Improving Safety at Passive Crossings with Restricted Sight Distance

JOHN E. TIDWELL, JR., AND JACK B. HUMPHREYS

Investigations were conducted regarding driver knowledge of grade-crossing information, the relation of driver behavior to driver knowledge, and techniques for advisory speed signing. A driver behavior-oriented method for evaluating passive crossings was developed. It was found that most drivers believe that all crossings regularly used by trains have active protection. Driver performance at the sites observed was not related to driver knowledge of grade-crossing facts. It was noted that drivers who looked for trains did not look a proper distance from the crossing or at an appropriate speed to be considered safe. A procedure was developed to assign safe speeds and to locate signing on the approach to the passive grade crossing. Suggestions are made for areas of future investigation.

Drivers who approach a passive grade crossing are expected to take note of the traffic-control devices associated with the crossing and take appropriate action to ensure that they can respond safely to a train near the crossing. One critical point in the system is the amount of sight distance available to the driver for observing trains. The available sight distance must be used by the driver in making a judgment as to whether to stop at the crossing to let a train pass or to continue through the crossing.

The present research included an investigation of driver knowledge of grade-crossing information, observations of driver performance at passive grade crossings with restricted sight distances, and the development of driver behavior-based methodologies for establishing safe approach speeds and evaluating passive crossings. The questions investigated included the following:

1. Are drivers aware of the hazards of grade crossings?
2. Do drivers recognize the standard traffic-control devices associated with grade crossings?
3. Do drivers know their responsibilities at grade crossings?
4. Does improved knowledge of grade-crossing information result in improved performances at grade crossings?
5. How can the actual conditions of the crossing best be communicated to the driver?
6. How can driver behavior at passive crossings be used to evaluate the safety of the crossing?
7. How can passive countermeasures be evaluated?

The present research was divided into four modules, each of which will be reported separately along with the pertinent findings and recommendations. The four modules are as follows:

1. Driver knowledge of grade-crossing information,
2. Driver knowledge related to driver performance,
3. Advisory speeds for passive grade crossings, and
4. Method for evaluating crossings.

DRIVER KNOWLEDGE OF GRADE-CROSSING INFORMATION

Methodology and Results

A 21-item questionnaire was developed to allow an evaluation of driver knowledge regarding grade-crossing-related information. Demographic information was obtained as well as information on exposure to various grade-crossing safety-education efforts. The questionnaire was completed by 829 drivers at a driver's license examining station in Knoxville, Tennessee. Sanders (1) and Dommasch and others (2) have also conducted prior work with questionnaires. However, their responses were obtained in connection with field studies and did not fully cover those items of interest in the present research.

Findings and Recommendations

Significant findings relative to passive crossings were as follows:

1. More than 54 percent of the drivers believe that all crossings or all except those rarely used by trains have active protection,
2. Fifty-six percent of the respondents believed that they were required to stop at passive crossings,
3. Questions that concern passive traffic-control devices were missed by approximately 30 percent of the drivers,
4. Drivers had adequate knowledge of the relative stopping distance of trains and the number of annual fatalities at grade crossings,
5. Exposure to various grade-crossing safety-educational efforts was generally of no advantage in responding to the questionnaire,
6. More than 51 percent of the drivers missed 4 or more of the 11 gradable questions, and
7. Only 4 percent of the respondents indicated that they knew of any enforcement action related to grade crossings.

It was recommended that the following items be emphasized in any public-education effort to improve safety at grade crossings:

1. Only the most hazardous grade crossings have active protection. There are many hazardous passive crossings.
2. The standard traffic-control devices associated with grade crossings should be shown and their placement discussed.
3. Drivers are required to slow down and look and listen for trains at passive grade crossings. A stop is not required except for certain vehicles and at crossings where public authorities have erected a standard stop sign.

It was also recommended that consideration be given to developing unique advance-warning signing to inform drivers that they are approaching a passive crossing. Currently, approach signing and pavement markings are the same for both active and passive crossings, even though vastly different driving behavior is expected. Drivers who approach passive crossings are expected to slow down and look and listen for trains. However, when approaching a crossing with active protection, drivers are expected to maintain speed and carefully observe the railroad-signal devices. The present research demonstrates the low level of knowledge concerning the extent of hazardous passive crossings. Also, the questionnaire responses indicated that enforcement was almost nonexistent as a motivation for safe performance at grade crossings. Therefore, research should be conducted to determine the benefits of enforcement at passive grade crossings.

DRIVER PERFORMANCE RELATED TO DRIVER KNOWLEDGE

Methodology

Two passive grade crossings with restricted sight distance were selected for observing driver behavior on the approaches. An event recorder was used to record time in 100-ft speed traps and to note the instant that the driver made a head movement. By using these data, the vehicle speed profile and the location and speed of the vehicle at the time that the driver looked for a train could be determined. The following dependent variables were determined for each of the drivers observed:

1. Was this a safe driver?
2. Did the driver look for a train?
3. Speed of the vehicle 15 ft from the crossing.
4. Slope of the speed profile approaching the crossing.

