated.	The lamps are activated only when a train is in proximity, so that there is no illuminated signal at other times. Only the crossbuck is reflectorized, and this does not discriminate active from passive crossings. The signal housings are black and not reflectorized, so that there is no good cue regarding the presence or absence of flashing signals at the particular crossing.	In contrast to signallized intersections, railroad crossings at night provide reduced cues to the nature of the crossing, and perhaps even to the existence of the crossing. Since a driver has different responsibilities on approaching a passive crossing vs. a crossing with an unactivated flashing signal, it is not clear what a conscientious driver is supposed to do on approach.

- Detection and recognition of trains as they approach the crossing involve the coordination of central and peripheral vision. Cues may be difficult to recognize, especially at night, and detection processes can be broadly influenced by driver expectancy. The conspicuity of a train already in the crossing can be limited at night, especially if the train is slow moving or stopped. Auditory signals may serve as important supplements to visual stimuli in the detection of trains, but cannot be considered as a primary means of warning because of practical limitations under real-world applications.

- Traffic control devices are used to improve driver awareness of the crossing and its characteristics. Passive devices themselves suffer conspicuity problems, and cues to identify the crossing as actively or passively protected are particularly limited. Active signals, both at the crossing and in advance of the crossing, are more conspicuous and provide additional information to the driver. Various improvements to the conspicuity and informational content of active signals have been suggested.

- Judgments about the speed, distance, and closing rate of objects are subject to a number of errors; some features of trains in particular as visual stimuli contribute to misperceptions. Problems exist for both daytime and nighttime viewing. The speed of one's own vehicle, and its significance, is often frequently misjudged.

- Decision making errors are an important cause of rail-highway collisions. Driver decision making at grade crossings must be viewed in the broader context of the driver's task. A number of factors contribute to inappropriate decisions at crossings, including: information limitations and ambiguity; information credibility; expectancies regarding trains; expectancies regarding crossings; costs of compliance; temporal constraints; competing inputs; disruptive effects of decision making itself; self-recognition of capabilities and biases; conflicting (implied) messages; safety concerns; effort; social influences; and emotional reactions.

- Driver compliance with grade crossing requirements is variable, and sometimes very poor. Requirements may be perceived as unreasonable, inconvenient, or unwise. Noncompliance may be supported by the actions of others, and there is generally little police enforcement of laws.

- Alcohol involvement is a significant factor in rail-highway crossings, particularly at night. However, this involvement does not appear any greater than, and may even be somewhat less than, for serious traffic accidents in general. The incidence of drugs or fatigue in grade crossing accidents is not known, but probably rather limited; however, there are many mechanisms by which drugs or fatigue could substantially enhance risk at crossings for the individual driver.

- Important driver characteristics that relate to involvement in rail-highway crossing accidents include local familiarity, age, sex, alcohol use, and general risk taking.

The influence of familiarity with the site is seen both in accident studies and in field observations, and may be an important consideration in trying to modify driver behavior.

- A wide range of countermeasure approaches was identified, addressing virtually all of the categories of driver performance: comprehension, detection, perception, decision making, and compliance. Safety measures can be loosely categorized as those that attempt to assist the driver in his task, and those that fundamentally alter the task. The former sort of countermeasures can typically be expected to address a limited number of accident scenarios.

- For many of the potential countermeasures identified, data on their potential behavioral effectiveness are lacking. Even where some aspect of driver behavior is substantially improved, remaining issues concern the ultimate influence on accident frequency, operational impact, costs, and cost effectiveness. It was possible to identify numerous countermeasure ideas that are promising in terms of driver behavior, but the magnitude of their potential safety impacts must be considered.

- The most useful view of the accident-involved driver at a grade crossing is not one of a reckless or oblivious risk taker and scofflaw. A more appropriate view is of a reasonably rational, though imperfect, decision maker attempting to optimize his actions based on limited information of various sorts. This view of the driver emphasizes certain countermeasures, and discourages an unproductive "blame the victim" attitude.

- Sight distance is highlighted as an important accident factor. Since the required sight distance is a joint function of visibility distance, vehicle speed, and train speed, safety benefits can come through either physical improvements to the sight or behavioral compensations by the driver. However, attempts to modify driver behavior should be based on realistic expectations about driver actions, and not just on the regulatory basis of assigned responsibilities.

- Countermeasure emphasis and implementation should take into consideration the particular characteristics of the driver highly familiar with the crossing.

- Information presented to the driver about crossings and trains suffers the limitation of being almost exclusively visual in nature. Auditory signals from trains or crossing devices are of limited practical effectiveness. Countermeasure concepts using non-visual modes warrant further consideration.

- There may be important benefits to viewing driver behavior countermeasures from a system perspective, rather than solely on a site-by-site basis. Improvements made at one site can potentially influence behavior at other sites, in either a positive or negative manner.

7. REFERENCES

Aberg, L. (1988). Driver behavior at flashing-light, rail-highway crossings. Accident Analysis and Prevention, 20(1), 59-65.

Allen, R.W., & Schwartz, S.H. (1978). Alcohol effects on driver risk (pp. 579-582). Proceedings of the Human Factors Society 22nd Annual Meeting. Detroit, Michigan, Human Factors Society.

Allen, R.W., Schwartz, S.H., Hoggs, J.R., & Stein, A.C. (1978). The effects of alcohol on the driver's decision making behavior (Report No. DOT-HS-803-608). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Aurelius, J.P., & Korobow, N. (1971). The visibility and audibility of trains approaching rail-highway grade crossings (Report No. FRA-RP-71-2). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Bates, L.H., (1985). Use of strobe lights at railroad grade crossings. ITE Journal, 55(11), 32-35.

Bellis, W.R. (1969, April). Development of an effective rumble strip. Traffic Engineering, 22-25.

Berg, W.D. (1985). Driver information needs and implications for safety measures (pp. 33-42). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Berg, W.D., Knoblauch, K., & Hucke, W. (1982). Causal factors in railroad-highway grade crossing accidents (pp. 47-54). Transportation Research Record, 847. Washington, D.C.: Transportation Research Board.

Biederman, I., Mezzanotte, R.J., & Rabinowitz, J.C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. Cognitive Psychology, 14, 143-177.

Bowman, B.L. (1985). Constant warning time devices for railroad-highway crossings (Report No. FHWA/RD-86/156). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Bowman, B.L. (1987). Analysis of railroad-highway crossing active advance warning devices (pp. 141-151). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board. (a)

Bowman, B.L. (1987). The effectiveness of railroad constant warning time systems (pp. 111-122). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board. (b)

Bowman, B.L., & McCarthy, K.P. (1985). Consequences of mandatory stops at railroad-highway crossings (Report No. FHWA-RD-86-014). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Boyle, A.J., & Wright, C.C. (1984). Accident "migration" after remedial treatment at accident blackspots. Traffic Engineering and Control, 25, 260-267.

Bragg, B.W.E., & Finn, P. (1982). Young driver risk-taking research: Technical report of experimental study (Report No. DOT-HS-806-375). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Brown, J.F. (1931). The visual perception of velocity. Psychologische Forschung, 14, 199-232.

Brown, B., & Cole, B.L. (1969). The effect of visual noise on the recognition of road traffic signal lights. Australian Road Research, 4(1), 35-48.

Brown, I.D., Tickner, A.H., & Simmonds, D.C.V. (1970). Effects of prolonged driving on overtaking criteria. Ergonomics, 13(2), 239-242.

