# DRIVER PERFORMANCE IN COUNTERMEASURE DEVELOPMENT AT RAILROAD-HIGHWAY GRADE CROSSINGS

James H. Sanders, BioTechnology, Inc.

This paper summarizes the findings of a field demonstration study to determine the requirements for grade-crossing-accident countermeasures. Information was obtained on driver behavior, knowledge, and attitudes by using the traffic-evaluator system, time-lapse photography, and questionnaires. A review of the safety-related factors brought to the grade-crossing situation by the driver also was made. The review included licensing and education, safety programs, attitudes and habits, and driver-vehicle capabilities and limitations. An extensive analysis of these data suggested countermeasure concepts and determined target populations for countermeasure intervention. Behavior measures were isolated that may be used to discriminate among candidate countermeasures when they are applied in the field-evaluation program presented in the study.

•THIS PAPER is a summary of a report prepared for the Federal Railroad Administration and National Highway Traffic Safety Administration (1).

The study represented a required preliminary step in the field testing of countermeasures to increase motorist safety at railroad-highway grade crossings. For several years, the responsible agencies have been investigating a number of variations in active and passive protection for crossings. The basic problem in countermeasure research is determining to what extent one has developed an improved design. The research to date generally has depended on the long-term accident history of a crossing. A multitude of uncontrolled variables, such as changes in rail and highway traffic patterns and physical aspects of the immediate area, conspire to negate any results gained from a study that requires several years.

There were 2 purposes of this study: (a) to present in 1 document a characterization of the driver and the driver's requirements and (b) to develop and validate some intermediate criteria for quickly determining the relative merits of a series of countermeasures. The historical methodology has been to find some intermediate criterion that is both feasible to measure and may be shown to relate to safety. The objectives of the study were as follows:

1. To better understand the driver population and the behavior drivers display at grade crossings,
2. To define a set of safety-oriented behavioral measures that are both operationally meaningful and capable of reliable experimental measurement,
3. To isolate a set of driver characteristics that can serve as predictors of driving performance,
4. To determine the extent to which the behavioral and predictor variables can be used to develop and evaluate railroad-highway countermeasures, and
5. To suggest the most cost-effective set of measures applicable to design and evaluation of the countermeasures.

Publication of this paper sponsored by Committee on Railroad-Highway Grade Crossings.

## ACCIDENT INVESTIGATIONS

A useful model derives from work by Dimling and Miller (2) that relates driver performance and system demands to accident occurrence. As shown in Figure 1, driver performance levels and system demands on the driver vary with time. An accident occurs when performance happens to fall below that required by system demands. Low performance levels do not necessarily result in accidents, nor does a high performance level guarantee against them. What is important is the relationship between performance level and demand level.

Of particular interest is the unpredictable manner in which system demands can change, which suggests a random factor in accident occurrence. In addition to illustrating the probabilistic nature of accidents, the model shown in Figure 1 makes it clear that improving driver performance is only one way to reduce accidents. An alternate approach is to reduce system demands. Both approaches are referred to as accident countermeasures and both are treated by the study.

The study began with an examination of the causative factors in grade-crossing accidents. We were forced to conclude that the information available is not adequate to provide definitive answers to many questions about why more than 3,000 vehicle-train accidents occur each year.

The accident histories of specific crossings may be obtained. It appears that there is frequently a recurrence of the same type of accident. The nature of the accidents frequently was found to suggest modifications to individual crossings that would reduce or eliminate a major proportion of those accidents. There appears to be a need for sophistication, research, and expansion of procedures for crossing evaluation and modification performed and implemented locally. Such an accident site classification, or diagnostic procedure, enables a traffic engineer to examine sites, determine the probability that the same type of accident will recur, and define appropriate countermeasures.

Along the same lines, it was noted that a broad range of hazard index formulas exist throughout the country. The numerical index ranking of crossings within a state generally determines the order in which improvements in crossings are made. A nationwide standard method of determining a hazard index for crossings should be developed that would apply proper weights to all pertinent variables. It may be found that those crossings that exceed maximum limits should be closed until they are upgraded to reasonable standards.