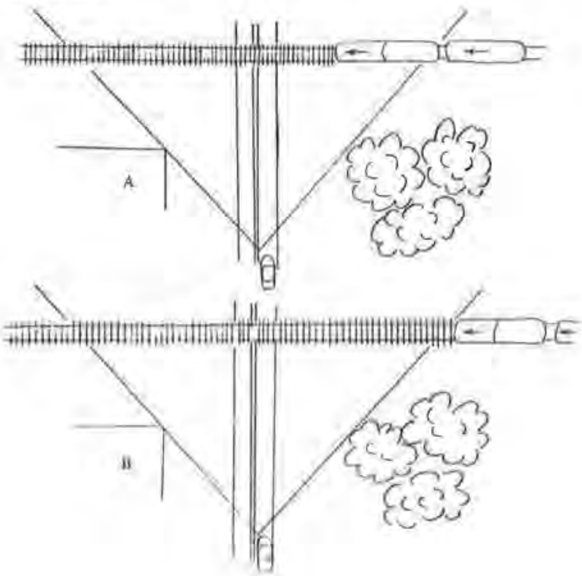
The last three digits of the vehicle's license tag were also recorded for later use in correlating with driver knowledge.

The drivers were stopped downstream from the crossing and asked to respond to a four-question multiple-choice questionnaire. The four questions dealt with areas of driver knowledge that were believed to have potential for affecting driver behavior on an approach to a passive grade crossing. These questions dealt with recognition of advance signing and the signing used at the crossing, extent of active protection, and a driver's duty at passive crossings. The portion of the roadways between the grade crossings and the interview sites contained several crossroads. Unfortunately, this caused some vehicles to be observed but not interviewed, and vice versa.

At site 1, the speeds and looking behavior of 94 drivers were recorded. Interview responses from 84 drivers were obtained. Matches of interviews and observations could be made for only 42 drivers.

At site 2, the speeds and looking behavior of 122 drivers were recorded. There were 137 drivers interviewed. Matches of interviews and observations could be made for only 47 drivers.

Figure 1. Two conditions of train conflict as drivers approach crossing and look for trains.



The logic developed by Richards and Bridges (3) was built on developing safe-unsafe criteria for driver-performance evaluation. In order for a driver to have been considered a safe performing driver, two criteria must be met:

1. The driver must look for a train far enough from the crossing to enable a safe stop short of the crossing, commensurate with the vehicle's approach speed, in the event a train were to be detected in the vicinity of the crossing; and
2. Commensurate with the track site distance available from the point where the driver looked, the vehicle's speed, and the maximum expected train speed at the crossing, the vehicle must be able to clear the crossing ahead of a train that might have been barely beyond the available site distance when the driver looked and made a go decision.

If a driver looks for a train and the speed and location of the look are proper, then the driver will safely clear the crossing if no train is detected, or the driver can safely stop if a train is detected. The driver may look many times but, if at least one look meets the safe criteria, then a safe crossing should result. Figure 1 is a schematic drawing of the two possibilities of train arrival relative to a driver's looking behavior. Either of the two conditions may be encountered each time a driver makes a judgment at the crossing.

An observed driver was considered to have made a safe judgment if at the time a go or no-go decision process was initiated the vehicle was an adequate distance from the crossing to safely stop (reaction and braking), based on vehicle speed when the judgment was made. Also, vehicle speed must be such that it would allow the vehicle to clear the crossing before the arrival of a train that was barely beyond the sight-distance limits.

In order to compute the total perception and stopping distances required for a safe stop at various speeds, an assumption was made concerning time for drivers to perceive a train at or near a crossing. Prior work, as reported by Richards and Bridges (3), Voorhees (4), the National Cooperative Highway Research Program (NCHRP) (5), and the American Association of State Highway Officials (6), seemed to support the assumption of a 2.5-s perception-reaction time for drivers who approach passive grade crossings or other hazards. Therefore, a 2.5-s perception-reaction distance was assumed in the development of tabulations of perception plus braking distances for vehicles that approach a grade crossing. Since the observed condition of the pavement was dry, it appeared that a reasonable set of assumptions was dry pavement and a 2.5-s perception-brake reaction time. This does not consider panic or emergency action stopping possibilities. A tabulation of stopping distances for various approach speeds was then developed.

The point at which any driver initiated a go or no-go decision process, as manifested by head movements, was plotted on the time-space diagram. By knowing the speed and distance from the crossing when the decision was made, the available track sight distance at the point of the look, the maximum train speed expected at the crossing, and the time it took the vehicle to reach the crossing, the driver could be classified as safe or unsafe.