Butcher, T.A. (1973). Evaluation of safety improvements at highway-railway grade crossings. Joint Highway Research Project (Report No. 1-73). Lafayette, Indiana: Purdue University.

Cairney, P.T. (1982). An exploratory study of risk estimates of driving situations. Proceedings of the ARRP Conference, 11(5), 233-240.

Coleman, J.A. (1980). Credibility (pp. 67-70). Proceedings, 1980 National Rail-Highway Crossing Safety Conference. Knoxville, Tennessee, June, 1980.

Coleman, J., Koziol, J.S., & Mengert, P.H. (1977). Railroad grade crossing passive signing study--Phase 1. Public Roads, 40(4), 141-144.

Compton, R.P., & Anderson, T.E. (1985). The incidence of driving under the influence of drugs 1985: An update of the state of knowledge (Report No. DOT-HS-806-900). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Coren, S., Porac, C., & Ward, L.M. (2nd ed.) (1984). Sensation and perception. Orlando, FL: Academic Press, Inc.

Cox, J.J. (1972). Road-rail protection--Audible warning effectiveness. Australian Road Research Board Conference Proceedings, 6, Part 2, 448-466.

Cunitz, R.J. (1981). Psychologically effective warnings. Hazard Prevention, 17(3), 5-7.

Dejaiffe, R. (1961). Methods of providing additional advance warning to highway traffic approaching a highway-railway grade crossing. American Railway Engineering Association Bulletin, 63(567).

Devoe, D.B., & Abernethy, C. (1975). Field evaluation of locomotive conspicuity lights (Report No. FRA-OR&D-75-54). Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Dommasch, I.N., Hollinger, R.L., & Reilly, E.F. (1976). Passive control at railroad-highway grade crossings (Abridgement) (pp. 58-59). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Donelson, A.C., Haas, G.C., & Walsh, P.J. (1986, March). The etiology of fatal traffic accidents involving alcohol and cannabis. Report to National Health Research and Development Program, Ottawa. Ontario.

Ebbesen, E.B., & Haney, M. (1973). Flirting with death: Variables affecting risk taking at intersections. Journal of Applied Social Psychology, 3(4), 303-324.

Eck, R.W., & Halkias, J.A. (1985). Further investigation of the effectiveness of warning devices at rail-highway grade crossings (pp. 94-101). Transportation Research Record, 1010. Washington, D.C.: Transportation Research Board.

Ells, J.G., Dewar, R.E., & Milloy, D.G. (1980). An evaluation of six configurations of the railway crossbuck sign. Ergonomics, 23(4), 359-367.

Erlick, D.E. (1961). Judgments of the relative frequency of a sequential series of two events. Journal of Experimental Psychology, 62, 105-112.

Evans, L. (1985). Human behavior feedback and traffic safety. Human Factors, 27(5), 555-576.

Evans, L., & Herman, R. (1976). Note on driver adaptation to modified vehicle starting acceleration. Human Factors, 18, 235-240.

Evans, L., & Wasielewski, P. (1983). Risky driving related to driver and vehicle characteristics. Accident Analysis and Prevention, 15(2), 121-136.

Fambro, D.B., & Heathington, K.W. (1984). Motorists' understanding of active warning devices used at railroad-highway grade crossings. ITE Technical Notes, 9(2), in ITE Journal, 54(4), 38-40.

Farber, E. (1969). Passing behavior on public highways under daytime and nighttime conditions. Highway Research Record, 292, 11-23.

Farr, E.H., & Hitz, J.S. (1985). Effectiveness of motorist warning devices at rail-highway crossings (Report No. FHWA/RD-85/015). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Freedman, M., Staplin, L.K., & Decina, L.E. (1985). Limited sight distance warning for vertical curves. Public Roads, 49, 46-53.

Fuller, R.G.C. (1984). Prolonged driving in convoy: The truck driver's experience. Accident Analysis and Prevention, 16(5/6), 371-382.

Gerathewohl, S.J. (1953). Conspicuity of steady and flashing light signals: Variation of contrast. Journal of the Optical Society of America, 43(7), 567-571.

Gillespie, T.D. (1986). Start-up accelerations of heavy trucks on grades (pp. 107-112). Transportation Research Record, 1052. Washington, D.C.: Transportation Research Board.

Glass, A.L., & Holyoak, K.J. (1986). Cognition (2nd ed.). New York: Random House.

Gordon, D., & Mast, T.M. (1976). Driver's judgment in overtaking and passing. Human Factors, 18, 53-62.

Gordon, D.A., McGee, H.W., & Hooper, K.G. (1984). Driver characteristics impacting highway design and operations. Public Roads, 48(1), 12-16.

Gossard, W. (1987). Sight distance: A factor in highway-rail grade crossing accidents (pp. 16-19). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

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.

Hagenauer, G.F., Upchurch, J., Warren, D., & Rosenbaum, M.J. (1982). Intersections (Chapter 5) (Report No. FHWA-TS-82-232). In Synthesis of safety research related to traffic control and roadway elements: Vol. 1. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Halkias, J.A., & Eck, R.W. (1985). Effectiveness of constant-warning-time versus fixed-distance warning systems at rail-highway grade crossings (pp. 101-116). Transportation Research Record, 1010. Washington, D.C.: Transportation Research Board.

Hare, C.T., & Hemion, R.H. (1968). Head lamp beam usage on U.S. Highways (Report No. AR-666). San Antonio, Texas: Southwest Research Institute.

Hartsell, C.I. (1967). Conduct study with the view toward developing alternate types of automatic crossing protection. American Railway Engineering Association Bulletin, 69(609).

Heathington, K.W., Fambro, D.B., & Richards. S.H. (1988). Field evaluation of innovative active warning devices for use at railroad-highway grade crossings, Vol. II (Report No. FHWA-RD-88-135). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Heathington, K.W., Fambro, D.B., & Rochelle, R.W. (1984). Evaluation of six active warning devices for use at railroad-highway grade crossings (pp. 1-4). Transportation Research Record, 956. Washington, D.C.: Transportation Research Board.

Heathington, K.W., & Urbanik, T. (1972). Driver information systems for highway-railway grade crossings (pp. 59-77). Highway Research Record, 414. Washington, D.C.: Highway Research Board.

Heathington, K.W., Wunderlich, R.C., & Humphreys, J.B. (1981). Domestic and foreign research and practices in railroad-highway grade crossing safety. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Henderson, R.L., Sivak, M., Olson, P.L., & Elliott, W.M. (1983). Motor vehicle rear lighting and signaling. In Crash Avoidance, SP-544 (pp. 121-144). Warrendale, PA: Society of Automotive Engineers, Inc.

Henderson, R.L., Ziedman, K., Burger, W.J., & Cavey, K.E. (1983). Motor vehicle conspicuity. In Crash Avoidance, SP-544 (pp. 145-188). Warrendale, PA: Society of Automotive Engineers, Inc.

Hills, B.L. (1980). Vision, visibility, and perception in driving. Perception, 9, 183-216.

Hopkins, J.B. (1980). Operational testing of locomotive-mounted strobe lights (Report No. DOT-TSC-FRA/ORD-80-48). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development.

Hopkins, J.B., & Holmstrom, F.R. (1976). Toward more effective grade-crossing flashing lights (pp. 1-14). Transportation Research Record, 562. Washington, D.C.: Transportation Research Board.