## DRIVER SAFETY APPRAISAL

An appraisal of driver factors related to safe performance was undertaken to assist development of the field study design and the human factors of countermeasure applications. Six of the major categories of factors that may contribute to safe driving performance are

1. Driver education,
2. State licensing procedures,
3. Safety programs,
4. Law enforcement,
5. Attitude and habit components of railroad-highway safety, and
6. Physiological capabilities and limitations.

The driver at the grade crossing represents a highly complex situation. His or her behavior is a product of a large number of interacting factors. Some of these are physical and objectively measurable such as characteristics of the site itself, nature and status of signs and warning devices, conditions of visibility and weather, and presence or absence of a train. Many others, however, are far less tangible. They include factors such as driver knowledge, driving experience, attitude, and perception-motor capabilities. Collectively, these intangibles may be designated as the human factors of grade-crossing behavior. Figure 2 shows these factors.

Evidence was not found during the study to indict a particular subgroup of high-risk drivers that could be characterized along physiological dimensions. Accordingly, the general capabilities and limitations of drivers in the areas of information processing and related topics, vision, audition, and vibration are discussed. The discussion should be useful in obtaining approximate estimates of the adequacy of existing and new countermeasures. Of particular importance is the demonstrated degradation of driver capabilities with age. Because drivers who are 60 years old and older constitute 14 percent of the driving population and because that percentage is increasing, the importance of considering this group in the development of new countermeasure concepts cannot be overemphasized. Representative sampling by age as well as across educational and geographical lines is essential in testing new countermeasure concepts. Consideration also should be given to handicapped people, especially those who are color blind (8 percent of the male population) and those who have hearing deficiencies.

Expectancy, or set, plays an important role in motorist performance. When the driver can anticipate upcoming requirements, decision making becomes more efficient and perception-response time increases. If the information on which to base expectancy is inadequate, then the driver may develop an expectancy that is at odds with the real situation. When expectancy and the real situation are not congruent, a conflict results and the driver may react in accord with his or her expectancy rather than with the requirements of the situation. In extreme cases, the driver may react in a fashion that is not compatible with either his or her expectancy or the actual situation; in fact, the driver may not react at all.

This indicates the importance of developing advance warning signs for railroad grade crossings that distinguish between crossings protected by active devices and those not protected. At passive crossings, responsibility for detecting the approach of a train rests with the driver. He or she should be made fully aware at the advance sign that the upcoming crossing is passive so that his or her attempts to detect the presence or absence of the train begin early in the approach to the track. It is important to attract the driver's attention to the existence of the crossing whether it is active or passive. Review of railroad grade-crossing accidents is provocative. Especially interesting is the frequent occurrence of accidents that are related to inadequate attention, such as when the motorist is attending to other items than the grade crossing. The implication is that warning devices, whether they are active, passive, elaborate, or minimal, should be of high attention value relative to other stimuli in the environment.

## DESCRIPTION OF FIELD STUDIES

Nine railroad-highway grade crossings were included in this study. They were selected to provide a broad range of types of crossings. Included were 3 passive crossings, 2 active crossings with high train volumes, and 4 active crossings matched as closely as possible by physical characteristics. The matched crossings were located in Virginia, Texas, Michigan, and California to permit investigation of regional differences.

All crossings were instrumented with an automated system for collection of time and position data on all vehicles (traffic evaluator system). This system tracked all vehicles for 500 ft (152.5 m) as they approached the crossings, and it provided speed and acceleration data and relationships between adjacent vehicles such as time and space headways. The system also was used to record covert observation of driver looking behavior, activations of crossing signals, train arrival times, and train speed readings obtained with speed-measuring radar. The system recorded all data on magnetic tape.

Time-lapse photography was used to provide a record of motorist behavior during train approaches and operation period of signals. In addition, a systematically selected sample of motorists was stopped and interviewed.