It had been anticipated that there would be a reasonable proportion of drivers at each site who exhibited safe behavior at these crossings with severely restricted sight distance. However, when the total perception and braking distances required for various approach speeds were compared with the observed values, it was apparent that the majority of drivers was not performing safely. When their approach speed was considered, the drivers looked for trains much too close to the crossing to allow a safe stop short of the crossing. In fact, only the two drivers at site 1 and the three at site 2 who actually stopped could be classified as safe. All of the other drivers were too close to the crossing when their looking movements took place to safely perceive a train and stop before the crossing. All of these drivers did meet the speed criteria for crossing clearance but they were not classified as safe drivers due to their looking too close to the crossing to allow a safe stop. The drivers who looked too close to allow for a safe stop are definitely potential accident victims under some possible situations of train arrival.

To find the relation of knowledge to driver behavior, the 42 matched observations at site 1 and the 47 matched observations at site 2 were grouped by responses to the questionnaire. Those giving correct responses for each question were placed into one group and the remainder placed in the second group. The number of drivers who stopped, number of lookers, mean speed (V) at a distance at 15 ft from the crossing, and the mean speed-profile slope were computed for the two groups for each question at each site. Table 1 shows three of the above measures for the correct and incorrect knowledge groups at sites 1 and 2. No attempt was made to draw a statistical inference from the number or vehicles that stopped (site 1, two; site 2, three) due to the low rates involved.

In order to determine whether the knowledge level of the respondents relative to each of the four questions was related to the dependent variable (i.e., looking behavior of the respondents), a series of chi-square analyses were conducted. This was done for both sites. The data were incorporated into a 2x2 contingency table, correct or incorrect knowledge being a dichotomous variable, as was looking behavior (looked or did not look). Of the analyses completed, only the looking behavior of those correctly answering question 2 (recognition of advance-warning sign) at site 2 were related (0.05 significance level). The findings suggest that those who had more information regarding the advance-warning sign exhibited less looking behavior. This finding was not replicated at site 1. Statistical tests on the pooled data for the dependent variables at the two sites indicated that the data could be pooled. When the data were pooled, the site 2 finding was replicated.

In order to determine whether the knowledge level of the respondents relative to each of the four questions was related to the mean vehicle speed 15 ft from the crossing or the mean speed gradient, a series of Student's t-analyses were conducted. The hypothesis was tested at the 0.05 significance level as to whether the mean speed at 15 ft from the crossing or the mean speed gradient for the correct and incorrect knowledge groupings for each of the four questions at each site was significantly different. These analyses did not yield any significant differences between the two knowledge groups for each of the four questions by using mean speed at 15 ft and mean speed gradient as the dependent variables. This was replicated for both sites and with the pooled data.

The matched responses to the questionnaires given at the two field sites were compared with those obtained through the more detailed questionnaire administered at the driver's license examining station. The short and long questionnaire had four common questions. A comparison was made to see if the knowledge level at the field sites differed significantly from that at the driver's license examining station.

The responses to each question at the three sites were subjected to a chi-square test to see if there was a significant (0.05 level) difference among the responses (correct versus incorrect) of the three groups for each of the four questions (2x3 contingency table). There was no significant difference in the knowledge level for questions 1, 3, and 4 as administered in the field ($\chi^2 = 2.564$, 4.670, and 1.261, respectively; $\chi^2_{0.05} = 5.991$; df = 2). However, there was a significant difference in the response to question 2 (recognition of advance-warning sign) with the field-site respondents scoring significantly lower on this question ($\chi^2 = 10.131$, $\chi^2_{0.05} = 5.991$, df = 2). This indicates that the knowledge level of the field sample was lower than the driver's license sample, since the groups rated statistically the same for knowledge on three questions and the field-site responses fell statistically lower for one question. Of course, it is possible that the environment of the questioning may be a factor in the ability of the drivers to answer correctly.

The response to the questionnaire obtained at the two sites were also compared statistically. There was no significant (0.05 level) difference between

Table 1. Driver behavior at sites 1 and 2 and pooled data related to responses to questions.

		Site 1		Site 2		Pooled Data (both sides)	
No.	Question	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
1	Recognize crossbuck						
	Mean V at 15 ft	29.00	30.75	31.05	36.44	30.15	33.19
	Slope	0.0695	0.0446	0.0455	0.0411	0.0561	0.0431
	Lookers	10	5	19	3	29	8
2	Recognize advance sign						
	Mean V at 15 ft	29.92	29.00	33.52	31.11	31.51	30.28
	Slope	0.0544	0.0614	0.0355	0.0527	0.0461	0.0561
	Lookers	7	8	5[a]	17	12[a]	25
3	Where signals placed						
	Mean V at 15 ft	30.07	29.22	33.37	31.21	31.91	30.24
	Slope	0.0524	0.0574	0.0437	0.0452	0.0475	0.0512
	Lookers	5	10	9	13	14	23
4	Approach passive crossing						
	Mean V at 15 ft	28.75	30.00	30.46	32.71	29.52	31.53
	Slope	0.0669	0.0542	0.0385	0.0454	0.0541	0.0493
	Lookers	5	10	6	16	11	26

Note: V = speed.

[a] Significant (0.05) difference.

the responses to each question at the two field sites.