Hopkins, J.B., & Newfell, A.T. (1975). Guidelines for enhancement of visual conspicuity of trains at grade crossings. (Report No. DOT-TSC-FRA-74-15 and FRA-OR&D-75-71). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Hopkins, J.B., & 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.: U.S. Department of Transportation, Federal Railroad Administration.

Hostetter, R.S., McGee, H.W., Crowley, K.W., & Hughes, W.C. (1985). Driver needs on two-lane rural highways: Vol. 1 (Report No. FHWA/RD-85/097). Washington, D.C. U.S. Department of Transportation, Federal Highway Administration.

Howett, G.L., Kelly, K.L., & Pierce, E.T. (1978). Emergency vehicle warning lights: State of the art (No. 480-16). Washington, D.C.: U.S. Department of Commerce, National Bureau of Standards.

Hughes, P.K., & Cole, B.L. (1986). What attracts attention when driving? Ergonomics, 29(3), 377-391.

Hughes, P.K., & Cole, B.L. (1984). Search and attention conspicuity of road traffic control devices. Australian Road Research, 14, 1-9.

Hulbert, S.F. (1967). Information and enforcement (pp. 27-30). Proceedings, Grade Crossing Safety Symposium. Texas Transportation Institute.

Hulbert, S. (1972). Driver information systems (pp. 110-132). Human Factors in Highway Traffic Safety Research. New York: Wiley & Sons, Inc.

Hulbert, S.F. & Burg, A. (1968). Appendix B: Application of human factors research in design of warning devices for highway-rail grade crossings. In D.W. Schoppert and D.W. Hoyt, Factors influencing safety at highway rail crossings (NCHRP Report 50). Washington, D.C.: Highway Research Board.

Institute of Transportation Engineers (1976). Transportation and traffic engineering handbook. Englewood Cliffs, NJ: Prentice Hall.

Jackson, T.T., & Grey, M. (1976). Field study of risk taking behavior of automobile drivers. Perceptual and Motor Skills, 43, 471-474.

Johansson, G., & Rumar, F. (1966). Drivers and road signs: A preliminary investigation of the capacity of car drivers to get information from road signs. Ergonomics, 9, 57-62.

Kahneman, D., Slovic, P., & Tversky, A. (Eds.) (1982). Judgment under uncertainty: Heuristics and biases. New York: Cambridge University Press.

Kemper, W.J. Modified railroad-highway grade crossing pavement marking and crossbuck study. Public Roads, in press.

King, G.F. (1975). Guidelines for uniformity in traffic signal design configurations (Report No. 38). Interim draft report to Transportation Research Board.

Knoblauch, K., Hucke, W., & 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.

Konecni, V.J., Ebbesen, E.B., & Konecni, D.K. (1976). Decision processes and risk taking in traffic: Driver response to onset of yellow light. Journal of Applied Psychology, 61(3), 359-367.

Koziol, J.S., & Mengert, P.H. (1978). Railroad grade crossing passive signing study (Report No. FHWA-RD-78-34). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Kryter, K.D. (1985). The effects of noise on man (2nd ed.). New York: Academic Press.

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

Lauer, A.R., & Suhr, V.W. (1956). An experimental study of four methods of reflectorizing railway box cars. Highway Research Bulletin, 146, 45-50.

Leibowitz, H.W. (1985). Grade crossing accidents and human factors engineering. American Scientist, 73, 558-562.

Leibowitz, H.W., & Owens, D.A. (1986). We drive by night. Psychology Today, 20(1), 55-58.

Lepkowski, J.R., & Mullis, W.F. (1973). Considerations for improving the conspicuity of railroad rolling stock (Report No. NBSIR 73-269). Washington, D.C.: Department of Transportation, Federal Railroad Administration.

Lerner, N.D., & Collins, B.L. (1980). The assessment of safety symbol understandability by different testing methods (Report No. NBSIR 80-2088). Washington, D.C.: U.S. Department of Commerce, National Bureau of Standards.

Lerner, N., Williams, A., & Sedney, C. (1988). Risk perception in highway driving. Wheaton, MD: COMSIS Corporation.

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

Lipinski, M.E., & Wortman, R.H. (1976). Effect of illumination on rural at-grade intersection accidents (Abridgement) (pp. 25-27). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Lunenfeld, H., & Powers, R.D. (1985). Improving highway information at hazardous locations--Seven case studies (Report No. DOT-I-85-16). Washington, D.C.: Office of the Secretary of Transportation.

Mace, D.J., Perchonok, K., & Pollack, L. (1982). Traffic signs in complex visual environments (Report No. FHWA/RD-82/102). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Maleck & Hummer (1986). Driver age and highway safety (pp. 6-12). Transportation Research Record, 1059. Washington, D.C.: Transportation Research Board.

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 Railroad Administration.

Meeker, F.L., & Barr, R.A. An observational study of driver behavior at a protected railroad grade crossing as trains approach. Accident Analysis and Review, in press.

Messer, C.J., Mounce, J.M., & Brackett, R.A. (1981). Highway geometric design consistency related to driver expectancy (Report No. FHWA-RD-81-036). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Michael, H.L. (1968). Factors influencing safety at highway-railway grade crossings--A summary of recent research. American Railway Engineering Association Bulletin, 69(614), 790-796.

Moran, A. (1982). Drivers' mental load and subjective risk estimates while driving road sections of different accident histories (pp. 72-75). Proceedings of Annual Human Factors Association of Canada 15th Annual Meeting. Toronto, Ontario: Human Factors Association of Canada.

Mortimer, R.G. (1988). Human factors in highway-railroad grade crossing accidents (pp. 35-70). In G.A. Peters and B.J. Peters (Eds.) Automotive Engineering and Litigation, Volume 2. New York: Garland Law Publishing.

Moskowitz, H. (1985). Marihuana and driving. Accident Analysis and Prevention, 17, 323-345.

National Highway Traffic Safety Administration. Fatal accident report system 1986 annual report. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

National Transportation Safety Board (1986). Safety study--Passenger/commuter train and motor vehicle collisions at grade crossings (Report No. NTSB/SS-86/04). Washington, D.C.: National Transportation Safety Board.

National Transportation Safety Board (1981). Safety effectiveness evaluation--The improvement of nighttime conspicuity of railroad trains (Report No. NTSB-SEE-81-3). Washington, D.C.: National Transportation Safety Board.

Nichelson, G.R. (1987). Sight distance and approach speed (pp. 20-25). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

OECD Road Research Group (1974, November. Capacity of at-grade junctions. Organization for Economic Cooperation and Development.

Pachella, R. (1974). The use of reaction time measures in information processing research. In B.H. Kantowitz (Ed.), Human information processing. Hillsdale, New Jersey: Erlbaum Associates.

Parsonson, P.S., & Rinalducci, E.J. (1982). Positive-guidance demonstration project at a railroad-highway grade crossing (pp. 29-34). Transportation Research Record, 844. Washington, D.C.: Transportation Research Board.