In summary, 112 h of traffic behavior data were obtained that yielded complete information on 18,552 vehicles. Fifty-seven trains were observed during the data collection periods. Of the 1,556 drivers selected to be interviewed, 1,267 completed the

**Figure 1. Hypothetical relationship of accidents, driver performance, and system demands.**

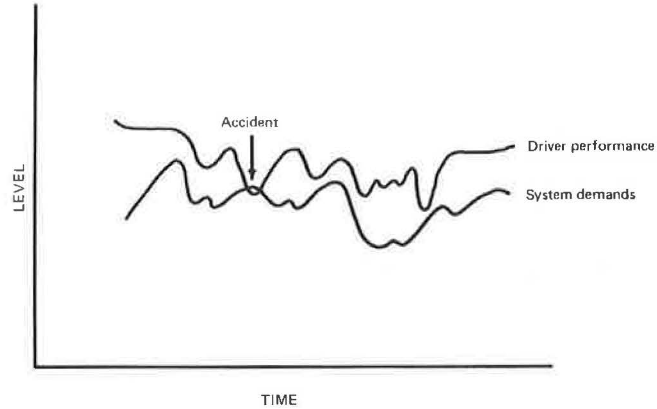



**Figure 2. Components of driver response.**

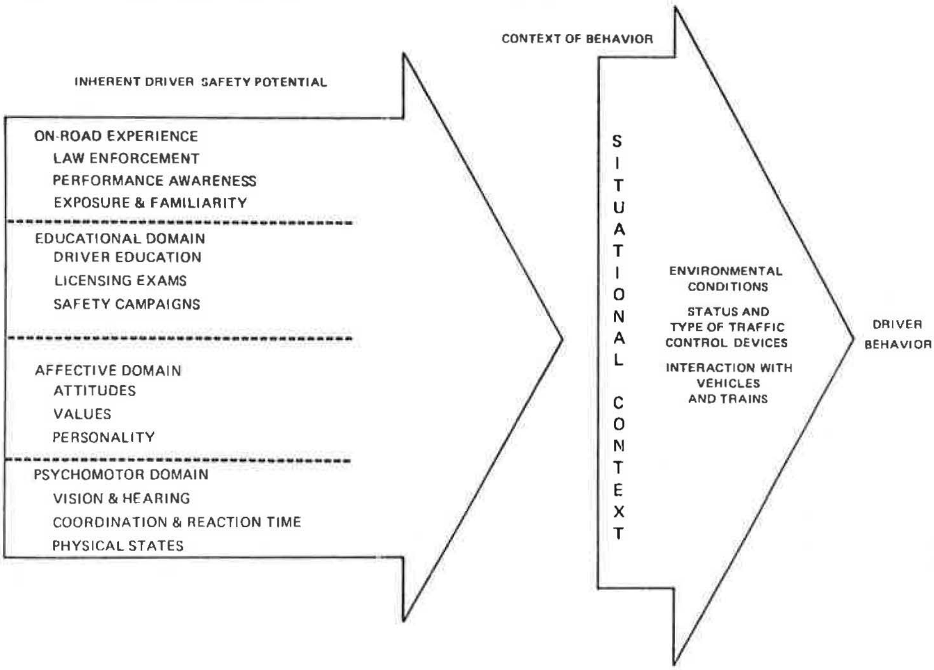



**Figure 3. Relationship of speed reduction to crossing roughness.**

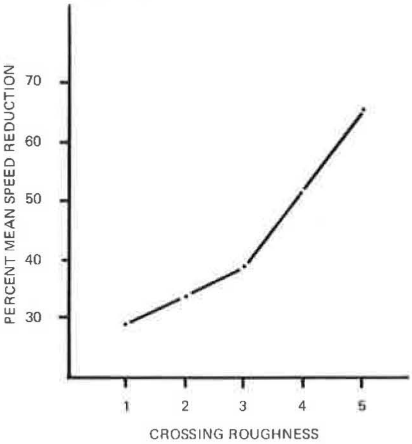
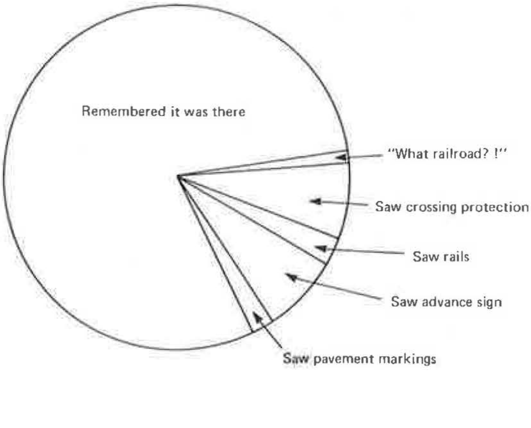



**Figure 4. Cues used to detect grade crossings.**



questionnaire. For each driver, a data set consisting of 176 items was prepared. The analysis of the resulting data yielded what we believe to be the most comprehensive set of information ever gathered relating to the knowledge, attitudes, and behavior of drivers regarding the railroad-highway grade crossings.

## ANALYSIS OF FIELD DATA

To direct the collection, reduction, and analysis of the field data, a battery of hypotheses was developed regarding the knowledge, attitude, and behavior of the driver at a railroad-highway grade crossing. The hypotheses were designed to yield information to develop safety countermeasures.

Most of the questionnaire items, speed and deceleration measures, geographic indicators, and stratifications of the data base were to support the testing of the hypotheses. Other items were included to develop an understanding of the public attitude on certain issues.

A number of the findings of this study are presented in this paper in a highly condensed form. We urge the interested reader to refer to the final report (1) to clarify statements or to examine the supporting material. Not all of these items represented new or surprising information, but they served to develop an understanding of the public attitude toward grade crossings.

1. Drivers slow for crossings because most crossings are bumpy. The speed reduction for the crossing was found to be directly related to crossing roughness as shown for 102 crossings in Figure 3.
2. Nearly 1 percent of the drivers stopped for an interview did not know they had just driven through a crossing. Most drivers detected the crossing by using the cues shown in Figure 4.
3. Drivers generally underestimated their speed by about 30 percent, which indicates the hazard if a driver has to stop for an unexpected train.