In summary, both the pooled data and that for each site did not support the hypothesis that good knowledge resulted in statistically better driving performance at grade crossings. The only significant difference between groups occurred with question 2. The group that answered question 2 correctly (advance-warning sign) had a significantly smaller percentage of drivers looking on the approach to the crossing. Therefore, the data did not indicate that the groups of drivers who answered knowledge questions correctly performed significantly better at the sites studied. This generally agrees with findings by Sanders (1) from a related effort.

Findings and Recommendations

1. Needless to say, it was surprising and somewhat disconcerting to learn that only 5 of 89 drivers (all of whom stopped at the crossing) could be classified as safe drivers. Twenty-six drivers did make head movements, which indicated that they were aware of the crossing, but they were not making their head movements when at a safe distance from the crossing or at a safe speed. Therefore, a significant number of drivers looked but still were unsafe due to their looking too close to the crossing.

To assist a looking driver to do so at a proper location and speed, a signing system should be employed at crossings with restricted sight distance that will convey appropriate information to the driver. A standard regulatory speed-zone sign is a candidate countermeasure. A new sign may be appropriate since no current traffic-control device clearly indicates to a driver a safe speed and locates the point where effective looking should take place.

2. The noncorrelation of knowledge with indices of safe performance such as stopping, looking movements, mean speed-profile slope, and mean speed 15 ft from the crossing seems to indicate that variables other than knowledge also have an effect on performance. Of course, a certain base level of knowledge is needed to perform safely. However, possessing that level of knowledge does not guarantee safe performance. (The use of seat belts is a good example of this phenomenon.) This does not negate the need for driver education. If no drivers are informed of the desired behavior, then proper performance will be lower overall compared with that expected if all drivers were properly informed. However, a segment of knowledgeable drivers apparently will still perform unsafely for other reasons, which includes lack of association of grade crossings with hazards.

Further research should be conducted at additional sites to confirm these results. It is hoped that sites might be found that yield more even proportions of safe and unsafe drivers as determined by observed speeds and head movements. The present research did not detect a significant effect. If validated by a future study, the noncorrelation of performance with knowledge may have significant implications on public-information campaigns such as Operation Life Saver.

3. Of the 89 matched questionnaires, 56 (63 percent) of the motorists interviewed believed that they were required to stop at all grade crossings.

Further research should be conducted in this area to determine if the erroneous belief that a stop is required at grade crossings affects driver performance at grade crossings. If the perceived requirement is considered too restrictive, then the driver may simply neglect to perform any special actions as he or she approaches a crossing.

4. The techniques used in this study are workable, but they are limited to sites where observers will not be distracting and where they will also have a view of the speed traps. These criteria severely limit the sites where this technique can be used.

The study technique would be greatly improved if a device such as Federal Highway Administration (FHWA) traffic analyzer was used to develop the speed profile on vehicles that approach the crossing. However, head movement data collection requires hidden observers. If head movements were deleted from the data collection, then a simplified procedure could be developed for research studies and for use by public officials in developing a priority ranking of crossings for the installation of active control devices. The procedure could be used at all crossings, not just those with severe sight-distance restrictions or with the hidden observers. However, the procedure could best be used by diagnostic teams in detailed investigations of selected hazardous crossings.

ADVISORY SPEED SIGNING FOR PASSIVE GRADE CROSSINGS

Methodology

The field observations indicated that drivers at the two sites who desired to perform safely, as manifested by their head movements, actually performed in an unsafe manner. This led to an investigation of a method for advising drivers of the proper speed for approaching a passive grade crossing. Such drivers are expected to drive at an appropriate speed and look and listen for trains. However, the driver is given no information that would assist him or her in selecting the appropriate speed and deciding where to begin looking for trains. The driver needs to have advisory information to offset the lack of information available concerning sight distance and train speeds.

Advisory speed signing is used at hazardous horizontal curves and approaches to intersections with limited sight distance. Lyles (7) recently studied signing systems for the latter, which may have application to the problem at hand. Similar signing for approaches to passive crossings with restricted sight distance would appear to be a low-cost countermeasure to improve safety at passive grade crossings.

In order to establish a safe speed for the approach to a passive crossing with restricted sight distance, the following procedure is suggested:

1. Measure the available right sight distance (RSD) and left sight distance (LSD), as noted in Figure 2. The RSD and LSD should be measured from each of the distances noted in the last column of Table 2. The associated perception-braking distance for the entire range of expected approach speeds should be covered.

2. By using the maximum train speed, determine if a driver who passes a point at the associated speed (for example, 126 ft from the crossing at 20 mph) could clear the crossing if a train was barely out of view when a go decision was made. In other words, based on the distances the train and the highway vehicle would be from the crossing and their speeds, would the highway vehicle clear the crossing ahead of the train? If the highway vehicle could clear the crossing before the arrival of a train barely outside of the sight-distance triangle, then the speed associated with the approach distance under consideration would be a candidate for the

Figure 2. Typical grade crossing for evaluation by using speed procedure.