Peterson, D.D., & Boyer, D.S. (1977). Innovative concepts and technology for railroad-highway grade crossing motorist warning systems. Vol. II, The generation and analysis of alternative concepts (Report No. FRA/ORD-77/37.II). Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Peterson, D.D., & Boyer, D.S. (1975). Feasibility study of in-vehicle warning systems (Report No. DOT-HS-256-3-752). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Pinnell, C., Mason, J.M., Berg, W.D., Coleman, J.A., & Rosenbaum, M.J. (1982). Railroad-Highway Grade Crossings (Chapter 13) (Report No. FHWA-TS-82-233). In Synthesis of safety research related to traffic control and roadway elements: Vol. 2. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Pitz, G.F. (1965). Response variability in the estimation of relative frequency. Perceptual and Motor Skills, 21, 867-873.

Poage, J.L., & Hopkins, J.B. (1983). Measurements and analysis of degradation of freight car reflectors in revenue service (pp. 67-74). Transportation Research Record, 904. Washington, D.C.: Transportation Research Board.

Poage, J.L., Pomfret, J.C., & Hopkins, J.B. (1982). Freight car reflectorization (Report No. FRA-RRS-83-1). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Post, T.J., Alexander, G.J., & 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.

Raab, F.H., Brooker, M.C., Ryan, T.E., & Waechter, J.R. (1977). Innovative concepts and technology for railroad-highway grade crossing motorist warning systems. Vol. I: Overview and concept generation and analysis (Report No. FRA/ORD-77/37.I) Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Rail-highway crossing accident/incident and inventory bulletin, No. 10, Calendar Year 1987. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, August 1988.

Richards, H.A. (1985). Alternative highway-rail safety improvements (pp. 70-74). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Richards, S.H., & Heathington, 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.

Risky decision-making in transport operations (1988, April). Ergonomics, 31(4).

Roer, P.O. (1968). Traffic safety and the use of intersection control devices (pp. 538-555). Proceedings, 1968 Convention, Canadian Good Roads Association. Toronto, Ontario, September-October, 1968.

Ruden, R.J., Burg, A., & 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.

Ruden, R.J., Wasser, C.F., Hulbert, S., & Burg, A. (1977). Motorists' requirements for active grade crossing warning devices (Report No. FHWA-RD-77-167). Washington, D.C.: U.S. Department of Transportation Federal Highway Administration.

Rumar, K. (1974). Conspicuity of beacons for emergency vehicles (Report No. 152). Sweden: Uppsala University.

Russell, E.R. (1974). Analysis of driver reaction to warning devices at a high accident rural grade crossing, Joint Highway Research Project (Report No. 74-16). Lafayette, Indiana: Purdue University.

Russell, E.R., & Konz, S. (1980). Night visibility of trains at railroad-highway grade crossings (Abridgement) (pp. 7-11). Transportation Research Record, 773. Washington, D.C.: Transportation Research Board.

Russell, E., Pelter, L., & Mather, R. (1979, July). Two field studies on rail-highway grade-crossing illumination. Paper presented at the 1st International Symposium on Transportation Safety. San Diego, CA.

Sanders, J.H. (1972). Speed profiles and time delay at rail-highway grade crossings (Report No. FHWA-RD-72-22). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Sanders, M.C., Aylworth, C., & O'Benar, J. (1974). An evaluation of five railroad engine alerting and warning light systems (Report No. RDTR 265). Crane, Indiana: Research and Development Department, Naval Ammunition Depot.

Sanders, J.H., Jr., Kolsrud, G.S., & Berger, W.G. (1973). Human factors countermeasures to improve highway-railway intersection safety (Report No: DOT-HS-800 888). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Sanders, J.H., McGee, H.W., & Yoo, C.S. (1978). Safety features of stop signs at rail-highway grade crossings Vol. I, Executive Summary (Report No. FHWA-RD-78-40). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Schoppert, D.W., & Hoyt, D.W. (1968). Factors influencing safety at highway-rail grade crossings (NCHRP Report 50). Washington, D.C.: Highway Research Board.

Schwab, R.N. (1976). Improved traffic operations during adverse environmental conditions (Project 1L). U.S. Department of Transportation, Federal Highway Administration.

Shinar, D. (1978). Psychology on the road: The human factor in traffic safety. New York: John Wiley & Sons.

Shinar, D., & Raz, S. (1982). Driver response to different railroad crossing protection systems. Ergonomics, 25(9), 801-808.

Shoptaugh, C.F. (1988). Risktaking and driver behaviors: A laboratory study (pp. 923-927). Proceedings of the Human Factors Society, 32nd Annual Meeting, Vol. 2. Santa Monica, CA: The Human Factors Society.

Skinner, R.E. (1971). Investigate uses and types of rumble strips and their adaptability for approaches to highway-railway grade crossings. American Railway Engineering Association Bulletin, 73(635), 198-199.

Sonefeld, O.F. (1979). Discussion (pp. 41-42) of R.G. McGinnis, Reflectorization of railroad rolling stock. Transportation Research Record, 737. Washington, D.C.: Transportation Research Board.

Stein, A.C., Allen, R.W., Cook, M.L., & Karl, R.L. (1983). A simulatory study of the combined effects of alcohol and marihuana on driving behavior--Phase II (Report No. DOT-HS-806-405). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Svenson, O. (1981). Are we all less risky and more skillful than our fellow drivers? Acta Psychologica, 47, 143-148.

Texas Highway Department (1974, September). Final diagnostic report, rail-highway safety improvement program. Austin, Texas.

Tidwell, J.E., Jr., & Humphreys, J.B. (1982). Improving safety at passive crossings with restricted sight distance (pp. 29-36). Transportation Research Record, 841. Washington, D.C.: Transportation Research Board.

Tidwell, J.E., Jr., & Humphreys, J.B. (1981). Driver knowledge of grade-crossing information (pp. 28-32). Transportation Research Record, 811. Washington, D.C.: Transportation Research Board.

Traffic Control Devices Handbook (1983). U.S. Department of Transportation, Federal Highway Administration.

Traister, C.W. (1965). Methods of providing additional advance warning to highway traffic approaching a highway-railway grade crossing. American Railway Engineering Association Bulletin, 67(595).

Transportation Research Board (1988). Transportation in an aging society (Special report 218). Washington, D.C.: Transportation Research Board.

Triggs, T.J. (1988). Speed estimation (pp. 569-598). In G.A. Peters and B.J. Peters (Eds.) Automotive engineering and litigation, Vol. 2. New York: Garland Law Publishing.

Triggs, T.J., & Berenyi, J.S. (1982). Estimation of automobile speeds under day and night conditions. Human Factors, 24(1), 111-114.

Tustin, B.H. (1985). Identifying engineering improvement alternatives for railroad-highway guide crossings (pp. 173-180). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Tustin, B.H., Richards, H., McGee, H., & Patterson, R. (1986). Railroad-Highway Grade Crossing Handbook--Second Edition (Report No. FHWA-TS-86-215). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Urbanik, T. (1971). Driver information systems for highway-railway grade crossings. Joint Highway Research Project (Report No. 11). Lafayette, Indiana: Purdue University.

Warren D.L. (1982). Speed zoning and control (Chapter 17) (Report No. FHWA-TS-82-233). In Synthesis of safety research related to traffic control and roadway elements: Vol. 2. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Watts, G., & Quimby, A. (1980). Aspects of road layout that affect drivers' perception and risk taking (Report No. TRRL-LR-920). Berkshire, England: Department of the Environment, Department of Transport.

Wickelgren, W. (1977). Speed accuracy tradeoff and information processing dynamics. Acta Psychologica, 41, 67-85.

Wickens, C.D. (1984). Engineering psychology and human performance. Columbus, Ohio: Charles E. Merrill Publishing Company.