4. Drivers were asked whether they saw pavement markings in advance of the crossing and to identify the standard symbol for pavement markings. The same proportion of the drivers stated that they saw (and correctly identified) standard markings at sites that had markings and sites that did not have markings.
5. All of the crossings used in the study had restrictions of visibility of oncoming trains in at least 1 of the 2 approach quadrants. Only 22 percent of the drivers said that something made it hard to detect trains at the crossing they had just passed, but most of those cited visibility.
6. The drivers interviewed generally did not know why the number of tracks was posted on the signs at the crossing.
7. Active advance warning was cited as a desirable protection feature by 68 percent of those interviewed at passive crossing and by 46 percent of those interviewed at active crossings.
8. The question, Do all railroad crossings have a signal or gate that warns you when a train is coming? produced surprising answers. When asked at active crossings, 22.8 percent of the drivers said yes. When asked of drivers at passive crossings, 15.4 percent said yes. At the crossing studied in California, more than 35 percent stated that all crossings had active warning systems.
9. More than 90 percent attributed railroad-highway accidents to driver carelessness.
10. Drivers felt alcohol was a major contributor to crossing accidents.
11. Most drivers felt that passive crossings are characterized by low train volumes and that some high-speed trains use them.
12. Thirty-five percent could recall no safety instruction or advice on crossing safety.
13. Fifty-four percent stated that they experienced an average delay in excess of 5 min when stopped for a train.
14. An extended view of time between signal activation and train arrival is held as seen by the following responses:

| Time | Percent Selecting | Time | Percent Selecting |
|---|---|---|---|
| 0 to 10 s | 5.0 | 1 to 2 min | 25.5 |
| 10 to 20 s | 21.7 | 2 to 4 min | 10.4 |
| 20 to 60 s | 32.3 | More than 4 min | 5.1 |

The actual time from the activation of automatic crossing signals to the arrival of the train at the crossing was measured at the 6 active crossings included in this study. These time measures are shown in Figure 5 by the speed of the train. The track circuits were set to activate the signal at a distance of around 2,000 ft (300 m) at 4 of the crossings. The setting of the other 2 could not be determined. Even for trains operating at similar speeds, actual warning time was highly variable and did not approximate the predicted 2,000-ft (300-m) time-speed curve. A similar but even more variable warning time plot is shown in Figure 6 for the time from the first audible train whistle to the train arrival.