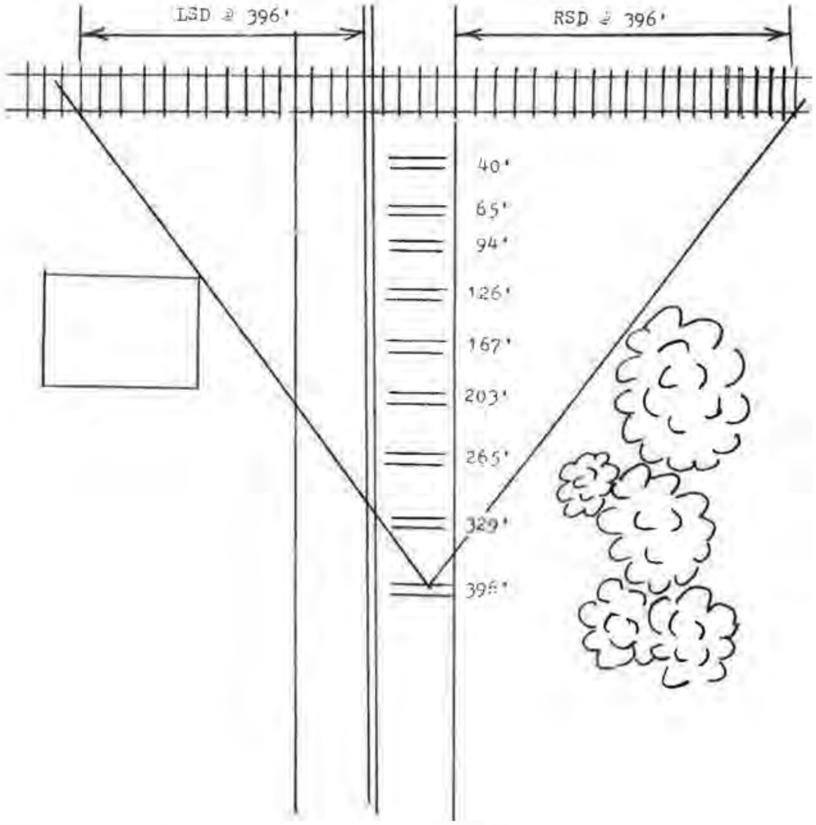


Table 2. Minimum values for use in locating points on approach roadway for evaluation of sight distance.

V (mph)	f (wet)[a]	Perception Distance at 2.5 s (ft)	S^b (ft)	Required Perception and Braking Distance[c] (ft)
5	0.40	18	2	40
10	0.40	37	8	65
15	0.40	55	19	94
20	0.40	73	33	126
25	0.38	92	55	167
30	0.36	100	83	203
35	0.35	128	117	265
40	0.33	147	162	329
45	0.32	165	211	396
50	0.31	183	269	462
55	0.31	202	325	547
60	0.30	220	401	641
65	0.30	238	470	728
70	0.29	257	564	841

Note: V = speed, f = friction, and S = braking distance.

[a] Coefficient of friction (6).

[b] Based on $S = V^2/[2(f)\,32.2]$, where V is in feet per second.

[c] General minimum legal clearance for stopped vehicle of 15 ft, plus 5 ft from driver's head to front bumper, i.e., add 20 ft.

advisory speed. For example, assume the track sight distance is measured 126 ft from the crossing. Further, assume that the measurements and computations indicate that a highway vehicle traveling at 20 mph at 126 ft from the crossing can clear the crossing before a train that may be hidden from view at 126 ft from the crossing. In this case 20 mph would be a candidate advisory speed.

3. After evaluating all of the appropriate points from Table 2, the highest candidate advisory speed should be used.

The advisory speed sign should be placed at a location where effective looking can take place. By using this procedure, the driver will be told where to look for a train and the speed at which the highway vehicle should be traveling at the point that looking takes place. If the driver obeys this signing, then the vehicle can either stop short of the crossing if a train is detected or clear the crossing safely if a train were just outside of the sight-distance triangle from the point of the recommended looking. In other words, the driver will be essentially guaranteed a safe crossing if the signing is followed. The site would have to be monitored for changes in the sight distance or train speeds that would affect the advisory speed. The worst-case situation should be the basis for the sight-distance computations.