Wierwille, W.W., Rahimi, M., & Casali, J.G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. Human Factors, 27(5), 489-502.

Wigglesworth, E.C. (1979). Epidemiology of road-rail crossing accidents in Victoria, Australia. Journal of Safety Research, 11(4), 162-171.

Wigglesworth, E.C. (1978). The effects of local knowledge and sight restrictions on driver behavior at open railway crossings. Journal of Safety Research, 10(3), 100-107.

Wilde, G.J.S. (1986). Beyond the concept of risk homeostasis: Suggestions for research and application towards the prevention of accidents and lifestyle-related disease. Accident Analysis and Prevention, 18, 377-401.

Wilde, G. (1976). Social interaction patterns in driver behavior: An introductory review. Human Factors, 18(5), 477-492.

Wilde, G.J.S., Cake, L.J., & McCarthy, M.B. (1975). An observational study of driver behaviour at signalized railroad crossings. (Report No. 75-16). Kingston, Ontario: Canadian Institute of Guided Ground Transport, Queen's University.

Wogalter, M.S., McKenna, N.A., & Allison, S.T. (1988). Warning compliance: Behavioral effects of cost and consensus (pp. 901-904). Proceedings of the Human Factors Society, 32nd Annual Meeting, Vol. 2. Santa Monica, CA: The Human Factors Society.

Zaidel, D., Hakkert, A-S., & Barkan, R. (1986). Rumble strips and paint stripes at a rural intersection (pp. 7-13). Transportation Research Record. 1069. Washington, D.C.: Transportation Research Board.

APPENDIX A

BIBLIOGRAPHY ON DRIVER BEHAVIOR AT RAIL-HIGHWAY CROSSINGS

Aberg, L. (1988). Driver behavior at flashing-light, rail-highway crossings. Accident Analysis and Prevention, 20(1), 59-65.

Aberg, L. (1985). Driver behaviour and risk of accident at flashing lights: Railway-highway crossings (Report No. 374-1985). Uppsala, Sweden: Uppsala University, Sweden Psykologiska Institutionen.

Amundsen, F.H. (1985, November). Norway curbs accidents at highway-rail. ITE Journal, 27-29.

Andrews, W.H. (1987). Improving the visibility of railroad-highway grade crossing signals. Public Roads, 51(2), 25-35.

Anderson, R.W. (1987). Grade crossing hazards. Transafety Reporter, 5(2), 4-5.

Andrews, W.H., Armstrong, G.A., & Bowers, T.L. (1987). Railroad-highway grade crossing signal visibility improvement project (Report No. FHWA/RD-86/186). Washington, D.C.: Federal Highway Administration.

Aurelius, J.P., & Korobow, N. (1971). The visibility and audibility of trains approaching rail-highway grade crossings (Report No. FRA-RP-71-2). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Baer, P., & Callahan, R. (1987). Grade crossing safety through low-cost improvements (pp. 39-43). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

Baer, P., & Volmer, N. (1987). Highway/railroad grade crossings. Identification and signing. Ames, Iowa: Iowa Department of Transportation, Rail and Water Division.

Baier, J. (1987). The design and selection of active warning systems for rail-highway crossings (pp. 34-38). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

Basha, P.E. (1985). Sight distance analysis at railway-highway intersections. ITE Journal, 55 (4), 2.

Bates, L.H., (1985). Use of strobe lights at railroad grade crossings. ITE Journal, 55(11), 32-35.

Berg, W.D. (1986). Critique of rail-highway grade crossing effectiveness ratios and resource allocation procedures (pp. 88-100). Transportation Research Record, 1069. Washington, D.C.: Transportation Research Board.

Berg, W.D. (1985). Driver information needs and implications for safety measures (pp. 33-42). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Berg, W.D. (1979). Experimental design for evaluating the safety benefits of railroad advance warning signs (Report No. FHWA-RD-79-78). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Berg, W.D., Fuchs, C., & Coleman, J. (1980). Evaluating the safety benefits of railroad advance-warning signs (pp. 1-6). Transportation Research Record, 773. Washington, D.C.: Transportation Research Board.

Berg, W.D., Knoblauch, K., & Hucke, W. (1982). Causal factors in railroad-highway grade crossing accidents (pp. 47-54). Transportation Research Record, 847. Washington, D.C.: Transportation Research Board.

Berg, W.D., Schultz, T.G., & Oppenlander, J.C. (1970). Proposed warrants for protective devices at railroad-highway grade crossings. Pt. 2: Urban areas. Traffic Engineering, 40(9), 36-42.

Bezkorovainy, G., & Holsinger, R.G. (1966). The use of stop signs at railroad crossings. Lincoln, Nebraska: Lincoln Traffic Engineering Department, City of Lincoln.

Bokun, S.G., & Moore, A.F. (1983). Evaluation of experimental railroad-highway grade crossings in Louisiana (Report No. FHWA LA-83/65). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Bowman, B.L. (1985). Analysis of railroad-highway crossing active advance warning devices (Report No. FHWA/RD-85/182). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Bowman, B.L. (1985). Constant warning time devices for railroad-highway crossings (Report No. FHWA/RD-86/156). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Bowman, B.L. (1985). The use of constant warning time devices. Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Bowman, B.L. (1987). Analysis of railroad-highway crossing active advance warning devices (pp. 141-151). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board.

Bowman, B.L. (1987). The effectiveness of railroad constant warning time systems (pp. 111-122). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board.

Bowman, B.L., & McCarthy, K.P. (1985). Consequences of mandatory stops at railroad-highway crossings (Report No. FHWA-RD-86-014). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Bowman, B.L., McCarthy, K.P., & Hughes, G. (1986). The safety, economic, and environmental consequences of requiring stops at railroad-highway crossings (pp. 117-125). Transportation Research Record, 1069. Washington, D.C.: Transportation Research Board.

Bowman, B.L., & McCarthy, K.P. (1986). The use of constant warning time systems at rail-highway grade crossings (pp. 110-117). Transportation Research Record, 1069. Washington, D.C.: Transportation Research Board.

Butcher, T.A. (1973). Evaluation of safety improvements at highway-railway grade crossings. Joint Highway Research Project (Report No. 1-73). Lafayette, Indiana: Purdue University.

Clements, W.J. (1987). Highway geometrics: Prime factors in safety for rail-highway crossings at grade (pp. 29-32). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

Coleman, J.A. (1980). Credibility (pp. 67-70). Proceedings, 1980 National Rail-Highway Crossing Safety Conference, Knoxville, Tennessee, June, 1980.

Coleman, J., Koziol, J.S., & Mengert, P.H. (1977). Railroad grade crossing passive signing study--Phase 1. Public Roads, 40(4), 141-144.

Coleman, J., Koziol, J.S., & Mengert, P.H., (1979). Railroad grade crossing passive signing study--Phase 2. Public Roads, 42(4), 128-135.

Coleman, J., & Stewart, G.R. (1976). Investigation of accident data for railroad-highway grade crossings (pp. 60-67). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Coulombre, R.E. (1974). Rail safety/grade crossing warning research program (pp. 77-84). Proceedings, 1974 National Conference on Railroad-Highway Crossing Safety. Colorado Springs, Colorado, August, 1974.

Cowley, J.E. (1976). Safety at Australian railway level crossings--An evaluation of the literature (Monograph). Melbourne, Australia: Ministry of Transport.