15. Seat belts were installed in 90.6 percent of the vehicles observed (most cars were newer than 1965 models). Of the cars with seat belts installed, 11.2 percent were in use. Fifty-eight percent of the cars had shoulder harnesses installed, but only 24 drivers (3.3 percent) were using them (observations were made in 1972).

16. Female drivers represented 31.4 percent of the random sample. The cars averaged 1.72 occupants.

## BEHAVIOR ANALYSIS

An integral part of the plan for hypothesis testing involved differentiating the drivers with desirable characteristics from those with undesirable traits. We anticipated that we would be able to identify target populations for classes of countermeasures and thus be able to prescribe the most promising techniques for a given target group.

To differentiate the drivers, we quantified 4 performance measures and combined them into a single factor called the index of safety-related behavior. The measures used in the analysis were

1. Whether the driver looked for trains,
2. The change in speed over the last 500 ft (152.5 m) before the crossing,
3. The distance from the track at which maximum deceleration occurred, and
4. The distance at which the stopping capability of the vehicle equaled the distance to the crossing.

A driver with a high safety orientation is one who (a) looks for trains, (b) shows a speed decrease greater than the mean decrease for all vehicles at his or her initial approach speed, (c) shows a point of maximum deceleration that is farther from the crossing than the mean point of all drivers, and (d) maintains a speed such that he or she always can stop short of the tracks until possibility of a train conflict has been eliminated.

The data were stratified along those dimensions that best served the various hypotheses being tested. The most general subset was of drivers not influenced by a lead vehicle or by a signal or train. Part-whole correlation matrices were used to identify safety-related behavior and responses, and a ranking of the population was made according to the safety index. Comparisons of the highest and lowest quartile (of the safety index) from questionnaire responses were of particular value in examining the extensive set of hypotheses. The distribution of drivers by the index of safety behavior is shown in Figure 7. The index was simplified to include only those factors that accounted for most of the ranking. Eliminating all but 2 factors did not appreciably change the ranking of drivers and yielded valid, inexpensive measures of driver performance for crossings with restrictions of visibility of trains.