Findings and Recommendations

Drivers need to know how fast they should be traveling on the approach to a passive crossing with restricted sight distance. They also need to know where looking for trains should take place. The standard advisory speed-warning sign could be used for this purpose. However, this sign generally conveys the message that the posted speed is applicable downstream from the sign. For example, the advisory speed for horizontal curves is located in advance of the point where the lower speed is required. A desirable system would be to post the standard regulatory speed sign at the point where the lowered speed is needed for effective looking. Of course, this should be preceded by advance signing that concerns the reduced speed zone. The standard advance railroad-warning sign should be located between the advance speed-zone sign and the regulatory sign. This would help the driver relate the hazard to the reduced speed zone. Regulatory signing would be useful for law enforcement personnel in judging whether or not a driver was performing safely at a passive crossing. Only 4 percent of the respondents in the Knoxville study knew of enforcement action related to grade crossings. This also might cause the driver to relate possible enforcement action to the crossing. Of course, enforcement action should be a part of the countermeasure. Lyles (7) studied various traffic-control-device treatments in advance of hazardous rural intersections. He found that regulatory signing in conjunction with a standard crossroad-warning sign was more effective than the standard crossroad sign alone. A similar study should be conducted to investigate the effectiveness of regulatory signing at passive crossings. Another alternative would be to develop a new signing system that conveys the following information:

1. The crossing being approached is a passive crossing,
2. The driver should approach the crossing at the speed posted, and
3. The point where effective looking for trains can take place should be identified.

It is recommended that both regulatory signing and new passive advance signing be given careful consideration for future research.

DRIVER BEHAVIOR AS INPUT INTO PRIORITIZATION OF PASSIVE CROSSINGS

Methodology

Sight distance at railroad grade crossings has been used in the past in the evaluation of crossings. Priority and warrant formulas for grade-crossing improvements have also attempted to use sight distance along with other factors as independent variables in the prediction of accidents or in relating the hazardousness of crossings. Also, independent variables used in research efforts to evaluate the effects of countermeasures have attempted to determine if the treatment increased the safety of the system. Here, again, the variables measured were actually surrogates for an evaluation of how the driver was actually coping with the crossing. Did the countermeasure enable or encourage the driver to traverse the crossing in a safer manner when compared with standard treatments or other treatments?

All states have procedures to guide management in determining which passive crossings should be upgraded to active protection. These procedures may be simply a method of setting priorities for the use of available grade-crossing protection funds or they may be actual numerical warrants to be applied to specific situations. There is no nationally recognized formula or warrant for providing active protection. In 1977, Sanford (8) reviewed the criteria used by the states. This review indicated that many of the states were using one or more of the following formulas for setting priorities for grade crossing improvements:

1. Hazard formula from NCHRP Report 50 (5) (used by 10 states),
2. The New Hampshire formula (4) (used by 7 states), and
3. The Peabody-Dimmick formula (9) (used by 6 states).

These formulas consider only the volume of highway and train traffic in conjunction with the present protection being provided. It should be noted that sight distance is not an input into the hazard index formula. The NCHRP report (5) procedure does allow adjustments for approach gradient number of lanes and angle of crossing. Sanford (8) also reported that 15 states and the District of Columbia used view and site conditions as parameters in priority formulas and/or in warrant formulas. These parameters are based on the judgment of the jurisdiction as to how important sight distance is to total safety. Sight distance is used subjectively by these states or as a weighted factor in an overall equation that considers several other variables.

None of the procedures currently available for use in evaluating countermeasures or for establishing priorities in a program for upgrading passive grade crossings actually consider driver behavior at the passive sites. Various measures are used as input into models that endeavor to rank the probability of train-vehicle collisions during a certain time period. However, current driver behavior at the crossings under consideration is a meaningful independent variable that could be used in establishing priorities.

The probability of a train-vehicle collision is related to the exposure of unsafe drivers to trains. Unsafe drivers are those who operate their vehicles in such a manner that they could not avoid an accident if a train were in the vicinity of the crossing while they approach that crossing. The probability of conflict is related to the probability of train arrival during the time that a driver is approaching the crossing in an unsafe manner. In order to approximate the probability of this conflict, an estimation of the number of potentially unsafe drivers who use the approach to the crossing under consideration must be determined.

As discussed earlier, the design of the field studies for research into driver behavior resulted in the concept of a window of speeds at each point along an approach roadway where a safe go or no-go decision could be made by the driver. The current literature indicates that present sight-distance measurement procedures are based on measurements of track sight distance taken at one or two locations along the approach roadway. However, the very nature of sight obstructions and the possibility of vehicles approaching the crossing at varying speeds can allow good sight distance at one point on the highway and poor sight distance at a point within the next 10 ft. Therefore, measurement from a standard point in the highway does not provide a complete measure of the influence of sight distance on the safety of the crossing. Sight distance is site specific as related to safety and the establishment of advisory speeds.

As discussed above, methods used by the states to evaluate grade crossings for priority ratings or warrants either overlook sight distance or include a judgment or factor adjustment to the ratings. The sight-distance factors used by the states are empirical factors based on the judgment of the developers of the formulas.

The procedure that follows has the potential of providing a direct index of the effect of sight distance on the safety of a crossing. The procedure consists of the following:

1. Measure the track sight distance from many locations on the two highway approaches.
2. By using the FHWA traffic analyzer or a similar technique, measure the speed of each vehicle as it crosses each point where track sight distances were determined.
3. Evaluate the speed and sight-distance data and determine the proportion of drivers who at some point on their approach to the crossing were operating at a speed where they could make a safe go decision (could stop safely and also clear the

crossing before a train just outside the sight-distance triangle would arrive).