Cox, J.J. (1972). Road-rail protection--Audible warning effectiveness. Australian Road Research Board Conference Proceedings, 6, Part 2, 448-466.

Davis, D.R. (1966). Railway signals passed at danger: The drivers, circumstances and psychological processes. Ergonomics, 9(3), 211-222.

Devoe, D.B., & Abernethy, C. (1975). Field evaluation of locomotive conspicuity lights (Report No. FRA-OR&D-75-54). Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Dommasch, I.N., Hollinger, R.L., & Reilly, E.F. (1976). Passive control at rail-highway grade crossings (Report No. FHWA-RD-78-T0296). Trenton, New Jersey: New Jersey Department of Transportation.

Dommasch, I.N., Hollinger, R.L., & Reilly, E.F. (1976). Passive control at railroad-highway grade crossings (Abridgement) (pp. 58-59). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Eck, R.W., & Halkias, J.A. (1984). Effectiveness of warning devices at rail-highway grade crossings (Report No. FHWA/WV-84/002). Morgantown, West Virginia: West Virginia University.

Eck, R.W., & Halkias, J.A. (1985). Further investigation of the effectiveness of warning devices at rail-highway grade crossings (pp. 94-101). Transportation Research Record, 1010. Washington, D.C.: Transportation Research Board.

Eck, R.W., & Shanmugam, R. (1987). Physical and operational characteristics of rail-highway grade crossings on low-volume roads (pp. 246-255). Transportation Research Record, 1106. Washington, D.C.: Transportation Research Board.

Ells, J.G., Dewar, R.E., & Milloy, D.G. (1980). An evaluation of six configurations of the railway crossbuck sign. Ergonomics, 23(4), 359-367.

Fambro, D.B., & Heathington, K.W. (1984). Motorists' understanding of active warning devices used at railroad-highway grade crossings. ITE Technical Notes, 9(2), in ITE Journal, 54(4), 38-40.

Farr, E.H., & Hitz, J.S. (1985). Effectiveness of motorist warning devices at rail-highway crossings (Report No. FHWA/RD-85/015). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Federal Highway Administration (1978). Traffic control systems for railroad-highway grade crossings. Manual on Uniform Traffic Control Devices for Streets and Highways: Part VIII. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Federal Railroad Administration & Federal Highway Administration (1971). Report to Congress. Railroad-highway safety. Part I. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, Federal Highway Administration.

Federal Railroad Administration & Federal Highway Administration (1972). Report to Congress. Railroad-highway safety. Part II. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, Federal Highway Administration.

Gillespie, T.D. (1986). Start-up accelerations of heavy trucks on grades (pp. 107-112). Transportation Research Record, 1052. Washington, D.C.: Transportation Research Board.

Gordon, D.A., McGee, H.W., & Hooper, K.G. (1984). Driver characteristics impacting highway design and operations. Public Roads, 48(1), 12-16.

Gossard, W. (1987). Sight distance: A factor in highway-rail grade crossing accidents (pp. 16-19). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

Grade crossing safety--today's needs: More coordination, cooperation--and money. Railway Age, 1980, 181(15), 32-38.

Grade crossings: Time for a new look? Railway Age, October, 1987, 59-60.

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. Santa Monica, California: The Human Factors Society.

Halkias, J.A., & Blanchard, L. (1987). Accident causation analysis at railroad crossings protected by gates (pp. 123-130). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board.

Halkias, J.A., & Eck, R.W. (1985). Effectiveness of constant-warning-time versus fixed-distance warning systems at rail-highway grade crossings (pp. 101-116). Transportation Research Record, 1010. Washington, D.C.: Transportation Research Board.

Hall, J.W. (1981). Rail-highway grade crossing safety (Report No. FHWA-NMDOT-81-82). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Hall, J.W. (1983). Field study of rail-highway grade-crossing crash sites (pp. 93-98). Transportation Research Record, 910. Washington, D.C.: Transportation Research Board.

Hauer, E., & Persaud, B.N. (1987). How to estimate the safety of rail-highway grade crossings and the safety effects of warning devices (pp. 131-140). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board.

Heathington, K.W. (1985). Facilitating field evaluation of new traffic control devices for railroad-highway grade crossings (pp. 127-133). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Heathington, K.W. (1982). Development of innovative railroad-highway active warning devices (pp. 16B-33B). Proceedings, 1982 National Conference on Railroad/Highway Safety. Kansas City, Missouri, August, 1982.

Heathington, K.W., Fambro, D.B., & Richards. S.H. (1988). Field evaluation of innovative active warning devices for use at railroad-highway grade crossings, Vol. I (Report No. FHWA-RD-88-130). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Heathington, K.W., Fambro, D.B., & Richards. S.H. (1988). Field evaluation of innovative active warning devices for use at railroad-highway grade crossings, Vol. II (Report No. FHWA-RD-88-135). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Heathington, K.W., Fambro, D.B., & Rochelle, R.W. (1984). Evaluation of six active warning devices for use at railroad-highway grade crossings (pp. 1-4). Transportation Research Record, 956. Washington, D.C. Transportation Research Board.

Heathington, K.W., Fambro, D.B., & Rochelle, R.W. (1983). Experimental plan for field testing three active warning devices for use at railroad-highway grade crossings. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Heathington, K.W., Fambro, D.B., & Rochelle, R.W. (1983). Laboratory evaluation of six active warning devices for use at railroad-highway grade crossings. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Heathington, K.W., & Urbanik, T. (1972). Driver information systems for highway-railway grade crossings (pp. 59-77). Highway Research Record, 414. Washington, D.C.: Highway Research Board.

Heathington, K.W., Wunderlich, R.C., & Humphreys, J.B. (1981). Domestic and foreign research and practices in railroad-highway grade crossing safety. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Hitz, J.S. (Ed.) (1977). Summary statistics of the national railroad-highway crossing inventory of public at-grade crossings (Report No. DOT-TSC-FRA-77-10). Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Hopkins, J.B. (1980). Operational testing of locomotive-mounted strobe lights (Report No. DOT-TSC-FRA/ORD-80-48). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development.

Hopkins, J.B., & Holmstrom, F.R. (1976). Toward more effective grade-crossing flashing lights (pp. 1-14). Transportation Research Record, 562. Washington, D.C.: Transportation Research Board.

Hopkins, J.B., & Newfell, A.T. (1975). Guidelines for enhancement of visual conspicuity of trains at grade crossings. (Report No. DOT-TSC-FRA-74-15 and FRA-OR&D-75-71). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Hopkins, J.B., & 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.: U.S. Department of Transportation, Federal Railroad Administration.

Hulbert, S. (1972). Driver information systems (pp. 110-132). Human Factors in Highway Traffic Safety Research. New York: Wiley & Sons, Inc.

Hulbert, S.F. (1967). Information and enforcement (pp. 27-30). Proceedings, Grade Crossing Safety Symposium. Texas Transportation Institute.

Hulbert, S.F. & Burg, A. (1968). Appendix B: Application of human factors research in design of warning devices for highway-rail grade crossings. In D.W. Schoppert and D.W. Hoyt, Factors influencing safety at highway rail crossings (NCHRP Report 50). Washington, D.C.: Highway Research Board.