**Figure 5. Warning time from signal activation to train arrival.**

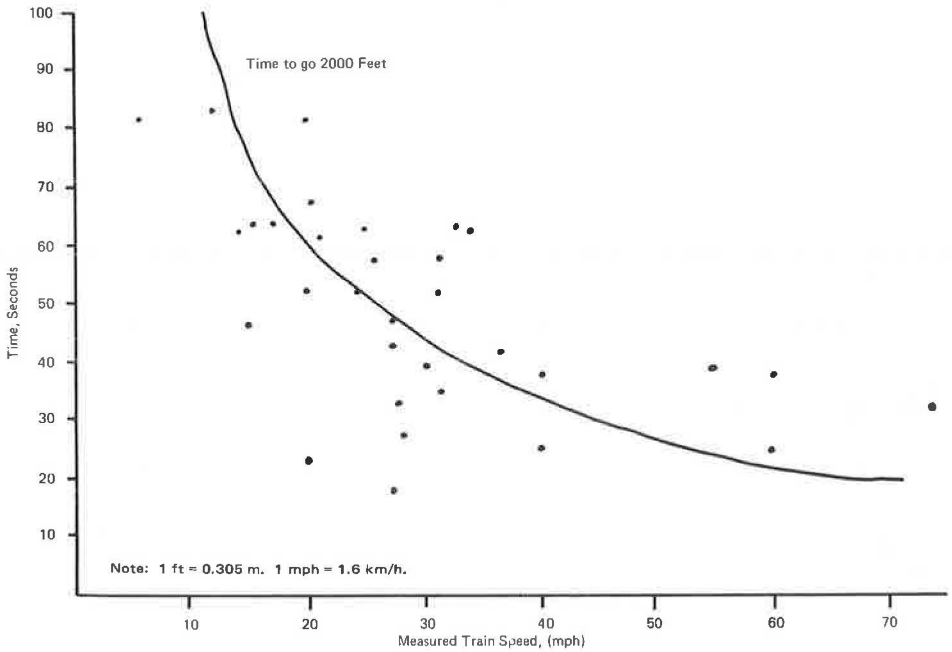
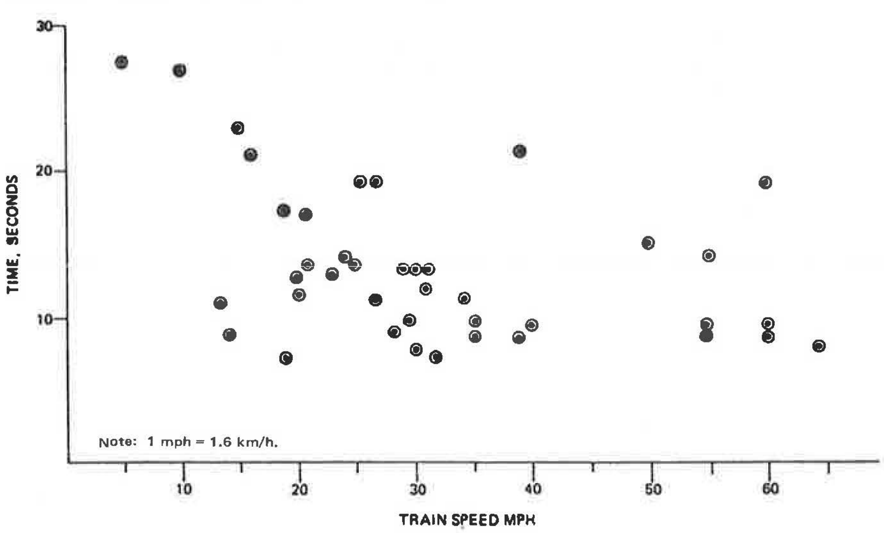



**Figure 6. Audible warning time versus train speed.**



Index = looking + (mean speed/crossing speed)

Looking is assigned a value of 1 if the driver makes obvious head movements to look for trains within 100 ft (30.5 m) of the crossing. For all other cases, a value of 0 is assigned. Crossing speed is the actual speed of the subject measured just before the crossing is reached. Mean speed is the average of the crossing speeds of all traffic.

The hypothesis testing used to structure the examination of the large number of variables is discussed in detail in the full report (1). The investigations were structured along the lines of the headings that follow. Only a terse summary is presented here.

## Measures of Behavior

The measures of driver behavior, as collected, were shown to be highly interrelated. An adequate description of the crossing behavior of the driver consists of whether the driver looked for trains, the speed of the vehicle at the crossing, and the percentage of speed reduction over the 500 ft (152.5 m) preceding the crossing. The sensitivity of these measures to a change in protection devices has been demonstrated only for crossings where sight distance is restricted until the driver is within 150 ft (45.7 m) of the crossing.

## Behavioral Differences

No consistent significant differences were found to exist in driver behavior at active and passive crossings. The high level of familiarity with the crossing appears to explain a strong relationship between train volume and safe behavior. Severe restrictions to visibility did not increase the frequency of looking behavior over the frequency observed at more open sites.

## Regional Differences

No clear relationship was established between any of the measures and the geographic

Figure 7. Distribution of calculated safety index.

location of the crossing. It was concluded, however, that the sample was inadequate to reject regional differences as a possibility.