The evaluation of speed data would be based on the criteria that (a) if at any one of the sample points the vehicle was traveling at a safe speed, then the driver is labeled a potentially safe driver; and (b) if the speeds at all evaluation points are outside of the safe window at each point, then the driver is labeled an unsafe driver.

The proportion of unsafe drivers could be used as input into a priority procedure by factoring the average daily traffic (ADT) to arrive at the expected number of drivers who are using the crossing in an unsafe manner. The proportion of safe drivers could also be used to evaluate countermeasures through before-and-after measurements. While this technique may be too time consuming for use at all passive crossings, it certainly appears that it would be useful to diagnostic teams as they study specific crossings. The technique will reveal how drivers perceive the hazardousness of the crossing.

The basic procedure can be used at all crossings since no hidden observers are necessary. It can also be used at night since head movements are not recorded. It could be used on a sampling basis for each approach, for use in expanding to 24-h traffic. The data collected would give direct consideration to measures currently being used in empirical formulas by the states. Such items as vehicle speed, train speed, crossing angle, highway alignment, and approach grades are considered directly by the driver along with sight distance as the driver drives through the crossing. Vehicle speed at the various points indicates how safely the driver is using the crossing. The real questions are, Could the driver stop if a train suddenly appeared? and, also, Could the vehicle clear the crossing after making a go decision? These would be a direct evaluation of a crossing's safety. If two crossings have the same car-train exposure, the one that is being operated with a higher product of unsafe drivers and trains should be given higher priority for grade-crossing improvement. The concept of dealing with unsafe drivers could have application to any ranking process by deleting the factors that are being evaluated directly, such as speeds, sight distance, etc.

A possible objection to the use of this procedure is that the assumption must be made that the driver is always alert and watchful for a train if the driver is labeled safe because the vehicle was traveling at the appropriate speed. This objection is removed if the safe driver is viewed as a potentially safe driver. In other words, if this procedure indicated that 50 percent of the drivers who use a crossing were traveling at an appropriate speed at some point on the approach to allow a safe go decision, then 50 percent would be the absolute upper limit of safe drivers. It may be that the attentive drivers who had proper speeds would be less than 50 percent, but one could be certain that 50 percent were unsafe since they could not have made a safe judgment due to their speeds. This would allow the procedure to be used for comparative purposes, assuming that the matter of interest is the relative number of unsafe drivers for input into countermeasure evaluation or priority procedures.

The real advantage of this procedure is that a human-factors-type measure of how a driver evaluates a crossing is obtained. If the driver evaluates it incorrectly, the speed profile will be an indicator of the wrong evaluation. If the drivers are not perceiving the restricted sight distance or train speed, the use of advisory speed signing should be considered and the site restudied. If the site continues to remain high in the priority listings, the installation of active protection or other countermeasures should definitely be considered.

The recommended procedure, then, is to develop for the approaches of each crossing under consideration an estimation of the number of drivers who approach the crossing in an unsafe manner each day. A train-unsafe vehicle product can then be used to establish priorities. A passive site with 10 trains/day and 400 vehicles that approach the crossing in an unsafe manner (both approaches) would have an exposure of 4000 train-unsafe vehicles. If this were compared with a passive site with 8 trains and 600 unsafe drivers, the exposure of 4800 would indicate that the second site should be considered for active protection first.

A comparison of this procedure with some of the currently used priority procedures was conducted with assumed data for a group of crossings. This comparison yielded a vastly different priority ranking of the crossings, which indicates the great influence that actual driver behavior can have on the relative safety of a group of crossings (10).

Findings and Recommendations

The procedure described can assist diagnostic teams by yielding a human factors evaluation of crossings under consideration. This procedure will also yield measures for use in countermeasure research.

This procedure should be considered by public authorities responsible for managing a grade-crossing improvement program. The procedure should be particularly helpful to diagnostic teams as they evaluate specific hazardous crossings and develop recommendations. Countermeasure research at passive crossings should also consider using the procedure.

ACKNOWLEDGMENT

The research reported here was conducted as part of a larger research effort in conjunction with John E. Tidwell's dissertation (10). The procedures, base data, and detailed findings are reported therein.

REFERENCES

1. J.H. Sanders. Human Factors Countermeasures to Improve Highway-Railway Intersection Safety. Federal Railroad Administration and National Highway Traffic Safety Administration, U.S. Department of Transportation, July 1, 1979.
2. I.N. Dommasch, R.L. Hollinger, and E.F. Reilly. Passive Control at Rail-Highway Crossings. New Jersey Department of Transportation, Trenton, May 1977.
3. H.A. Richards and G.S. Bridges. Railroad Grade Crossings. In Traffic Control and Roadway Elements--Their Relation to Highway Safety, Highway Safety Foundation, Washington, DC, 1968.
4. A. Voorhees. Factors Influencing Safety at Highway Rail Grade Crossings. NCHRP, Project 3-8, Jan. 1967.
5. Factors Influencing Safety of Highway-Railroad Crossings. NCHRP, Rept. 50, 1968.
6. A Policy on Geometric Design of Rural Highways. American Association of State Highway Officials, Washington, DC, 1965.
7. R.W. Lyles. Evaluation of Signs for Hazardous Rural Intersections. TRB, Transportation Research Record 782, 1980, pp. 22-30.
8. J.L. Sanford. Criteria Used by State Highway Agencies to Determine Warrants and Priorities for Warning Devices at Rail Highway Crossings. Highway Traffic Center, Urbana, IL, April 1977.
9. L.E. Peabody and T.B. Dimmick. Accident Hazards