Humphreys, J.B., & Heathington, K.W. (1981). Evaluating the effectiveness of innovative railroad-highway crossing warning devices. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Hungerford, J.C., & Heathington, K.W. (1981). Conceptualization and subjective evaluation of innovative railroad-highway crossing active warning devices. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Jackson, L.E. (1982). Railroad/highway grade crossing accidents involving trucks transporting bulk hazardous materials. ITE Journal, 52(10).

Kansas State University (1983). Compilation of state laws and regulations on matters affecting rail-highway crossings (Report No. FHWA-TS-83-203). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Kearney, E.F. (1979). Drivers' duties at railroad grade crossings. Traffic Laws Commentary, 89(1).

Kemper, W.J. Modified railroad-highway grade crossing pavement marking and crossbuck study. Public Roads, in press.

Knoblauch, K., Hucke, W., & Berg, W. (1982). Rail highway crossing accident causation study. Vol. I, Executive Summary (Report No. FHWA-RD-81-82). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Knoblauch, K., Hucke, W., & 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.

Koziol, J.S., & Mengert, P.H. (1978). Railroad grade crossing passive signing study (Report No. FHWA-RD-78-34). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

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

Lauer, A.R., & Suhr, V.W. (1956). An experimental study of four methods of reflectorizing railway box cars. Highway Research Bulletin, 146, 45-50.

Leibowitz, H.W. (1985). Grade crossing accidents and human factors engineering. American Scientist, 73, 558-562.

Leibowitz, H.W., & Owens, D.A. (1986). We drive by night. Psychology Today, 20(1), 55-58.

Lepkowski, J.R., & Mullis, W.F. (1973). Considerations for improving the conspicuity of railroad rolling stock (Report No. NBSIR 73-269). Washington, D.C.: Department of Transportation, Federal Railroad Administration.

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

Lipinski, M.E., & Wortman, R.H. (1976). Effect of illumination on rural at-grade intersection accidents (Abridgement) (pp. 25-27). Transportation Research Record, 611. Washington, D.C. Transportation Research Board.

Lunenfeld, H. (1982). The positive guidance approach to satisfying driver information needs at rail/highway grade crossings (pp. 1F-8F). Proceedings, 1982 National Conference on Railroad Highway Safety. Kansas City, Missouri, August, 1982.

Lunenfeld, H., & Powers, R.D. (1985). Improving highway information at hazardous locations--Seven case studies (Report No. DOT-I-85-16). Washington, D.C.: Office of the Secretary of Transportation.

Mahalel, D., & Prashker, J.N. (1987). A behavioral approach to risk estimation of rear-end collisions at signalized intersections (pp. 96-102). Transportation Research Record, 1114. Washington, D.C.: Transportation Research Board.

Mather, Richard A. (1983). Public railroad-highway grade crossing illumination project in Oregon. Washington, D.C.: Transportation Research Board.

McGinnis, R.G. (1979). Reflectorization of railroad rolling stock (pp. 31-40). Transportation Research Record, 737. Washington, D.C.: Transportation Research Board.

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 Railroad Administration.

Meeker, F.L., & Barr, R.A. An observational study of driver behavior at a protected railroad grade crossing as trains approach. Accident Analysis and Review, in press.

Messiter, G.F. (1972). Crashes at railway level crossings. Sydney, Australia: New South Wales Department of Motor Transport.

Michael, H.L. (1968). Factors influencing safety at highway-railway grade crossings--A
summary of recent research. American Railway Engineering Association Bulletin, 69(614), 790-796.

Monroe, R.L., Munsell, D.K., & Rudd, T.J. (1981). Constant warning time concept development for motorist warning at grade crossings (Report No. FRA/ORD-81/07). Washington, D. C.: U.S. Department of Transportation, Federal Railroad Administration.

Morrissey, J. (1980). The effectiveness of flashing lights and flashing lights with gates in reducing accident frequency at public rail-highway crossings, 1975-1978. (Report No. DOT-TSC-FRA-80-19). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Mortimer, R.G. (1988). Human factors in highway-railroad grade crossing accidents (pp. 35-70). In G.A. Peters and B.J. Peters (Eds.) Automotive Engineering and Litigation, Volume 2. New York: Garland Law Publishing.

National Transportation Safety Board (1986). Safety study--Passenger/commuter train and motor vehicle collisions at grade crossings (Report No. NTSB/SS-86/04). Washington, D.C.: National Transportation Safety Board.

National Transportation Safety Board (1981). Safety effectiveness evaluation--The improvement of nighttime conspicuity of railroad trains (Report No. NTSB-SEE-81-3). Washington, D.C.: National Transportation Safety Board.

New study assesses motorist understanding of grade-crossing laws (1988). Transafety Reporter, 6(3), 3.

Nichelson, G.R. (1987). Sight distance and approach speed (pp. 20-25). Proceedings, 1987 National Conference on Highway-Rail Safety. Denver, Colorado, September, 1987.

North Dakota couple awarded $11 million from Burlington Northern Railroad. Transafety Reporter, 1986, 4(1), 1-2.

Nylund, E.E., & Holtermann, P.C. (1980). Identification and evaluation of off-track train detection systems for grade crossing application (Report No. FRA/ORD-80-32). Washington, D.C.: U.S. Department of Transportation. Federal Railroad Administration.

Overton, J.M. (1985). Railroad-highway crossing research activities (pp. 121-126). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri: July, 1985.

Paltell, E. (1984). An investigation of safety problems at skewed rail-highway grade crossings (Report No. VHWA/VA-84-47). Richmond, Virginia: Virginia Department of Highways and Transportation.

Parsonson, P.S., & Rinalducci, E.J. (1982). Positive-guidance demonstration project at a railroad-highway grade crossing (pp. 29-34). Transportation Research Record, 844. Washington, D.C.: Transportation Research Board.

Paulis, S.F., & Meyer, E.D. (1981). Illinois experimental railroad crossing signing study. Springfield, Illinois: Department of Transportation, Division of Traffic Safety.

Peterson, D.D., & Boyer, D.S. (1977). Innovative concepts and technology for railroad-highway grade crossing motorist warning systems. Vol. II, The generation and analysis of alternative concepts (Report No. FRA/ORD-77/37.II). Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Peterson, D.D., & Boyer, D.S. (1975). Feasibility study of in-vehicle warning systems (Report No. DOT-HS-256-3-752). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Pinnell, C., Mason, J.M., Berg, W.D., Coleman, J.A., & Rosenbaum, M.J. (1982). Railroad-Highway Grade Crossings (Chapter 13) (Report No. FHWA-TS-82-233). In Synthesis of safety research related to traffic control and roadway elements: Vol. 2. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Poage, J.L., & Hopkins, J.B. (1983). Measurements and analysis of degradation of freight car reflectors in revenue service (pp. 67-74). Transportation Research Record, 904. Washington, D.C.: Transportation Research Board.

Poage, J.L., Pomfret, J.C., & Hopkins, J.B. (1982). Freight car reflectorization (Report No. FRA-RRS-83-1). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Powell, J.L. (1982). Effects of rail-highway grade crossings on highway users (pp. 21-28). Transportation Research Record, 841. Washington, D.C.: Transportation Research Board.

Priest, W.C., & Knoblauch, K. 1978). Analysis of NPRM strobe lights on locomotives (Report No. FRA/OPPD-79/4). Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration.

Raab, F.H., Brooker, M.C., Ryan, T.E., & Waechter, J.R. (1977). Innovative concepts and technology for railroad-highway grade crossing motorist warning systems. Vol. I: Overview and concept generation and analysis (Report No. FRA/ORD-77/37.I) Cambridge, Massachusetts: U.S. Department of Transportation, Transportation Systems Center.