## Driver Knowledge

The data did not support increasing driver awareness of legal regulations as a potential accident countermeasure. There are indications, however, that enforcement of required behavior is a factor in accident reduction. Driver awareness of enforcement yields more careful overall behavior and tends to increase awareness in general.

A significant inverse relationship was found to exist between estimates of fatalities and safe behavior. The data do not support fatality statistics publication as a countermeasure.

## Driver Awareness

Drivers who were observed to perform more safely more frequently correctly identified or remembered the characteristics of protective devices at the crossing. It cannot be stated, however, that knowledge or recognition of the devices at a crossing contributes in a direct causal fashion to safer performance.

Looking behavior and percentage of speed decrease were lower for drivers with high familiarity than for very unfamiliar drivers. This result, supported by the accident investigations, makes drivers with high familiarity candidates for countermeasure programs. Developing effective countermeasures for this group of drivers may be difficult because of the high probability of a regression to previous behavioral patterns after an initial acclimation period.

## Risk Taking

It was found that drivers who perform less safely according to the behavior measures tended to score more highly as risk takers. The only element that clearly reached significance, however, was the use of seat belts. It does not appear that countermeasures will be productive in this area.

## Experiential Characteristics

Drivers who report long delays when stopped at grade crossings tended to behave less safely. Drivers who crossed against an activated signal were most frequently found in the unsafe quartile and generally were observed to be in a hurry to complete their trips. Accuracy of perception and differences in perception of grade-crossing devices did not differentiate drivers.

## Demographic Characteristics

The population sample indicated a stable group. The drivers nearly always lived in the community where the crossing was located and had obtained their first license to operate a motor vehicle in the state where the crossing was located. This relation was true even in the suburbs of Washington, D.C.

The proportion of males and females in the sample approximated their proportions in railroad-highway accidents. There was no significant difference in the proportions of females in the safe and unsafe driver quartiles. However, male drivers were overrepresented in the group of unsafe drivers. Both exposure to grade crossings and the overconfidence of highly familiar drivers are felt to be factors in accident causation.

### Perception of Causes of Grade-Crossing Accidents

The data do not support a relationship between driver perception of causes of accidents and performance at crossings. Thus the study did not support application of countermeasures designed to change drivers' perception of accidents as a means to obtain more safety-oriented behavior.

### Stated Behavior

Drivers tend to reduce speed for grade crossings because of track roughness. This was cited most often as the motivation for speed reduction by drivers who did not look for trains or were otherwise categorized as unsafe drivers.

Drivers were found to report having performed actions such as looking for trains, lowering windows, and reducing speed in direct relation to having performed them. Unsafe drivers did not state (believe) that they had performed more safely than they were observed to have performed.

## SUMMARY

This study formulated valid and sensitive measures of behavior for carefully selected types of grade crossings, particularly those that had restrictions to visibility along the approach. There is a need for the determination of performance measures to be applied to open and other crossings, such as those reached immediately after a turn. That is, performance measures are needed that are valid at crossings where near looking behavior and speed reduction are not necessarily related to the detection of a train hazard.

Chapter 8 of the report (1) presents a program plan for undertaking a field evaluation of railroad-highway grade-crossing-accident countermeasures. The framework of the field evaluation includes the following steps:

1. Development of countermeasures
   a. Development of countermeasure concepts
   b. Selection of countermeasures
2. Development of countermeasure evaluation methods
   a. Specification of driver and site characteristics
   b. Specification of behavioral measures
   c. Specification of knowledge, attitude, and self-report measures
3. Development of experimental design and procedures
   a. Extent of generalization required
   b. Data collection procedures
   c. Data analysis procedures
4. Validation by accident reduction

## REFERENCES

1. J. H. Sanders, G. S. Kolsrud, and W. G. Berger. Human Factors Countermeasures to Improve Highway-Railway Intersection Safety. Biotechnology, Inc., June 1973.
2. J. A. Dimling, Jr., and L. Miller. Summary and Recommended Standards. In Driver Licensing and Performance, National Highway Safety Bureau, Vol. 3, Rept. 224, March 1969.