at Grade Crossings. Public Roads Magazine, Washington, DC, Vol. 22, No. 6, 1941.
10. J.E. Tidwell, Jr. Highway-Railway Grade Crossing Safety: Driver Perception of Hazard and Risk. Univ. of Tennessee, Knoxville, Ph.D dissertation, Dec. 1980.

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

Radar-Platoon Technique for Efficient and Complete Speed Measurements

SAM YAGAR AND MICHEL VAN AERDE

A technique by which a single observer can accurately estimate speeds of all vehicles in a single lane of traffic with the use of a radar device, regardless of the volume of traffic in that lane, is described. This is accomplished by considering platoons of vehicles rather than each individual vehicle. For each platoon, the speed, platoon composition, and lead-vehicle type are recorded. The speed is measured by means of a radar unit while the platoon composition and platoon lead-vehicle type are observed visually and recorded manually. On two-lane highways, this technique can provide detailed volume counts and speed measurements for one direction of traffic flow and summarized (e.g., 5-min) vehicle counts for the opposite direction. For total two-way volumes of less than 500 vehicles/h, the single observer can provide detailed volume counts and exact speed measurements for both directions.

Although there exist many direct and indirect methods for measuring the traffic characteristics of a highway, they tend to be geared toward one specific type of measurement and do not produce, by themselves, the type of complete data that are required for a thorough analysis of highway performance. Any extra data must therefore be obtained by using other techniques and additional resources. Some of these basic data-acquisition methods are listed below and described in a previous paper (1):

1. Volume counts--visual observation, mechanical counter, and microcomputer; and
2. Speed measurements--license-plate matching, stopwatch technique, microcomputer, and radar.

There are many indicators that either individually or collectively indicate how effectively a highway accommodates various levels of traffic. The total number of vehicles and the average speed of these vehicles are two of the most commonly obtained statistics. Although speed and total volume are perhaps the most important indicators of the operating performance of a highway, other types of data are needed for a more complete analysis.

It is often important to know the vehicle composition of the traffic stream, for one can seldom consider either a truck, a bus, or a motorcycle to be equivalent to a car in this regard. In addition, one is also interested in the spatial distribution of these vehicles, for again it is important to know if these vehicles are all traveling as a single group, known as a platoon, or as individual, independent units.

Similarly, one needs to know more than just the average speed of all vehicles. To know the frequency distribution of their speeds and to determine to what degree drivers are prevented from driving at their desired speeds are often of equal or even greater importance.

Obtaining this type of complete data has been expensive and time consuming. One could either employ excessive amounts of resources or settle for a smaller data set.

With this thought in mind, the radar-platoon technique was developed and tested (2). After 500 h of application in the field it has been found to be fast, accurate, and relatively inexpensive in terms of time and money. These advantages make this method for monitoring the performance of a highway most efficient and highly practical.

DESCRIPTION OF RADAR-PLATOON TECHNIQUE

The radar-platoon technique for obtaining traffic data is based on the use of a radar unit for measuring speeds and the division of the traffic flow into platoons for the purpose of assigning these speeds. Whereas various other techniques for measuring speeds require either extra calculations or several people to take a single reading, the radar unit operated by a single individual automatically produces instantaneous values of speed.

Even with the radar unit, it is not always possible to individually record the speed of every vehicle that passes by, especially at higher volumes. However, vehicles tend to form groups (platoons) at these higher volumes. Since platoons travel as one unit, the average speed of the platoon can be taken to adequately represent the speed of each member of that platoon for most practical purposes. The division of the traffic flow into platoons therefore allows a representative speed of each vehicle to be recorded.

The radar-platoon technique consists of counting the number of vehicles of each type in each platoon, recording the platoon lead-vehicle type, and recording an average speed of the given platoon from the radar unit. This can be accomplished without great difficulty by a single person, as the speeds of vehicles in a platoon are virtually identical.

All data collection for a given location is carried out by one person positioned along the road. The data-collection equipment should be sufficiently removed from the lane in which the traffic is moving (about 5 m or more, if possible) so that it does not affect traffic and preferably on the same side of the road as the principal-flow lane. Although the equipment usually consists of a vehicle that houses the radar set and operator, it is preferable to have the operator completely off the roadway, with only the radar antenna at the side of the road and camouflaged in some manner.

The use of the radar-platoon technique is described in terms of two-lane highways where it has been principally used to date. From the selected