Rail-highway crossing accident/incident and inventory bulletin, No. 9, Calendar Year 1986. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, June 1987.

Rail-highway crossing accident/incident and inventory bulletin, No. 10, Calendar Year 1987. Washington, D.C.: U.S. Department of Transportation, Federal Railroad Administration, August 1988.

Railroad-highway grade crossings: Update, Bibliography 58. Washington, D.C.: Transportation Research Board, 1980.

Railroad-highway grade crossings, Bibliography 57. Washington, D.C.: Transportation Research Board, 1976.

Richards, H.A. (1985). Alternative highway-rail safety improvements (pp. 70-74). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Richards, S.H., & Heathington, 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.

Ruden, R.J., Burg, A., & 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.

Ruden, R.J., Wasser, C.F., Hulbert, S., & Burg, A. (1977). Motorists' requirements for active grade crossing warning devices (Report No. FHWA-RD-77-167). Washington, D.C.: U.S. Department of Transportation Federal Highway Administration.

Russell, E.R. (1974). Analysis of driver reaction to warning devices at a high accident rural grade crossing, Joint Highway Research Project (Report No. JHRP-74-16). Lafayette, Indiana: Purdue University.

Russell, E., & Konz, S. (1979, July). An evaluation of illumination at rail-highway grade crossings. Kansas State University.

Russell, E.R., & Konz, S. (1980). Night visibility of trains at railroad-highway grade crossings (Abridgement) (pp. 7-11). Transportation Research Record, 773. Washington, D.C.: Transportation Research Board.

Russell, E.R., Michael, H.L., & Butcher, T.A. (1976). Analysis of changes in driver reaction to improved warning devices at a rural grade crossing, Joint Highway Research Project (Report No. 76-7). Lafayette, Indiana: Purdue University.

Russell, E.R., Michael, H.L., & Butcher, T.A. (1976). Driver reaction to improved warning devices at a rural grade crossing (Abridgement) (p. 68). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Sanders, J.H. (1972). Speed profiles and time delay at rail-highway grade crossings (Report No. FHWA-RD-72-22). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Sanders, J.H. (1976). Driver performance in countermeasure development at railroad-highway grade crossings (pp. 28-37). Transportation Research Record, 562. Washington, D. C.: Transportation Research Board.

Sanders, J.H., Jr., Kolsrud, G.S., & Berger, W.G. (1973). Human factors countermeasures to improve highway-railway intersection safety (Report No: DOT-HS-800 888). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Sanders, J.H., McGee, H.W., & Yoo, C.S. (1978). Safety features of stop signs at rail-highway grade crossings Vol. I, Executive Summary (Report No. FHWA-RD-78-40). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Sanders, J.H., McGee, H.W., & Yoo, C.S. (1978). Safety features of stop signs at rail-highway grade crossings. Vol. II, Technical Report (Report No. FHWA-RD-78-41). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Sanders, M.C., Aylworth, C., & O'Benar, J. (1974). An evaluation of five railroad engine alerting and warning light systems (Report No. RDTR 265). Crane, Indiana: Research and Development Department, Naval Ammunition Depot.

Schoppert, D.W., & Hoyt, D.W. (1968). Factors influencing safety at highway-rail grade crossings (NCHRP Report 50). Washington, D.C.: Highway Research Board.

Schulte, W.R. (1976). Effectiveness of automatic warning devices in reducing accidents at grade crossings (pp. 49-57). Transportation Research Record, 611. Washington, D.C.: Transportation Research Board.

Shinar, D, & Raz, S. (1982). Driver response to different railroad crossing protection systems. Ergonomics, 25(9), 801-808.

Skinner, R.E. (1971). Investigate uses and types of rumble strips and their adaptability for approaches to highway-railway grade crossings. American Railway Engineering Association Bulletin, 73(635), 198-199.

Snider, J.N., & Hungerford, J.C. (1982). Laboratory specification and testing of alternative active railroad-highway grade crossing warning devices. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Sonefeld, O.F. (1979). Discussion (pp. 41-42) of R.G. McGinnis, Reflectorization of railroad rolling stock. Transportation Research Record, 737. Washington, D.C.: Transportation Research Board.

Texas Highway Department (1974, September). Final diagonstic report, rail-highway safety improvement program. Austin, Texas.

Tidwell, J.E., Jr., & Humphreys, J.B. (1982). Improving safety at passive crossings with restricted sight distance (pp. 29-36). Transportation Research Record, 841. Washington, D.C.: Transportation Research Board.

Tidwell, J.E., Jr., & Humphreys, J.B. (1981). Driver knowledge of grade-crossing information (pp. 28-32). Transportation Research Record, 811. Washington, D.C.: Transportation Research Board.

Tustin, B.H. (1985). Identifying engineering improvement alternatives for railroad-highway guide crossings (pp. 173-180). Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, Missouri, July, 1985.

Tustin, B.H. (1981). Investigation of anomalous rail-highway crossings. Presented at the 60th Annual Meeting of the Transportation Research Board, Washington, D. C., January, 1981.

Tustin, B.H., Richards, H., McGee, H., & Patterson, R. (1986). Railroad-Highway Grade Crossing Handbook--Second Edition (Report No. FHWA-TS-86-215). Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Urbanik, T. (1971). Driver information systems for highway-railway grade crossings. Joint Highway Research Project, (Report No. 11). Lafayette, Indiana: Purdue University.

Wigglesworth, E.C. (1979). Epidemiology of road-rail crossing accidents in Victoria, Australia. Journal of Safety Research 11(4), 162-171.

Wigglesworth, E.C. (1978). The effects of local knowledge and sight restrictions on driver behavior at open railway crossings. Journal of Safety Research, 10(3), 100-107.

Wigglesworth, E.C. (1978). Human factors in level crossing accidents. Accident Analysis and Prevention, 10(3), 229-240.

Wigglesworth, E.C. (1977). The effect of local knowledge and of sight restrictions on driver behaviour at "open" road-rail crossings (Monograph). Melbourne, Australia: Royal Australasian College of Surgeons.

Wigglesworth, E.C. (1976). Human factors in road-rail crossing accidents (Monograph). Melbourne, Australia: Ministry of Transport.

Wilde, G.J.S., Cake, L.J., & McCarthy, M.B. (1976). Driver approach behaviour at six signalized railroad crossings. Zeitschrift fuer Verkehrssicherheit, 22(4), 163-169.

Wilde, G.J.S., Cake, L.J., & McCarthy, M.B. (1975). An observational study of driver behaviour at signalized railroad crossings. (Report No. 75-16). Kingston, Ontario: Canadian Institute of Guided Ground Transport, Queen's University.

Wujcik, M. (1987). Crossing programs succeed. Progressive Railroading, 30(11), 24.

Wunderlich, R.C., Heathington, K. W., Wheeler, D.J., & Humphreys, J.B. (1982). Investigation of the effectiveness of railroad-highway grade crossing warning devices. Knoxville, Tennessee: Transportation Center, The University of Tennessee.

Zaidel, D., Hakkert, A-S., & Barkan, R. (1986). Rumble strips and paint stripes at a rural intersection (pp. 7-13). Transportation Research Record. 1069. Washington, D.C.: Transportation Research Board.